Article

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 concertedly 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.

Keywords
climate change, co-production, environmental politics, geographies of science, modelling

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 conceptualizations of 'nature' (Castree, 2005), the nature of the 'global' and the 'local' (Randalls, 2016), modernity and difference (Head and 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 article we examine work which contributes to a more recent concern of geographical scholarship –

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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 conceptualizations 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 and 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, actor-network theory (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 and 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 and 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 and 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 and 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 materialization of science's socio-cultural boundaries (Galison and Thompson, 1999; 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 ANT, which extend Bloor's (1976) symmetry principle to the analytical distribution of agency across human and nonhuman actors (Latour and Woolgar, 1979; Latour, 1987, 1999, 2005; Law and 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 and 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 globalization (MacLeod, 2000; Bennett and Hodge, 2011; Jasanoff, 2006). Geographers of science, so far, have taken much of their inspiration from the sociospatial school of thought (Finnegan, 2008), seeking to develop 'social geographies of both warranted assertability 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 and Livingstone, 1999: 16, emphasis in original). As well as the social and material spaces of knowledge-making and the 'performance spaces of science' (Livingstone, 2005a: 97; Wainwright and Williams, 2008), historical geographers have analysed the range of social, literary and communicative technologies which must be mobilized to enable scientific knowledge to travel (e.g. Naylor, 2006; Keighren, 2010; Ogborn and Withers, 2010; Withers and 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 theorizing 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 standardization and the secure transfer of ideas and artefacts than about understanding more unstable geographies of encounter and hybridization 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 and 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 and Turnbull, 1995; Verran, 1998; Turnbull, 1997; Chambers and Gillespie, 2000; Anderson and Adams, 2008; Pollock and Subramaniam, 2016). 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 in conventional historiographies of 'western' science (Chambers and 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 globalization (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 and 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).[1] The rest of this article 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 and Spedding, 2005; Matless and Cameron, 2006; Richards, 2011a; 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 and 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, computerized 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 recognizing 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 '*longue 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 the Second World War, 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: 241–2). 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 Sörlin, 2009: 248).[2] Tarfala 'became an internationally recognized field-based bulwark of climate scepticism' (p. 247) which persisted among Stockholm glaciologists and geographers into the 1980s. Exercising no such 'cult of local observations' (p. 249), Rossby's group, of which the first Intergovernmental Panel on Climate Change (IPCC) chair Bert Bolin was a part, turned their attentions instead to globally representative observations like those of the Mauna Loa CO_2 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, 2013; 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 subdisciplines 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', influenced by historical geographies of exploration and scientific fieldwork, colonial exploitation and postcolonial geopolitics, have all shaped this uneven geography of concern (Bravo and Sörlin, 2002; 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, 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 and 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 politicized. Geographers working in postcolonial and political ecology traditions have critiqued strands of adaptation science for its depoliticization 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 geographic fields (Cote and 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, 2011; Nielsen and 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 and Geoghegan, 2010: 296; also Leyshon and 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 IPCC has been the pre-eminent focus (for an earlier review see Hulme and 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' (O'Reilly, 2015: 108). 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 organization 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 and 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, 2011; Hulme, 2011; Nielsen and 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 and Liverman, 2008; Lovell and Liverman, 2010). New practices of carbon accounting are co-produced with re-territorializations 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 and 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 essentializing '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 and 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 organizations like the IPCC is challenging, due both to questions of access and to the dispersed, largely virtual nature of the organization. Few have been welcomed into relationships of 'ethnographic complicity' (Marcus, 1998: 105) – O'Reilly (2015), in collaborative relationships with IPCC authors, and 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 and Gabrys, 2011), examining, for example, the place of film (Svoboda, 2016), print and online media (Carvalho and 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 and 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 and 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 and 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 synthesizing 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 destabilization of 2°C as a valid threshold of 'dangerous' climate change. The exchanges, filmed for the internet and circulated in transcript form (Baer and Kammen, 2009), were a public performance of, or contestation between, different idealizations 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 and Star, 2008) – science and politics – created ruptures in these tacit expectations of speech and discourse. Farbotko and 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 and 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 and 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 and 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 organizations like the IPCC (e.g. Hollin and Pearce, 2015). Innovative methodologies such as 'collaborative event ethnography' (Campbell and 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 and 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 emphasized, 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 and 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 territorialization 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 and Chaturvedi, 2010; Blok, 2010; Lövbrand and 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).

I 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 and Wynne, 1996; Jasanoff and 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 dynamic 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 (but still uncertain) over time (Van der Sluijs et al., 1998; IPCC, 2014), so too has GMT endured as the organizing 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 and 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 and Gibson, 2012; Jasanoff, 2010; Knox, 2014) while privileging certain synoptic processes and variables over other, more locally-relevant changes (Stott and 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 and Chaturvedi, 2010) risks enframing it as a space to be colonized 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 and 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 and Knutti, 2011; see also Jankovic, 2004). This 'interbreeding' raises epistemological questions about pluralism (Betz, 2009; Lenhard and 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 and 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 internationalization 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 the UK is a notable exception (see also Krueck and 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 and 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 and 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 and Dessai, 2008; Tang and 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, with 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 and 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 and Shapin, 1991; Smith and 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 systems. 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 and 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 and Thorne, 2010) and the development of new, locally-focused 'climate services' targeted at both public and private sector users (Krauss and Von Storch, 2012; Vaughan and Dessai, 2014; Webber and 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 institutionalized (and localized) as a form of government which acts through the regulated choices of citizens and 'stakeholders', and through increasingly marketized 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 spatialization 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 and Hulme, 2012; Mahony, 2014). Regional models promise greater spatial realism through the 'dynamical downscaling' of global simulations, and we might identity 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 and Dessai, 2008; Rickards et al., 2014) and of a broader regime of calculative and imaginative practices of anticipation (De Goede and Randalls, 2009; Anderson, 2010; Matthews and 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 organizations 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 recognized by IPCC authors in guidelines for regional modelling: 'An important geopolitical 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 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 and Kull, 2009); and the effects of this co-production on shifting societal engagements with climate change (Jónsdóttir, 2013; also Ahlborg and 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 emphasizes the diverse and contested spatialities of climate change knowledges. The notion of epistemic geographies emphasizes 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; Powell, 2007a: 322). 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' (2010: 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 societal transformation 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 organizational spaces of climate work including emissions accounting (Asdal, 2008, 2011; Lovell and Mackenzie, 2011) and carbon trading (Callon, 2009; Lovell and 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 and 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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Notes

1. 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).
2. Fleming (2016: 80) disputes this point.

References

Adler CE and Hirsch Hadorn G (2014) The IPCC and treatment of uncertainties: Topics and sources of dissensus. *Wiley Interdisciplinary Reviews: Climate Change* 5(5): 663–676.

Agrawala S (1998) Context and early origins of the Intergovernmental Panel on Climate Change. *Climatic Change* 39(4): 605–620.

Ahlborg H and Nightingale AJ (2012) Mismatch between scales of knowledge in Nepalese forestry: Epistemology, power, and policy implications. *Ecology and Society* 17(4): 16.

Anderson B (2010) Preemption, precaution, preparedness: Anticipatory action and future geographies. *Progress in Human Geography* 34(6): 777–798.

Anderson K (2015) Duality in climate science. *Nature Geoscience* 8: 898–900.

Anderson W and Adams V (2008) Pramoedya's chickens: Postcolonial studies of technoscience. In: Hackett EJ, Amsterdamska O, Lynch M and Wajcman J (eds) *The Handbook of Science and Technology Studies*. Cambridge, MA: MIT Press, 181–204.

Anderson K and Peters G (2016) The trouble with negative emissions. *Science* 354(6309): 182–183.

Arendt H (2013) *The Human Condition, 2nd edn*. Chicago, IL: University of Chicago Press.

Asdal K (2008) Enacting things through numbers: Taking nature into account/ing. *Geoforum* 39(1): 123–132.

Asdal K (2011) The office: The weakness of numbers and the production of non-authority. *Accounting, Organizations and Society* 36(1): 1–9.

Asdal K (2015) What is the issue? The transformative capacity of documents. *Distinktion: Scandinavian Journal of Social Theory* 16(1): 74–94.

Ash J, Kitchin R and Leszczynski A (2016) Digital turn, digital geographies? *Progress in Human Geography*. DOI: 10.1177/0309132516664800.

Ashley R (1983) The eye of power: The politics of world modeling. *International Organization* 37(3): 495–535.

Baer P and Kammen DM (2009) Dialog on science and policy to address the climate crisis to conclude the International Association of Research Universities Climate Congress, Copenhagen, Denmark. *Environmental Research Letters* 4(2).

Barnes B (1977) *Interests and the Growth of Knowledge*. London: Routledge.

Barnes J (2015) Scale and agency: Climate change and the future of Egypt's water. In: Barnes J and Dove M (eds) *Climate Cultures: Anthropological Perspectives on Climate Change*. New Haven, CT: Yale University Press, 127–145.

Barnett J, Christoff P, Rangan H and Sutherland E (2009) *An Inconvenient Truth* (2006): Review symposium. *Geographical Research* 47(2): 204–211.

Barry A (1993) The history of measurement and the engineers of space. *The British Journal for the History of Science* 26(4): 459–468.

Barry A (2013a) *Material Politics: Disputes along the Pipeline*. Oxford: Wiley.

Barry A (2013b) The translation zone: Between actor-network theory and international relations. *Millennium – Journal of International Studies* 41(3): 413–429.

Bassi JP (2015) *A Scientific Peak: How Boulder Became a World Center for Space and Atmospheric Science*. Boston, MA: American Meteorological Society.

Beck S (2011) Moving beyond the linear model of expertise? IPCC and the test of adaptation. *Regional Environmental Change* 11(2): 297–306.

Beck S (2012) The challenges of building cosmopolitan climate expertise: The case of Germany. *Wiley Interdisciplinary Reviews: Climate Change* 3(1): 1–17.

Beck S, Esguerra A and Görg C (2014) The co-production of scale and power: The case of the Millennium Ecosystem Assessment and the Intergovernmental Platform on Biodiversity and Ecosystem Services. *Journal of Environmental Policy & Planning* (December): 37–41.

Beck U, Blok A, Tyfield D and Zhang JY (2013) Cosmopolitan communities of climate risk: Conceptual and empirical suggestions for a new research agenda. *Global Networks* 13(1): 1–21.

Bennett BM and Hodge JM (eds) (2011) *Science and Empire: Knowledge and Networks of Science Across the British Empire, 1800–1970*. Basingstoke: Palgrave Macmillan.

Benson E (2012) One infrastructure, many global visions: The commercialization and diversification of Argos, a satellite-based environmental surveillance system. *Social Studies of Science* 42(6): 843–868.

Betz G (2009) Underdetermination, model-ensembles and surprises: On the epistemology of scenario-analysis in climatology. *Journal for General Philosophy of Science* 40(1): 3–21.

Bhatasara S (2015) Rethinking climate change research in Zimbabwe. *Journal of Environmental Studies and Sciences*. DOI: 10.1007/s13412-015-0298-9.

Biermann F (2001) Big science, small impacts – in the South? The influence of global environmental assessments on expert communities in India. *Global Environmental Change* 11(4): 297–309.

Blok A (2010) Topologies of climate change: Actor-network theory, relational-scalar analytics, and carbon-market overflows. *Environment and Planning D: Society and Space* 28(5): 896–912.

Bloor D (1976) *Knowledge and Social Imagery*. Chicago, IL: University of Chicago Press.

Bohn M (2011) Concentrating on CO_2: The Scandinavian and Arctic measurements. *Osiris* 26(1): 165–179.

Bottoms S (2012) Climate change 'science' on the London stage. *Wiley Interdisciplinary Reviews: Climate Change* 3(4): 339–348.

Boykoff MT (2011) *Who Speaks for the Climate? Making Sense of Media Reporting on Climate Change*. Cambridge: Cambridge University Press.

Brace C and Geoghegan H (2010) Human geographies of climate change: Landscape, temporality, and lay knowledges. *Progress in Human Geography* 35(3): 284–302.

Braun B (2006) Environmental issues: Global natures in the space of assemblage. *Progress in Human Geography* 30(5): 644–654.

Braun B and Whatmore SJ (2010) *Political Matter: Technoscience, Democracy, and Public Life*. Minneapolis, MN: University of Minnesota Press.

Bravo M and Sörlin S (eds) (2002) *Narrating the Arctic: A Cultural History of Nordic Scientific Practice*. Canton, MA: Science History Publications.

Bravo MT (2009) Voices from the sea ice: The reception of climate impact narratives. *Journal of Historical Geography* 35(2): 256–278.

Brenton T (1994) *The Greening of Machiavelli: The Evolution of International Environmental Politics*. London: Earthscan.

Brewer PR and McKnight J (2015) Climate as comedy: The effects of satirical television news on climate change perceptions. *Science Communication* 37(5): 635–657

Brown K (2013) Global environmental change I: A social turn for resilience? *Progress in Human Geography* 38(1): 107–117.

Bumpus AG and Liverman DM (2008) Accumulation by decarbonization and the governance of carbon offsets. *Economic Geography* 84(2): 127–155.

Callon M (1986) Some elements of a sociology of translation: Domestication of the scallops and the fishermen of St. Brieuc Bay. In: Law J (ed.) *Power, Action & Belief: A New Sociology of Knowledge*. London: Routledge & Kegan Paul, 196–229.

Callon M (2009) Civilizing markets: Carbon trading between in vitro and in vivo experiments. *Accounting, Organizations and Society* 34(3–4): 535–548.

Cameron F, Hodge B and Salazar JF (2013) Representing climate change in museum space and places. *Wiley Interdisciplinary Reviews: Climate Change* 4(1): 9–21.

Campbell LM and Brosiusa JP (2010) Collaborative event ethnography: Conservation and development trade-offs at the Fourth World Conservation Congress. *Conservation and Society* 8(4): 245–255.

Carey M (2007) The history of ice: How glaciers became an endangered species. *Environmental History* 12: 497–527.

Carey M (2010) *In the Shadow of Melting Glaciers: Climate Change and Andean Society*. Oxford: Oxford University Press.

Carey M, Jackson M, Antonello A and Rushing J (2016) Glaciers, gender, and science: A feminist glaciology framework for global environmental change research. *Progress in Human Geography*. DOI: 10.1177/0309132515623368.

Carvalho A and Burgess J (2005) Cultural circuits of climate change in U.K. broadsheet newspapers, 1985–2003. *Risk Analysis: An Official Publication of the Society for Risk Analysis* 25(6): 1457–1469.

Castree N (2002) False antitheses? Marxism, nature and actor-networks. *Antipode* 34(1): 111–146.

Castree N (2005) *Nature*. London: Routledge.

Castree N (2015) Changing the Anthropo(s)cene: Geographers, global environmental change and the politics of knowledge. *Dialogues in Human Geography* 5(3): 301–316.

Castree N, Adams WM, Barry J, Brockington D, Büscher B, Corbera E, Demeritt D, Duffy R, Felt U, Neves K, Newell P, Pellizzoni L, Rigby K, Robbins P, Robin L, Rose DB, Ross A, Schlosberg D, Sörlin S, West P, Whithead M and Wynne B (2014) Changing the intellectual climate. *Nature Climate Change* 4(9): 763–768.

Chambers DW and Gillespie R (2000) Locality in the history of science: Colonial science, technoscience, and indigenous knowledge. *Osiris* 15(1): 221–240.

Clarke AE and Star SL (2008) The social worlds framework: A theory/methods package. In: Hackett EJ, Amsterdamska O, Lynch M and Wajcman J (eds) *The Handbook of Science and Technology Studies*. Cambridge, MA: MIT Press, 113–138.

Collins HM (1992) *Changing Order: Replication and Induction in Scientific Practice*. Chicago, IL: University of Chicago Press.

Cosgrove D (2008) *Geography and Vision: Seeing, Imagining and Representing the World*. London: I.B. Tauris.

Cote M and Nightingale AJ (2012) Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 36(4): 475–489.

Craggs R (2014) Postcolonial geographies, decolonization, and the performance of geopolitics at Commonwealth conferences. *Singapore Journal of Tropical Geography* 35(1): 39–55.

Craggs R and Mahony M (2014) The geographies of the conference: Knowledge, performance and protest. *Geography Compass* 8(6): 414–430.

Crampton JW (2001) Maps as social constructions: Power, communication and visualization. *Progress in Human Geography* 25(2): 235–252.

Crang M (1998) Places of practice and the practice of science. *Environment and Planning A* 30(11): 1971–1974.

Dahan A (2010) Putting the earth system in a numerical box? The evolution from climate modeling toward global change. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41(3): 282–292.

Daipha P (2015) *Masters of Uncertainty: Weather Forecasters and the Quest for Ground Truth*. Chicago, IL: University of Chicago Press.

Daston L (2004) Taking note(s). *Isis* 95(3): 443–448.

Davies G (2013a) Writing biology with mutant mice: The monstrous potential of post genomic life. *Geoforum* 48: 268–278.

Davies G (2013b) Mobilizing experimental life: Spaces of becoming with mutant mice. *Theory, Culture & Society* 30(7–8): 129–153.

Davies G (2013c) Arguably big biology: Sociology, spatiality and the knockout mouse project. *BioSocieties* 8(4): 417–431.

Davies SR, Selin C, Rodegher S, Altamiro Allende C, Burnam-Fink M, DiVittorio C, Glerup C, Keys C, Kimball M, Liao M, Monfreda C and Trinidad B (2014) Studying Emerge: Findings from an event ethnography. *Futures* 70: 75–85.

Dean M (1999) *Governmentality: Power and Rule in Modern Society*. London: SAGE.

Death C (2010) *Governing Sustainable Development: Partnerships, Protests and Power at the World Summit*. London: Taylor & Francis.

Death C (2011) Summit theatre: Exemplary governmentality and environmental diplomacy in Johannesburg and Copenhagen. *Environmental Politics* 20(1): 1–19.

De Goede M and Randalls S (2009) Precaution, preemption: Arts and technologies of the actionable future. *Environment and Planning D: Society and Space* 27(5): 859–878.

De Laet M and Mol A (2000) The Zimbabwe bush pump: Mechanics of a fluid technology. *Social Studies of Science* 30(2): 225–263.

Demeritt D (2001) The construction of global warming and the politics of science. *Annals of the Association of American Geographers* 91(2): 307–337.

Demeritt D (2006) Science studies, climate change and the prospects for constructivist critique. *Economy and Society* 35(3): 453–479.

Dittmer J (2016) Theorizing a more-than-human diplomacy: Assembling the British Foreign Office, 1839–1874. *The Hague Journal of Diplomacy* 11(1): 78–104.

Dittmer J and McConnell F (eds) (2016) *Diplomatic Cultures and International Politics: Translations, Spaces and Alternatives*. London: Routledge.

Doel RE (2003) Constituting the postwar earth sciences: The military's influence on the environmental sciences in the USA after 1945. *Social Studies of Science* 33(5): 635–666.

Donovan AR and Oppenheimer C (2015) Modelling risk and risking models: The diffusive boundary between science and policy in volcanic risk management. *Geoforum* 58: 153–165.

Donovan AR, Oppenheimer C and Bravo M (2012) Contested boundaries: Delineating the 'safe zone' on Montserrat. *Applied Geography* 35(1–2): 508–514.

Dowling D (1999) Experimenting on theories. *Science in Context* 12(2): 261–273.

Doyle T and Chaturvedi S (2010) Climate territories: A global soul for the Global South? *Geopolitics* 15(3): 516–535.

Driver F (1994) Making space for science. *Ecumene* 1: 389–393.

Edwards PN (2006) Meteorology as infrastructural globalism. *Osiris* 21(1): 229–250.

Edwards PN (2010) *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA: MIT Press.

Edwards PN, Mayernik MS, Batcheller AL, Bowker GC and Borgman CL (2011) Science friction: Data, metadata, and collaboration. *Social Studies of Science* 41(5): 667–690.

Elliott P (2000) The birth of public science in the English provinces: Natural philosophy in Derby, c.1690–1760. *Annals of Science* 57(1): 61–100.

Eriksen SH, Nightingale AJ and Eakin H (2015) Reframing adaptation: The political nature of climate change adaptation. *Global Environmental Change* 35: 523–533.

European Commission (2014) *Towards a European Market of Climate Services: Workshop Report*. Brussels: European Commission.

Farbotko C and McGregor HV (2010) Copenhagen, climate science and the emotional geographies of climate change. *Australian Geographer* 41(2): 159–166.

Ferraris M (2013) *Documentality: Why It Is Necessary to Leave Traces*. New York, NY Fordham University Press.

Fine GA (2009) *Authors of the Storm: Meteorologists and the Culture of Prediction*. Chicago, IL: University of Chicago Press.

Finnegan DA (2008) The spatial turn: Geographical approaches in the history of science. *Journal of the History of Biology* 41(2): 369–388.

Fisher S (2014) The emerging geographies of climate justice. *Geographical Journal* 181(1): 73–82.

Fleming JR (2016) *Inventing Atmospheric Science: Bjerknes, Rossby, Wexler, and the Foundations of Modern Meteorology*. Cambridge, MA: MIT Press.

Fløttum K and Gjerstad Ø (2016) Narratives in climate change discourse. *Wiley Interdisciplinary Reviews: Climate Change*. DOI: 10.1002/wcc.429.

Fogel C (2004) The local, the global, and the Kyoto Protocol. In: Jasanoff S and Martello ML (eds) *Earthly Politics: Local and Global in Environmental Governance*. Cambridge, MA: MIT Press, 103–126.

Fogel C (2005) Biotic carbon sequestration and the Kyoto Protocol: The construction of global knowledge by the Intergovernmental Panel on Climate Change. *International Environmental Agreements: Politics, Law and Economics* 5(2): 191–210.

Ford JD, Cameron L, Rubis J, Maillet N, Nakashima D, Willox AC and Pearce T (2016) Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change* 6(4): 349–353.

Ford JD, Vanderbilt W and Berrang-Ford L (2011) Authorship in IPCC AR5 and its implications for content: Climate change and indigenous populations in WGII. *Climatic Change* 113(2): 201–213.

Forsyth I (2013) The more-than-human geographies of field science. *Geography Compass* 7(8): 527–539.

Forsyth T (2003) *Critical Political Ecology: The Politics of Environmental Science*. London: Routledge.

Foucault M (1980) *Power/Knowledge: Selected Interviews and Other Writings*. London: Harvester Press.

Foucault M (1986) Of other spaces. *Diacritics* 16(1): 22–27.

Galison P (1997) *Image and Logic: A Material Culture of Microphysics*. Chicago, IL: University of Chicago Press.

Galison P and Thompson E (eds) (1999) *The Architecture of Science*. Cambridge, MA: MIT Press.

Gebauer C and Doevenspeck M (2015) Adaptation to climate change and resettlement in Rwanda. *Area* 47(1): 97–104.

Geden O (2015) Policy: Climate advisers must maintain integrity. *Nature* 521(7550): 27–28.

Gieryn TF (1983) Boundary-work and the demarcation of science from non-science: Strains and interests in professional ideologies of scientists. *American Sociological Review* 48(6): 781–795.

Gieryn TF (2000) A space for place in sociology. *Annual Review of Sociology* 26: 463–496.

Gieryn TF (2006) City as truth-spot: Laboratories and field-sites in urban studies. *Social Studies of Science* 36(1): 5–38.

Gieryn TF (2008) Laboratory design for post-Fordist science. *Isis* 99(4): 796–802.

Giorgi F, Pal JS, Bi X, Sloan L, Elguindi N and Solmon F (2006) Introduction to the TAC special issue: The RegCNET network. *Theoretical and Applied Climatology* 86(1–4): 1–4.

Golinski J (2005) *Making Natural Knowledge: Constructivism and the History of Science*. Chicago, IL: University of Chicago Press.

Golinski J (2010) *British Weather and the Climate of Enlightenment*. Chicago, IL: University of Chicago Press.

Gramelsberger G (2006) Story telling with code: Archaeology of climate modelling. *TeamEthno-online* 2: 77–84.

Gramelsberger G (2010) Conceiving processes in atmospheric models: General equations, subscale parameterizations, and 'superparameterizations'. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41(3): 233–241.

Gregory D (1995) A geographical unconscious: Spaces for dialogue and difference. *Annals of the Association of American Geographers* 85(1): 175–186.

Guillemot H (2010) Connections between simulations and observation in climate computer modeling: Scientists' practices and 'bottom-up epistemology' lessons. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41(3): 242–252.

Gurevitch L (2014) Google warming: Google Earth as eco-machinima. *Convergence: The International Journal of Research into New Media Technologies* 20(1): 85–107.

Haas P (1992) Introduction: Epistemic communities and international policy coordination. *International Organization* 46(1): 1–35.

Haas P (2004) When does power listen to truth? A constructivist approach to the policy process. *Journal of European Public Policy* 11(4): 569–592.

Hamilton S (2015) Action, technology, and the homogenisation of place: Why climate change is antithetical to political action. *Globalizations* (May): 1–16.

Harley JB (2002) *The New Nature of Maps: Essays in the History of Cartography*. Baltimore, MD: Johns Hopkins University Press.

Harper KC (2003) Research from the boundary layer: Civilian leadership, military funding and the development of numerical weather prediction (1946–55). *Social Studies of Science* 33(5): 667–696.

Head L and Gibson C (2012) Becoming differently modern: Geographic contributions to a generative climate politics. *Progress in Human Geography* 36(6): 699–714.

Helmreich S (1998) *Silicon Second Nature: Culturing Artificial Life in a Digital World*. Berkeley, CA: University of California Press.

Henke C and Gieryn TF (2008) Sites of scientific practice: The enduring importance of place. In: Hackett EJ, Amsterdamska O, Lynch ME and Wajcman J (eds) *Handbook of Science and Technology Studies*. Cambridge, MA: MIT Press, 353–376.

Hevly B (1996) The heroic science of glacier motion. *Osiris* 11: 66–86.

Heymann M (2010) The evolution of climate ideas and knowledge. *Wiley Interdisciplinary Reviews: Climate Change* 1(4): 581–597.

Heymann M, Gramelsberg G and Mahony M (eds) (forthcoming) *Cultures of Prediction in Atmospheric and Climate Science: Epistemic and Cultural Shifts in Computer Modelling and Simulation*. London: Routledge.

Hinchliffe S (2001) Indeterminacy in decisions: Science, policy and politics in the BSE (Bovine Spongiform Encephalopathy) crisis. *Transactions of the Institute of British Geographers* 26(2): 182–204.

Hodder J (2015) Conferencing the international at the World Pacifist Meeting, 1949. *Political Geography* 49: 40–50.

Ho-Lem C, Zerriffi H and Kandlikar M (2011) Who participates in the Intergovernmental Panel on Climate Change and why: A quantitative assessment of the national representation of authors in the Intergovernmental Panel on Climate Change. *Global Environmental Change* 21(4): 1308–1317.

Hollin GJS and Pearce W (2015) Tension between scientific certainty and meaning complicates communication of IPCC reports. *Nature Climate Change* 5(8): 753–756.

Howe JP (2014) *Behind the Curve: Science and the Politics of Global Warming*. London: University of Washington Press.

Howkins A (2011) Melting empires? Climate change and politics in Antarctica since the International Geophysical Year. *Osiris* 26(1): 180–197.

Hulme M (2008) Geographical work at the boundaries of climate change. *Transactions of the Institute of British Geographers* 33(1): 5–11.

Hulme M (2009) *Why We Disagree about Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge: Cambridge University Press.

Hulme M (2010a) Claiming and adjudicating on Mt Kilimanjaro's shrinking glaciers: Guy Callendar, Al Gore and extended peer communities. *Science as Culture* 19: 303–326.

Hulme M (2010b) Problems with making and governing global kinds of knowledge. *Global Environmental Change* 20(4): 558–564.

Hulme M (2011) Reducing the future to climate: A story of climate determinism and reductionism. *Osiris* 26(1): 245–266.

Hulme M (2013) How climate models gain and exercise authority. In: Hastrup K and Skrydstrup M (eds) *The Social Life of Climate Change Models: Anticipating Nature*. London: Routledge, 30–44.

Hulme M (2014) *Can Science Fix Climate Change?: A Case Against Climate Engineering*. Oxford: Wiley.

Hulme M and Dessai S (2008) Negotiating future climates for public policy: A critical assessment of the development of climate scenarios for the UK. *Environmental Science & Policy* 11(1): 54–70.

Hulme M and Mahony M (2010) Climate change: What do we know about the IPCC? *Progress in Physical Geography* 34(5): 705–718.

Inkster I and Morrell J (eds) (1983) *Metropolis and Province: Science in British Culture, 1780–1850*. Philadelphia, PA: University of Pennsylvania Press.

IPCC (2013) Organization. Available at: http://www.ipcc.ch/organization/organization.shtml#.UcLdOvnqmSo (accessed 15 November 2016).

IPCC (2014) *Climate Change 2013: The Physical Science Basis*. Cambridge: Cambridge University Press.

IPCC (2015) *Update on the Decision Pathway for Consideration of Requests from Researchers for Access to Non-public Material or Meetings*. Geneva: WMO.

Jankovic V (2000) *Reading the Skies: A Cultural History of the English Weather, 1650–1820*. Manchester: Manchester University Press.

Jankovic V (2004) Science migrations: Mesoscale weather prediction from Belgrade to Washington, 1970–2000. *Social Studies of Science* 34(1): 45–75.

Jasanoff S (2004) Ordering knowledge, ordering society. In: Jasanoff S (ed.) *States of Knowledge: The Co-Production of Science and Social Order*. London: Routledge, 13–45.

Jasanoff S (2005) *Designs on Nature: Science and Democracy in Europe and the United States*. Princeton, NJ: Princeton University Press.

Jasanoff S (2006) Biotechnology and empire: The global power of seeds and science. *Osiris* 21: 273–292.

Jasanoff S (2010) A new climate for society. *Theory, Culture & Society* 27(2–3): 233–253.

Jasanoff S (2011) Cosmopolitan knowledge: Climate science and global civic epistemology. In: Dryzek J, Norgaard RB and Schlosberg D (eds) *Oxford Handbook of Climate Change and Society*. Oxford: Oxford University Press, 129–143.

Jasanoff S and Wynne B (1998) Science and decision making. In: Rayner S and Malone EL (eds) *Human Choice and Climate Change, Vol*. 1. Columbus, OH: Batelle Press, 1–87.

Johnson P (2013) The geographies of heterotopia. *Geography Compass* 7(11): 790–803.

Jones R, Noguer M, Hassell D, Hudson D, Wilson S, Jenkins G and Mitchell J (2004) *Generating high resolution climate change scenarios using PRECIS*. Exeter: Met Office Hadley Centre. Available at: http://www.metoffice.gov.uk/media/pdf/6/5/PRECIS_Handbook.pdf (accessed 15 November 2016).

Jónsdóttir Á (2013) Scaling climate: The politics of anticipation. In: Hastrup K and Skrydstrup M (eds) *The Social Life of Climate Change Models: Anticipating Nature*. Abingdon: Routledge, 128–144.

Kandlikar M and Sagar A (1999) Climate change research and analysis in India: An integrated assessment of a South-North divide. *Global Environmental Change* 9(2): 119–138.

Keighren IM (2010) *Bringing Geography to Book: Ellen Semple and the Reception of Geographical Knowledge*. London: I.B. Tauris.

Kinsley S (2014) The matter of 'virtual' geographies. *Progress in Human Geography* 38(3): 364–383.

Knorr-Cetina K (1999) *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, MA: Harvard University Press.

Knox H (2014) Footprints in the city: Models, materiality, and the cultural politics of climate change. *Anthropological Quarterly* 87(2): 405–429.

Knox H (2015) Thinking like a climate. *Distinktion: Scandinavian Journal of Social Theory* (August): 1–19.

Knutti R (2010) The end of model democracy? *Climatic Change* 102(3–4): 395–404.

Kohler RE (2002) *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology*. Chciago, IL: University of Chicago Press.

Krauss W (2009) Localizing climate change: A multi-sited approach. In: Falzon M-A (ed.) *Multi-sited Ethnography: Theory, Praxis and Locality in Contemporary Research*. Farnham: Ashgate, 149–164.

Krauss W and Von Storch H (2012) Post-normal practices between regional climate services and local knowledge. *Nature and Culture* 7(2): 213–230.

Krueck CP and Borchers J (1999) Science in politics: A comparison of climate modeling centres. *Minerva* 37(2): 105–123.

Kuus M (2014) *Geopolitics and Expertise: Knowledge and Authority in European Diplomacy*. Oxford: Wiley-Blackwell.

Laborde S (2015) Environmental research from here and there: Numerical modelling labs as heterotopias. *Environment and Planning D: Society and Space* 33: 265–280.

Lahsen M (2004) Transnational locals: Brazilian experiences of the climate regime. In: Jasanoff S and Martello ML (eds) *Earthly Politics: Local and Global in Environmental Governance*. Cambridge, MA: MIT Press, 151–172.

Lahsen M (2005) Seductive simulations? Uncertainty distribution around climate models. *Social Studies of Science* 35(6): 895–922.

Lahsen M (2007) Trust through participation? Problems of knowledge in climate decision-making. In: Pettenger ME (ed.) *The Social Construction of Climate Change: Power, Knowledge, Norms, Discourses*. London: Routledge, 173–196.

Lahsen M (2009) A science–policy interface in the Global South: The politics of carbon sinks and science in Brazil. *Climatic Change* 97(3–4): 339–372.

Lahsen M (2013) Anatomy of dissent: A cultural analysis of climate skepticism. *American Behavioral Scientist* 57(6): 732–753.

Lane S, Odoni N, Landström C, Whatmore SJ, Ward N and Bradley S (2011) Doing flood risk science differently: An experiment in radical scientific method. *Transactions of the Institute of British Geographers* 36(1): 15–36.

Larner W (2011) C-change? Geographies of crisis. *Dialogues in Human Geography* 1(3): 319–335.

Latour B (1987) *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press.

Latour B (1990) Drawing things together. In: Lynch M and Woolgar S (eds) *Representation in Scientific Practice*. Cambridge, MA: MIT Press, 19–68.

Latour B (1993) *We Have Never Been Modern*. Cambridge, MA: Harvard University Press.

Latour B (1999) *Pandora's Hope: Essays on the Reality of Science Studies*. Cambridge, MA: Harvard University Press.

Latour B (2004) Why has critique run out of steam? From matters of fact to matters of concern. *Critical inquiry* 30: 225–248.

Latour B (2005) *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.

Latour B and Woolgar S (1979) *Laboratory Life: The Construction of Scientific Facts* Princeton, NJ: Princeton University Press.

Lave R (2013) Intervention: Critical physical geography. *The Canadian Geographer/Le Géographe canadien* 58(1): 1–10. Available at: http://geography.berkeley.edu/wp-content/uploads/2015/01/Lave-et-al-2013.pdf (accessed 15 November 2016).

Law J (1986) On methods of long-distance control: Vessels, navigation and the Portuguese route to India. In: Law J (ed.) *Power, Action & Belief: A New Sociology of Knowledge*. London: Routledge & Kegan Paul, 234–263.

Law J (1987) On the social explanation of technical change: The case of the Portuguese maritime expansion. *Technology and Culture* 109(8): 121–36.

Law J and Mol A (2001) Situating technoscience: An inquiry into spatialities. *Environment and Planning D: Society and Space* 19: 609–621.

Lenhard J and Winsberg E (2010) Holism, entrenchment, and the future of climate model pluralism. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41(3): 253–262.

Leszczynski A (2015) Spatial media/tion. *Progress in Human Geography* 39(6): 729–751.

Leyshon C and Geoghegan H (2012) Anticipatory objects and uncertain imminence: Cattle grids, landscape and the presencing of climate change on the Lizard Peninsula, *UK.* Area 44(2): 237–244.

Livingstone DN (2002) *Science, Space and Hermeneutics*. Wiesbaden: Franz Steiner Verlag.

Livingstone DN (2003) *Putting Science in Its Place: Geographies of Scientific Knowledge*. Chicago, IL: University of Chicago Press.

Livingstone DN (2005a) Text, talk and testimony: Geographical reflections on scientific habits. An afterword. *The British Journal for the History of Science* 38(1): 93–100.

Livingstone DN (2005b) Science, text and space: Thoughts on the geography of Reading. *Transactions of the Institute of British Geographers* 30: 391–401.

Livingstone DN (2007) Science, site and speech: Scientific knowledge and the spaces of rhetoric. *History of the Human Sciences* 20(2): 71–98.

Livingstone DN (2014) *Dealing with Darwin: Place, Politics, and Rhetoric in Religious Engagements with Evolution*. Baltimore, MD: Johns Hopkins University Press.

Lorimer H (2003) Telling small stories: Spaces of knowledge and the practice of geography. *Transactions of the Institute of British Geographers* 28(2): 197–217.

Lorimer H and Spedding N (2005) Locating field science: A geographical family expedition to Glen Roy, Scotland. *The British Journal for the History of Science* 38(1): 13–33.

Lorimer J (2012) Multinatural geographies for the Anthropocene. *Progress in Human Geography* 36(5): 593–612.

Lövbrand E and Stripple J (2006) The climate as political space: On the territorialisation of the global carbon cycle. *Review of International Studies* 32(2): 217.

Lövbrand E and Stripple J (2011) Making climate change governable: Accounting for carbon as sinks, credits and personal budgets. *Critical Policy Studies* 5(2): 187–200.

Lövbrand E, Stripple J and Wiman B (2009) Earth system governmentality. *Global Environmental Change* 19(1): 7–13.

Lovell H and Ghaleigh NS (2013) Climate change and the professions: The unexpected places and spaces of carbon markets. *Transactions of the Institute of British Geographers* 38(3): 512–516.

Lovell H and Liverman D (2010) Understanding carbon offset technologies. *New Political Economy* 15: 255–273.

Lovell H and Mackenzie D (2011) Accounting for carbon: The role of accounting professional organisations in governing climate change. *Antipode* 43(3): 704–730.

MacLeod R (ed.) (2000) *Nature and Empire: Science and the Colonial Enterprise*. Chicago, IL: University of Chicago Press.

Mahony M (2013) Boundary spaces: Science, politics and the epistemic geographies of climate change in Copenhagen, 2009. *Geoforum* 49: 29–39.

Mahony M (2014) The predictive state: Science, territory and the future of the Indian climate. *Social Studies of Science* 44(1): 109–133.

Mahony M (2015) Climate change and the geographies of objectivity: The case of the IPCC's burning embers diagram. *Transactions of the Institute of British Geographers* 40: 153–167.

Mahony M (2016) For an empire of 'all types of climate': Meteorology as an imperial science. *Journal of Historical Geography* 51: 29–39.

Mahony M and Hulme M (2012) Model migrations: Mobility and boundary crossings in regional climate prediction. *Transactions of the Institute of British Geographers* 37(2): 197–211.

Mahony M and Hulme M (2016) Modelling and the nation: Institutionalising climate prediction in the UK, 1988–92. *Minerva*. DOI: 10.1007/s11024-016-9302-0.

Marcus GE (1995) Ethnography in/of the world system: The emergence of multi-sited ethnography. *Annual Review of Anthropology* 24: 95–117.

Marcus GE (1998) *Ethnography through Thick and Thin*. Princeton, NJ: Princeton University Press.

Martin-Nielsen J (2013) *Eismitte in the Scientific Imagination: Knowledge and Politics at the Center of Greenland*. Basingstoke: Palgrave Macmillan.

Masco J (2009) Bad weather: On planetary crisis. *Social Studies of Science* 40(1): 7–40.

Masson D and Knutti R (2011) Climate model genealogy. *Geophysical Research Letters* 38(8). DOI: 10.1029/2011GL046864.

Matless D (2014) *In the Nature of Landscape: Cultural Geography on the Norfolk Broads*. Oxford: Wiley.

Matless D (2016) Climate change stories and the Anthroposcenic. *Nature Climate Change* 6: 118–119.

Matless D and Cameron L (2006) Experiment in landscape: The Norfolk excavations of Marietta Pallis. *Journal of Historical Geography* 32(1): 96–126.

Matthews AS and Barnes J (2016) Prognosis: Visions of environmental futures. *Journal of the Royal Anthropological Institute* 22(S1): 9–26.

McQuillan D (2016) The Anthropocene, resilience and post-colonial computation. *Resilience*. DOI: 10.1080/21693293.2016.1240779.

Mearns LO, Giorgi F, Whetton P, Pabon D, Hulme M and Lal M (2003) *Guidelines for use of climate scenarios developed from regional climate model experiments*. Geneva: IPCC. Available at: http://www.ipcc-data.org/guidelines/dgm_no1_v1_10-2003.pdf (accessed 15 November 2016).

Melillo JM, Butler S, Johnson J, Mohan J, Steudler P, Lux H, Burrows E, Bowles F, Smith R, Scott L, Vario C, Hill T, Burton A, Zhou Y-M and Tang J (2011) Soil warming, carbon-nitrogen interactions, and forest carbon budgets. *Proceedings of the National Academy of Sciences of the United States of America* 108(23): 9508–9512.

Meusburger P, Livingstone DN and Jons H (eds) (2010) *Geographies of Science*. Heidelberg: Springer Verlag.

Miller CA (2000) The dynamics of framing environmental values and policy: Four models of societal processes. *Environmental Values* 9: 211–233.

Miller CA (2001) Challenges in the application of science to global affairs: Contingency, trust, and moral order. In: Miller CA and Edwards PN (eds) *Changing the Atmosphere: Expert Knowledge and Environmental Governance*. Cambridge, MA: MIT Press, 247–285.

Miller CA (2004a) Resisting empire: Globalism, relocalization, and the politics of knowledge. In: Jasanoff S and Martello ML (eds) *Earthly Politics: Local and Global in Environmental Governance*. Cambridge, MA: MIT Press, 81–102.

Miller CA (2004b) Interrogating the civic epistemology of American democracy: Stability and instability in the 2000 US presidential election. *Social Studies of Science* 34(4): 501–530.

Miller CA (2004c) Climate science and the making of a global political order. In: Jasanoff S (ed.) *States of Knowledge: The Co-production of Science and Social Order*. London: Routledge, 46–66.

Miller CA (2015) Globalizing security: Science and the transformation of contemporary political imagination. In: Jasanoff S and Kim S-H (eds) *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power*. Chicago, IL: University of Chicago Press, 277–299.

Mol A (2002) *The Body Multiple: Ontology in Medical Practice*. Durham, NC: Duke University Press.

Moore A (2008) Rethinking scale as a geographical category: From analysis to practice. *Progress in Human Geography* 32(2): 203–225.

Morrison M (1999) Models as autonomous agents. In: Morgan MS and Morrison M (eds) *Models as Mediators: Perspectives on Natural and Social Science*. Cambridge: Cambridge University Press, 38–65.

Morseletto P, Biermann F and Pattberg P (2016) Governing by targets: Reductio ad unum and evolution of the two-degree climate target. *International Environmental Agreements: Politics, Law and Economics*. DOI: 10.1007/s10784-016-9336-7.

Moss RH, Meehl GA, Lemos MC, Smith JB and Arnold JR (2013) Hell and high water: Practice-relevant adaptation science. *Science* 342(6159): 696–698.

Naylor S (2002) The field, the museum and the lecture hall: The spaces of natural history in Victorian Cornwall. *Transactions of the Institute of British Geographers* 27(4): 494–513.

Naylor S (2005) Introduction: Historical geographies of science – places, contexts, cartographies. *The British Journal for the History of Science* 38(1): 1–12.

Naylor S (2006) Nationalizing provincial weather: Meteorology in nineteenth-century Cornwall. *The British Journal for the History of Science* 39(3): 407–433.

Naylor S (2010) *Regionalizing Science: Placing Knowledges in Victorian England*. Abingdon: Taylor & Francis.

Nielsen JØ and Sejersen F (2012) Earth system science, the IPCC and the problem of downward causation in human geographies of global climate change. *Geografisk Tidsskrift* 112(2): 194–202.

Nightingale AJ (2016) Adaptive scholarship and situated knowledges? Hybrid methodologies and plural epistemologies in climate change adaptation research. *Area* 48(1): 41–47.

Nye MJ (1993) National styles? French and English chemistry in the nineteenth and early twentieth centuries. *Osiris* 8: 30–49.

O'Reilly J (2015) Glacial dramas: Typos, projections, and peer review in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Barnes J and Dove M (eds) *Climate Cultures: Anthropological Perspectives on Climate Change*. New Haven, CT: Yale University Press, 107–126.

O'Reilly J (2016) Sensing the ice: Field science, models, and expert intimacy with knowledge. *Journal of the Royal Anthropological Institute* 22(S1): 27–45.

O'Reilly J, Oreskes N and Oppenheimer M (2012) The rapid disintegration of projections: The West Antarctic ice sheet and the Intergovernmental Panel on Climate Change. *Social Studies of Science* 42(5): 709–731.

Oels A (2005) Rendering climate change governable: From biopower to advanced liberal government? *Journal of Environmental Policy & Planning* 7(3): 185–207.

Ogborn M and Withers CWJ (eds) (2010) *Geographies of the Book*. Farnham: Ashgate.

Ophir A and Shapin S (1991) The place of knowledge: A methodological survey. *Science in Context* 4(1): 3–21.

Orlove B, Lazrus H, Hovelsrud GK and Giannini A (2014) Recognitions and responsibilities: On the origins and consequences of the uneven attention to climate change around the world. *Current Anthropology* 55(3): 249–275.

Owens S (2005) Making a difference? Some perspectives on environmental research and policy. *Transactions of the Institute of British Geographers* 30(3): 287–292.

Pal JS, Giorgi F, Bi X, Elguindi N, Solmon F and Rauscher SA (2007) Regional climate modeling for the developing world: The ICTP RegCM3 and RegCNET. *Bulletin of the American Meteorological Society* 88(9): 1395–1409.

Pearce W, Holmberg K, Hellsten I and Nerlich B (2014) Climate change on Twitter: Topics, communities and conversations about the 2013 IPCC Working Group 1 Report. *PloS One* 9(4): e94785.

Peeters M, Chen H and Li Z (2016) Contrasting emission trading in the EU and China: An exploration of the role of the courts. *Climate Law* 6(1–2): 197–226.

Petersen AC (2006) *Simulating Nature: A Philosophical Study of Computer-Simulation Uncertainties and Their Role in Climate Science and Policy Advice*. Amsterdam: Het Spinhuis.

Phadke R (2015) Behind the walls: Manifestations of place and space at COP21. *Engaging Science, Technology, and Society* 1: 88–97.

Pickering A (1995) *The Mangle of Practice: Time, Agency, and Science*. Chicago, IL: University of Chicago Press.

Pickles J (2004) *A History of Spaces: Cartographic Reason, Mapping, and the Geo-Coded World*. London: Routledge.

Pollock A and Subramaniam B (2016) Resisting power, retooling justice: promises of feminist postcolonial technosciences. *Science, Technology & Human Values*, 41(6): 1–16.

Popke J (2016) Researching the hybrid geographies of climate change: Reflections from the field. *Area* 48(1): 2–6.

Porter T (1995) *Trust in Numbers*. Princeton, NJ: Princeton University Press.

Powell RC (2002) The sirens' voices? Field practices and dialogue in geography. *Area* 34(3): 261–272.

Powell RC (2007a) Geographies of science: Histories, localities, practices, futures. *Progress in Human Geography* 31(3): 309–329.

Powell RC (2007b) 'The rigours of an Arctic experiment': The precarious authority of field practices in the Canadian High Arctic, 1958–1970. *Environment and Planning A* 39(8): 1794–1811.

Powell RC (2008) Becoming a geographical scientist: Oral histories of Arctic fieldwork. *Transactions of the Institute of British Geographers* 33(4): 548–565.

Powell RC and Vasudevan A (2007) Geographies of experiment. *Environment and Planning A* 39(8): 1790–1793.

Preston BL, Rickards L, Fuenfgeld H and Keenan R (2015) Toward reflexive climate adaptation research. *Current Opinion in Environmental Sustainability* 14: 127–135.

Raj K (2007) *Relocating Modern Science: Circulation and the Construction of Knowledge in South Asia and Europe, 1650–1900*. Basingstoke: Palgrave Macmillan.

Ramírez-i-Ollé M (2015) *The making of dendroclimatological knowledge: A symmetrical account of trust and scepticism in science*. PhD thesis, University of Edinburgh.

Randalls S (2010a) History of the 2°C climate target. *Wiley Interdisciplinary Reviews: Climate Change* 1(4): 598–605.

Randalls S (2010b) Weather profits: Weather derivatives and the commercialization of meteorology. *Social Studies of Science* 40(5): 705–730.

Randalls S (2011a) Optimal climate change: Economics and climate science policy histories (from heuristic to normative). *Osiris* 26(1): 224–242.

Randalls S (2011b) Broadening debates on climate change ethics: Beyond carbon calculation. *The Geographical Journal* 177(2): 127–137.

Randalls S (2016) Climatic globalities: Assembling the problems of global climate change. In: Van Munster R and Sylvest C (eds) *The Politics of Globality since 1945: Assembling the Planet*. London: Routledge, 145–163.

Rangan H and Kull CA (2009) What makes ecology 'political'?: Rethinking 'scale' in political ecology. *Progress in Human Geography* 33(1): 28–45.

Ravetz JR (2003) Models as metaphors. In: Kasemir B, Jäger J, Jaeger CC and Gardner MT (eds) *Public Participation in Sustainability Science*. Cambridge: Cambridge University Press, 62–78.

Ribot J (2014) Cause and response: Vulnerability and climate in the Anthropocene. *The Journal of Peasant Studies* 41(5): 667–705.

Rice JL, Burke BJ and Heynen N (2015) Knowing climate change, embodying climate praxis: Experiential knowledge in Southern Appalachia. *Annals of the Association of American Geographers* 105(2): 1–10.

Richards K (2011a) The field. In: Agnew J and Livingstone DN (eds) *The Sage Handbook of Geographical Knowledge*. London: SAGE, 53–63.

Richards K (2011b) The weather station and the Meteorological Office. In: Agnew J and Livingstone DN (eds) *The Sage Handbook of Geographical Knowledge*. London: SAGE, 149–157.

Rickards L, Ison R, Fünfgeld H and Wiseman J (2014) Opening and closing the future: Climate change, adaptation, and scenario planning. *Environment and Planning C: Government and Policy* 32(4): 587–602.

Riles A (2006) *Documents: Artifacts of Modern Knowledge*. Ann Arbor: University of Michigan Press.

Rose G (2015) Rethinking the geographies of cultural 'objects' through digital technologies: Interface, network and friction. *Progress in Human Geography* 40(3): 334–351.

Rose N (1993) Government, authority and expertise in advanced liberalism. *Economy and Society* 22(3): 283–299.

Rose N (1999) *Powers of Freedom: Reframing Political Thought*. Cambridge: Cambridge University Press.

Rudiak-Gould P (2013) 'We have seen it with our own eyes': Why we disagree about climate change visibility. *Weather, Climate, and Society* 5(2): 120–132.

Rupke N (1999) A geography of enlightenment: The critical reception of Alexander von Humboldt's Mexico work. In: Livingstone DN and Withers CWJ (eds) *Geography and Enlightenment*. Chicago, IL: University of Chicago Press, 319–344.

Russill C (2016) The climate of communication: From detection to danger. In: O'Lear S and Dalby S (eds) *Reframing Climate Change: Constructing Ecological Geopolitics*. London: Routledge, 31–51.

Schaffer S (1991) The Eighteenth Brumaire of Bruno Latour. *Studies in History and Philosophy of Science* 22(1): 174–192.

Schatzki TR (2005) Peripheral vision: The sites of organizations. *Organization Studies* 26(3): 465–484.

Schatzki TR (2006) On organizations as they happen. *Organization Studies* 27(12): 1863–1873.

Schinkel W (2016) Making climates comparable: Comparison in paleoclimatology. *Social Studies of Science*. DOI: 10.1177/0306312716633537.

Scott JC (1998) *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. New Haven, CT: Yale University Press.

Secord JA (2000) *Victorian Sensation: The Extraordinary Publication, Reception, and Secret Authorship of Vestiges of the Natural History of Creation*. Chicago, IL: University of Chicago Press.

Secord JA (2004) Knowledge in transit. *Isis* 95(4): 654–672.

Shackley S (2001) Epistemic lifestyles in climate change modelling. In: Miller CA and Edwards PN (eds) *Changing the Atmosphere*. Cambridge, MA: MIT Press, 107–134.

Shackley S and Wynne B (1996) Representing uncertainty in global climate change science and policy: Boundary-ordering devices and authority. *Science, Technology & Human Values* 21(3): 275–302.

Shackley S, Young P, Parkinson S and Wynne B (1998) Uncertainty, complexity and concepts of good science in climate change modelling: Are GCMs the best tools? *Climatic Change* 38(2): 159–205.

Shapin S (1984) Pump and circumstance: Robert Boyle's literary technology. *Social Studies of Science* 14(4): 481–520.

Shapin S (1988) The house of experiment in seventeenth-century England. *Isis* 79(3): 373.

Shapin S (1998) Placing the view from nowhere: Historical and sociological problems in the location of science. *Transactions of the Institute of British Geographers* 23(1): 5–12.

Shapin S and Schaffer S (1985) *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life*. Princeton, NJ: Princeton University Press.

Sharman A (2014) Mapping the climate sceptical blogosphere. *Global Environmental Change* 26(1): 159–170.

Sharman A and Howarth C (2016) Climate stories: Why do climate scientists and sceptical voices participate in the climate debate? *Public Understanding of Science*. DOI: 10.1177/0963662516632453.

Shaw C (2016) *The Two Degrees Dangerous Limit for Climate Change: Public Understanding and Decision Making*. London: Routledge.

Simon S and Randalls S (2016) Geography, ontological politics and the resilient future. *Dialogues in Human Geography* 6(1): 3–18.

Sismondo S (2008) Models, simulations, and their objects. *Science in Context* 12(2): 247–260.

Skrydstrup M (2009) Planetary resilience: Codes, climates and cosmo-science in Copenhagen. In: Hastrup K (ed.) *The Question of Resilience: Social Responses to Climate Change*. Copenhagen: Det Kongelige Danske Videnskabernes Selskab, 336–357.

Skrydstrup M (2016) Of spheres and squares: Can Sloterdijk help us rethink the architecture of climate science? *Social Studies of Science*. DOI: 10.1177/0306312716647214.

Smith C and Agar J (1998) Introduction: Making space for science. In: Smith C and Agar J (eds) *Making Space for Science: Territorial Themese in the Shaping of Knowledge*. Basingstoke: Palgrave Macmillan.

Sörlin S (2009) Narratives and counter-narratives of climate change: North Atlantic glaciology and meteorology, c.1930–1955. *Journal of Historical Geography* 35(2): 237–255.

Sörlin S (2011) The art of a science diplomat: Field coproduction of climate knowledge and the rise and fall of Hans Ahlmann's 'polar warming'. *Osiris* 26(1): 66–88.

Stilgoe J (2015) *Experiment Earth: Responsible Innovation in Geoengineering*. London: Taylor & Francis.

Stott PA and Thorne PW (2010) How best to log local temperatures? *Nature* 465(7295): 158–159.

Sundberg M (2006) Credulous modellers and suspicious experimentalists? Comparison of model output and data in meteorological simulation modelling. *Science Studies* 19(1): 52–68.

Sundberg M (2007) Parameterizations as boundary objects in the climate arena. *Social Studies of Science* 37(3): 473–488.

Sundberg M (2010) The dynamics of coordinated comparisons: How simulationists in astrophysics, oceanography and meteorology create standards for results. *Social Studies of Science* 41(1): 107–125.

Svoboda M (2016) Cli-fi on the screen(s): Patterns in the representations of climate change in fictional films. *Wiley Interdisciplinary Reviews: Climate Change* 7(1): 43–64.

Tadaki M, Salmond J, Le Heron R and Brierley G (2012) Nature, culture, and the work of physical geography. *Transactions of the Institute of British Geographers* 37(4): 547–562.

Tang S and Dessai S (2012) Usable science? The UK climate projections 2009 and decision support for adaptation planning. *Weather, Climate, and Society* 44: 1–45.

Turchetti S, Naylor S, Dean K and Siegert M (2008) On thick ice: Scientific internationalism and Antarctic affairs, 1957–1980. *History and Technology* 24(4): 351–376.

Turnbull D (1997) Reframing science and other local knowledge traditions. *Futures* 29(6): 551–562.

Turnbull D (2000) *Masons, Tricksters and Cartographers: Comparative Studies in the Sociology of Scientific and Indigenous Knowledge*. London: Routledge.

Turnbull D (2002) Travelling knowledge: Narratives, assemblage, encounters. In: Bourguet M-N, Licoppe C and Sibum HO (eds) *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century*. London: Routledge, 273–294.

Traweek S (1988) *Life Times and Beamtimes: The World of High Energy Physicists*. Cambridge, MA: Harvard University Press.

Twyman C, Smith TA and Arnall A (2015) What is carbon? Conceptualising carbon and capabilities in the context of community sequestration projects in the Global South. *Wiley Interdisciplinary Reviews: Climate Change* 6(6): 627–641.

Van der Sluijs JP (2002) A way out of the credibility crisis of models used in integrated environmental assessment. *Futures* 34(2): 133–146.

Van der Sluijs J, Van Eijndhove J, Shackley S and Wynne B (1998) Anchoring devices in science for policy: The case of consensus around climate sensitivity. *Social Studies of Science* 28(2): 291–323.

Van Tuinen S (2009) Air conditioning spaceship earth: Peter Sloterdijk's ethico-aesthetic paradigm. *Environment and Planning D: Society and Space* 27(1): 105–118.

Vaughan C and Dessai S (2014) Climate services for society: Origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdisciplinary Reviews: Climate Change* 5(5): 587–603.

Veale L, Endfield G and Naylor S (2014) Knowing weather in place: The Helm Wind of Cross Fell. *Journal of Historical Geography* 45: 25–37.

Venturini T, Baya Laffite N, Cointet J-P, Gray I, Zabban V and De Pryck K (2014) Three maps and three misunderstandings: A digital mapping of climate diplomacy. *Big Data & Society* 1(2): 1–19

Verran H (1998) Re-imagining land ownership in Australia. *Postcolonial Studies* 1(2): 237–254.

Wainwright SP (2012) Science studies in physical geography: An idea whose time has come? *Progress in Physical Geography* 36(6): 786–812.

Wainwright SP and Williams C (2008) Spaces of speech and places of performance: An outline of a geography of science approach to embryonic stem cell research and diabetes. *New Genetics and Society* 7(2): 161–173.

Walker M (2012) The 'national' in international and transnational science. *The British Journal for the History of Science* 45(3): 359–376.

Watson-Verran H and Turnbull D (1995) Science and other indigenous knowledge systems. In: Jasanoff S, Peterson J and Pinch T (eds) *Handbook of Science and Technology Studies*. Thousand Oaks, CA: SAGE, 115–139.

Weart S (2010) The development of general circulation models of climate. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 41(3): 208–217.

Webber S (2015) Mobile adaptation and sticky experiments: Circulating best practices and lessons learned in climate change adaptation. *Geographical Research* 53(1): 26–38.

Webber S and Donner SD (2016) Climate service warnings: Cautions about commercializing climate science for adaptation in the developing world. *Wiley Interdisciplinary Reviews: Climate Change*. DOI: 10.1002/wcc.424.

Weisser F (2014) Practices, politics, performativities: Documents in the international negotiations on climate change. *Political Geography* 40: 46–55.

Weisser F and Müller-Mahn D (2016) No place for the political: Micro-geographies of the Paris Climate Conference 2015. *Antipode*. DOI: 10.1111/anti.12290.

Weisser F, Bollig M, Doevenspeck M and Müller-Mahn D (2014) Translating the 'adaptation to climate change' paradigm: The politics of a travelling idea in Africa. *The Geographical Journal* 180(2): 111–119.

Welsh M (2013) Resilience and responsibility: Governing uncertainty in a complex world. *The Geographical Journal* 180(1): 15–26.

Whatmore SJ (2002) *Hybrid Geographies: Natures, Cultures, Spaces*. London: SAGE.

Whatmore SJ (2009) Mapping knowledge controversies: Science, democracy and the redistribution of expertise. *Progress in Human Geography* 33(5): 587–598.

Whitehead M (2011) *State, Science and the Skies: Governmentalities of the British Atmosphere*. Oxford: Wiley-Blackwell.

Whitehead M, Jones R and Jones M (2007) *The Nature of the State: Excavating the Political Ecologies of the Modern State*. Oxford: Oxford University Press.

Withers CWJ (2007) *Placing the Enlightenment: Thinking Geographically about the Age of Reason*. Chicago, IL: University of Chicago Press.

Withers CWJ and Livingstone DN (1999) Introduction: On geography and enlightenment. In: Livingstone DN and Withers CWJ (eds) *Geography and Enlightenment*. Chicago, IL: University of Chicago Press, 1–28.

Withers CWJ and Keighren IM (2011) Travels into print: Authoring, editing and narratives of travel and exploration, c.1815–c.1857. *Transactions of the Institute of British Geographers* 36(4): 560–573.

Withers CWJ, Higgitt R and Finnegan D (2008) Historical geographies of provincial science: Themes in the setting and reception of the British Association for the Advancement of Science in Britain and Ireland, 1831–c.1939. *British Journal for the History of Science* 41(3): 385–415.

Wynne B (2003) Seasick on the Third Wave? Subverting the hegemony of propositionalism: Response to Collins and Evans (2002). *Social Studies of Science* 33(3): 401–417.

Wynne B (2010) Strange weather, again: Climate science as political art. *Theory, Culture & Society* 27: 289–305.

Yamane A (2009) Climate change and hazardscape of Sri Lanka. *Environment and Planning A* 41(10): 2396–2416.

Yusoff K (2005) Visualizing Antarctica as a place in time: From the geological sublime to 'real time'. *Space and Culture* 8(4): 381–398.

Yusoff K (2009) Excess, catastrophe, and climate change. *Environment and Planning D: Society and Space* 27(6): 1010–1029.

Yusoff K (2013) Geologic life: Prehistory, climate, futures in the Anthropocene. *Environment and Planning D: Society and Space* 31(5): 779–795.

Yusoff K and Gabrys J (2011) Climate change and the imagination. *Wiley Interdisciplinary Reviews: Climate Change* 2(4): 516–534.

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