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Is co-producing science for adaptation decision-making a risk worth taking?

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Abstract

Over the last decade, researchers have repeatedly sought to understand why adaptation planning and decision-making have failed to progress as quickly as once hoped. A major concern is that policy paralysis and inaction have arisen due to practical difficulties of delivering climate science that can actually be used for adaptation decision-making. Non-scientific actors are increasingly called upon to help reverse this trend by deliberately co-producing science. Scientists and knowledge users are expected to work closely together to produce more usable climate information. To date, our understanding of the barriers that impede the co-production of science for adaptation decision-making come almost exclusively from the perspective of decision-makers, not scientists. This paper responds to that gap by drawing on documentary analysis of key Government texts and in-depth interviews (n=48) with climate scientists, government officials, and boundary workers involved in the UK's latest climate projections, UKCP09. Our research shows that co-production is far from a neutral activity, but the contested outcome of intense political struggles over its meaning and application. Frictions, antagonism and power imbalances can develop between those involved over 'who' co-produces science and 'how' they do it, as constraints on scientists to deliver climate science that is both usable and world-leading prove irreconcilable. Not only do scientists and users understand usable science differently but other scientists distanced from the process understand and respond to it differently as well. This can create risks for scientists and the field more broadly. If scientists respond too strongly to user needs there is the risk of antagonizing peers and creating disagreements over whether climate science is being farther than it's ready to go. If scientists don't respond strongly enough to user needs there is the risk that users will not adapt or may make poor decisions instead. This raises the question of whether deliberately co-producing climate science for adaptation decision-making is a risk worth taking.

Keywords**:** Climate science, adaptation, co-production, institutional politics, tensions, and barriers

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Highlights

1. Adaptation planning and decision-making have failed to progress as quickly as once hoped
2. A major concern is inaction relates to practical difficulties of delivering usable climate science
3. Co-producing climate science for adaptation is promising but not a neutral activity
4. Frictions, antagonism and power imbalances over 'who' co-produces science and 'how'
5. Co-producing climate science poses important risks to scientists and the field

1. Introduction

Far from the taboo subject it once was, adaptation to climate change is now politically accepted as something that needs tackling both globally and locally across different levels of governance (IPCC 2014; Pielke et al 2007). The UK Government has enacted legislation - Climate Change Act 2008 - requiring the risks from climate change to be assessed and policies developed to adapt to them every five years. As yet, this political apparatus has failed to yield much in the way of concrete adaptation actions in households (Porter et al 2014), local government (Porter et al 2015) or wider society (Tompkins et al 2010).

Other countries have experienced similar difficulties. A wide range of adaptation barriers have been identified from a lack of knowledge about climate risks and responses (Archie et al 2014; Bierbaum et al 2013; Kiem & Austin 2013), weak or inconsistent political leadership (Amunsden et al 2010; Hardoy et al 2014; Hjerpe et al 2014), institutional fragmentation (Biesbroek et al 2011; Ekstrom & Moser 2014; Mukheibir et al 2013), to insufficient funding (Barnett et al 2015; Eisenack et al 2014; Moser & Ekstrom 2010). For Moss et al (2013), practical difficulties of delivering climate science that can actually be used for adaptation decision-making has slowed progress (see Briley et al 2015; Dilling & Lemos 2011; Kirchhoff et al 2013). Limited in the details it can provide (Mearns 2010), and its inherent uncertainty (Lemos & Rood 2010), climate science can find it hard to be 'not only credible, but also salient and legitimate' (Cash et al 2003: 8086). If the information provided is inconvenient or inaccessible (Moser & Ekstrom 2010), untrustworthy and unfamiliar (Archie et al 2014; Kiem & Austin 2013), too complex or resource-intensive (Tribbia & Moser 2008; Wilby & Kennan 2012), and fails to align with institutional mandates or priorities (Rayner et al 2005; Tang & Dessai 2012), uptake and use can be disappointing. This is what Lemos et al (2012) term 'the climate information usability gap'. To narrow that gap climate science needs to be done differently. This has sparked a debate over the merits of science *for* adaptation (to support policy/practice) vs. science *of* adaptation (to better understand) (Swart et al 2014; also Castree et al 2014; Hinkel et al 2014).

On one side stand practice-oriented researchers calling for non-scientific actors to be included in adaptation science so that societally relevant problems are co-designed, co-produced, and wherever possible, co-learning encouraged (Dilling & Lemos 2011; Kirchhoff et al 2013; Nowotny et al 2001). Dissatisfied with scientists who prioritize basic, disciplinary-bounded, and curiosity-driven research, at the expense of more relevant or usable science, recent empirical studies argue for the need to deliberately co-produce science to bridge the cognitive and institutional divides between science and decision-making (Lemos & Morehouse 2005; Meadows et al 2015) through knowledge brokerage (Meyer 2011) and boundary organizations (Agrawala et al 2001; Miller 2001). On the other side, critical scholars fear that practice-oriented science is too closed, lacking in reflexivity, and limits adaptation debates by depoliticizing them (Lovbrand 2011; Preston et al 2015a; Swart et al 2014). The closeness between science and practice runs the risk that 'they become trapped in a vicious cycle where the problem-solving' lens of decision-makers dominates every discussion, and in turn, theoretical and methodological insights from disciplinary sciences are sidelined (Swart et al 2014: 4). This can led to a 'trade-off between research that is co-produced to be accountable to the knowledge needs of societal decision-makers [science *for* adaptation], and co-produced research that seeks to challenge and transform existing ways of thinking [science *of* adaptation]' (Lovbrand 2011: 231). In this paper, we critically explore the science *for* adaptation paradigm to better understand the risks involved in this new mode of knowledge production.

To date, our understanding of the barriers that impede the creation of usable science come almost exclusively from the perspective of decision-makers (Briley et al 2015; Bruno Soares & Dessai 2015; Dilling & Lemos 2011). To explain why 'potentially useful climate information often goes unused' Lemos et al (2012: 789) argue that this is down to a subtle yet important distinction between 'what scientists understand as *useful* information and what users recognize as *usable* in their decision-making' (emphasis added). Scientists, for instance, when choosing the focus of their research will make a series of assumptions about what they think decision-makers need, but tend to do so without fully understanding the priorities or pressures of end users (Feldman & Ingram 2009; Lemos & Rood 2010). Users, in turn, may define their needs differently or may be unclear about exactly how this new knowledge will fit/conflict with their current decision-making practices and choose to ignore it, irrespective of its usefulness (Rayner et al 2005; Rice et al 2009). This new useful-usable science vocabulary serves to differentiate between the science *of* adaptation (useful) from the science *for* adaptation (usable). Few studies, however, have explored the barriers of creating usable science from the perspective of scientists (Cvitanovic et al 2015a; 2015b; Hegger & Dieperink 2015). This paper responds to this gap in the literature by drawing on documentary analysis of key Government texts and in-depth interviews to assess the efforts of climate scientists, government officials, boundary workers, and users to narrow the ‘climate information usability gap’ (Lemos et al 2012).

We focus on the UK's latest climate projections, UKCP09, which are 'designed as an input to the difficult choices that planners and other decision-makers will need to make, in sectors such as transport, healthcare, water resources, and coastal defences, to ensure the UK is adapting well' (Jenkins et al 2009: 9). The UK has a long history of producing climate scenarios/projections (Hulme & Dessai 2008). Earliest examples - CCIRG91 and CCIRG96 - were aimed primarily at the research community and policymakers. But once the Government initiated the United Kingdom's Climate Impacts Programme (UKCIP) a boundary organization based at the University of Oxford in 1997, subsequent ones - UKCIP98 and UKCIP02 - have targeted a broader set of decision-makers, including key infrastructure operators, public bodies, consultants, regulators, private utility companies, and industry associations (Gawith et al 2009; McKenzie-Hedger et al 2006). The UK's most recent climate projections, UKCP09, embraced the ethos behind usable science involving non-scientific actors throughout their design and delivery (Steynor et al 2012). UKCP09 includes several products – a user interface, marine and costal projections, a weather generator – but our focus is on the land climate change projections (Jenkins et al 2009). Moving away from single values, the projections use probability distributions to represent uncertainty of future climate changes, across the whole of the UK down to 25km grid cells from now to the end of the century. Applauded by some for encouraging bottom-up vulnerability assessments (Kelly 2014; Steynor et al 2012; Street et al 2009), others have criticized the projections for offering a false sense of certainty in adaptation planning and decision-making (Frigg et al 2014; Heaphy 2015; Tang & Dessai 2012).

We concentrate on the efforts of scientists at the Met Office Hadley Centre to produce the UK's land climate change projections for two reasons. First, the Met Office enjoys a close working relationship with Government based on a single, large, research contract known as the Climate Prediction Programme (Defra 2007a). Under that contract, scientists must deliver policy-relevant knowledge, whenever called upon by government officials, but also ensure it makes an original contribution to science for inclusion in the IPCC assessment reports (Shackley 2001). Second, the Met Office acts as an obligatory passage point through which UK climate science flows. Possessing the only Global Climate Model (GCM) for the UK and the only supercomputer capable of processing it, a small, centralized research network has developed around the Met Office. These characteristics have shaped not only how UK climate science is done but also how others have responded to it.

After explaining our data and methods, we explore why Met Office scientists agreed to co-produce climate projections with users. We then focus on the Met Office's efforts to quantify uncertainty in the modeling, and show how the usability of climate information is not a fixed characteristic of the science itself. Instead, it's the contested outcome of intense political struggles over its meaning and application. To enhance the relevance of the data, we follow the Met Office's efforts to deliver higher spatial resolution outputs, and how useful and usable science clash as more actors become involved. Finally, we highlight a series of concerns voiced by the research community in response to the projections over the creation of usable science. To close, we reflect on how the push for usable science reassigns the roles and responsibilities of climate scientists, and importantly, raises questions not only about the credibility, saliency, and legitimacy of the science itself but also for the field itself.

2. Data and Methods

This paper is based on a 'source triangulation' between two broad types of primary data (Glaser & Strauss 1967), relating to the origins, production, and use of the UK's 2009 climate projections. First, we collected and reviewed official documents, including policy briefs, independent reviews, and paper materials relating to user consultations, pertaining to the creation and use of climate science, adaptation, and policy. As matters of public record, they set out the official grounds in which different actors explain their actions to others (Goffman 1959).

To explore the 'backstage' experiences hinted at, but often hidden from view in these documents (Hligartner 2000), our second data source came from forty-eight in-depth interviews, conducted during the summer of 2013, with Met Office Hadley Centre staff who were tasked with designing, building, and delivering the UK's latest climate projections (n=15); researchers specializing in atmospheric science, computer modeling, and Bayesian statistics, who were either part of the independent review panel for the projections or have extensively applied the projections (n=15); and government officials, particularly from the Department for Environment, Food and Rural Affairs (Defra), who funded and steered the work alongside translators, including the United Kingdom's Climate Impacts Programme (UKCIP) staff and consultants, who were charged with ensuring decision-makers' voices were heard throughout the production process (n=18). They were all selected from a purposeful sample of actors who played multiple roles in developing the projections and reflect the mixture of supporters and critics. Wherever possible, interviews took place in the participant's workplace, were audio-recorded (with consent) and transcribed. A conversational approach was adopted, using open-ended questions to encourage people to reflect on their experiences. Transcripts were coded manually in NVivo with emergent themes identified and elaborated upon iteratively through successive engagement with documentary materials. To introduce greater rigor and validity to our findings, the analysis was triangulated between the different sources and methods used (Baxter & Eyles 1997).

3. Creating usable science: The UK's climate projections

After the release of the UK's previous climate scenarios, UKCIP02, Met Office staff and Defra officials began discussions for its replacement. Whereas UKCIP02 was borne out of what scientists thought was useful for decision-making, with little input from users (Hulme & Dessai 2008); the new climate projections would open up the production process to as many users as possible (Steynor et al 2012; Street et al

2009). ‘Interactions between the scientific community who developed the projections and the stakeholder community who will be using them' would be encouraged to 'ensure as far as possible that while remaining scientifically valid, the outputs meet user requirements' (UKCIP 2014). It was ‘far from easy’ to get the Met Office to do science differently, however (Government Official 2, Interview).

Between the release of UKCIP02, in 2002, and UK's latest climate projections, UKCP09, in 2009 the user community had changed considerably. In 2004, 'the user community was still very small. It was basically just central government, the research community, and some water companies' (Government Official 5, Interview). Those using UKCIP02 were relatively easy to identify, as a license was needed to access the data. To find out what users needed, several workshops were held across the country (UKCIP 2004; 2005). Invitations were also extended to those working in sectors including energy, forestry, building and local government. Three overarching needs were identified. First, access to climate information needed to be improved. Not only was the 'process of getting hold of the data longwinded, which put people off' (Met Office Scientist 1, Interview) but the format of the data was also often incompatible with the software used (Gawith et al 2009). Extra time, money, and energy were needed to convert the data into something usable. Second, uncertainty in climate models needed to be treated more explicitly. Aware that different climate models give different answers, unambiguous advice was called for on how to interpret model outputs (UKCIP 2006a). Lastly, the geographical scale of the data needed to be increased too. UKCIP02 was considered 'too coarse' to inform 'local adaptation decisions' (UKCIP Officer 4, Interview). An official government review, and later a survey of licensed users, reiterated these conclusions (ESYS 2004; UKCIP 2006a; 2006b).

A summary of the workshops, however, warned that 'different users have different needs... [so] climate information... cannot assume a uniform audience' (UKCIP 2006a: 1). For instance, researchers were keen on probabilistic projections yet decision-makers were less so, whilst decision-makers favored an increase in the geographical scale of the data researchers were less supportive (UKCIP 2006b). These findings were fed back to Defra and the Met Office where work had already begun on the new climate projections. In 2006, Defra revised the setup for developing and delivering the projections. Rather than leaving the Met Office to manage the process alone, Defra officials, UKCIP staff, and users were brought in. Three new groups were created. A steering group took over responsibility for the entire project chaired by Defra; day-to-day modeling decisions were taken by the project management group run by the Met Office; and a user panel was set up by UKCIP to relay feedback to the other groups every few months (Defra 2007b). This insistence on introducing a user panel stemmed, in part, from a realization that to build trust between scientists and users two-way communications were needed (Lemos & Morehouse 2005; McKenzie-Hedger et al 2006), to avoid misunderstandings (Nonaka 1994), and improve uptake (UKCIP Officer 2, Interview). Defra were also keen to involve new users. An analysis by UKCIP found that whilst:

> 'the research community comprised 80% of the user community when the UKCIP02 [climate] scenarios were released, by 2006/7 the research community made up only 20%... it was the same number overall... but the user community had expanded into other areas' (UKCIP Officer 5, Interview).

These new users would be selected for the user panel 'based on their experience and ability to represent the needs of their respective communities or sectors' (Defra 2007b) so included researchers, government agencies, regulators, infrastructure operators, utility companies, consultancies and industry associations. Yet who the user of the new climate projections was had became a very complicated, as a result. Whereas the Met Office 'had researchers in mind' (Met Office Scientist 3, Interview), Defra saw the projections as aimed at 'almost anyone really' (Government Official 5, Interview). These different users had very different needs. This may help explain why 'Met Office scientists were reluctant to join the user panel initially' (UKCIP Officer 1, Interview) thinking they already knew what users wanted. Indeed, accommodating user engagement activities into the already overstretched job descriptions of most Met Office scientists can encounter some resistance as these activities are not institutionally rewarded or valued in the same way as more traditional research outputs (Jacobs et al 2006; Lemos & Morehouse 2005), and engaging users carries a risk of not being seen as a 'serious' scientist by peers (Porter et al 2012). Despite these concerns, once Met Office scientists attended a few user panel meetings they soon 'realized the value of these face-to-face interactions' in gaining a deeper understanding of the barriers faced by users and how these might be resolved:

> 'I see part of my role as turning what I think users want into something that is scientifically [doable]... There are going to be things [users] won't ask for because it's not something they necessarily think they need. They just say, 'I can't do this and I can't do that'. So I have to ask: What does this mean? Why can't they do it? Why aren't they getting it?' (Met Office Scientist 3, Interview).

Appeals of 'users always asking for things that are scientifically impossible or things that are just too costly to do' to avoid doing science differently (UKCIP Officer 1, Interview), were gradually replaced by a willingness of Met Office scientists to engage users and move climate science beyond something that is only useful, and with the potential to be used, to something that is usable and can inform adaptation decision-making.

4. Results

4.1. When Useful Isn't Usable Science

The usability of climate information is often treated as a fixed characteristic of the science itself, rather than the outcome of intense political struggles over its meaning and application (Porter et al 2015). Whereas users repeatedly called for uncertainty to be better characterized in the new climate projections (UKCIP 2004; 2005; 2006a;

2006b), Met Office scientists understood this need very differently. For them, every source of uncertainty should be made explicit in the modeling as well as the limitations attached to them. Importantly this involved introducing Bayesian probabilities for the first time - a complex method used to convey the degree to which evidence (e.g. observational data, model outputs, and expert knowledge) support a particular climate future (see Heaphy 2015). Ambiguity, or ignorance, towards these different kinds of uncertainty allowed the divide between what scientists think is useful and users understand as usable science to grow, pitting one against the other.

Since the mid-1990s, uncertainty has attracted more and more attention in modeling circles. Modelers realized that small errors in initial conditions - the starting point for model simulations - can have a very large effect on how models behave (Parker 2013). Whilst much has been learnt about the climate system some key physical processes are still not fully understood and limited computing power have affected how they are represented in the models (Jenkins et al 2009). IPCC assessment reports have made the scientific and policy community aware of these uncertainties, notably that 'different climate models, under the same emission scenarios [starting point], can perform differently' (Met Office Scientist 6, Interview). In turn, the UK's previous climate scenarios, UKCIP02, made users aware of these uncertainties by including an analysis of 'how other climate models don't give the same result for the UK' (Met Office Scientist 4, Interview; see Hulme et al 2002: 24). An official review of UKCIP02 concluded that these uncertainties were a major concern for users, as 'the level of confidence' in climate information was not high enough for them 'to justify major adaptation decisions' (ESYS 2004: 15). Users told UKCIP that they wanted the new climate projections to provide 'easily accessible uncertainty information' (UKCIP 2006a: 7). They also wanted advice on how to interpret multi-model ensembles - where different climate models run under the same conditions are compared to determine the upper and lower bounds of uncertainty and the spread of results within. Institutional politics made it difficult for Met Office scientists to accept this method for assessing uncertainty.

Institutional priorities set out by Government departments under the Climate Prediction Programme contract, require the Met Office to produce policy-relevant knowledge that also makes an original contribution to scientific knowledge. This primary objective can clash with the secondary objective to create usable science. For instance, performing a multi-model ensemble to capture model uncertainties (e.g. initial conditions, physical processes, and spread of results), as users called for above, displaces the central role played by the Met Office's own climate model. This was risky as several external reviews were investigating the impact of the Met Office's climate research within, and beyond, the UK and whether funding should be revised (Beddington 2010; Lawton 2009; Risk Solutions 2006). Met Office staff dismissed this method because these kinds of ensembles often lack any documentation on the physical processes, parameters, or geographical scales used by the models, making direct comparisons difficult as 'the models are similar in some ways but different in others' (Climate Scientist 5, Interview). Interpreting multi-model ensemble outputs is also problematic because:

> 'they provide no basis to advise users on whether a response "near the middle" should be considered more likely than one "at the edge", or if the actual response lies outside the modeled range altogether' (Met Office Scientist 6, Interview).

Met Office scientists favored another approach: a hybrid one. They used a method piloted a few years before, known as a perturbed physics ensemble (Murphy et al 2004), where the same climate model is run over and over again but with slightly different parameters to produce a spread of results. These outputs are then combined with a multi-model ensemble to identify any major discrepancies (Jenkins et al 2009). Consequently attention shifts back onto the Met Office's own climate model and expertise. Pioneering this novel approach proved an effective way to couple the need to 'push the science forward' (Met Office Scientist 3, Interview; see Collins et al 2007; Harris et al 2013; Sexton et al 2012), generate endorsements from the wider community (Stocker 2004), and act as a shop window onto the climate services provided by the Met Office. Institutional pressure to build up and circulate the Met Office brand (Mahony & Hulme 2012) also permeates down to the individual level. Met Office scientists need to carve out their own intellectual niche to advance their careers (Met Office Scientist 8, Interview) or keep alive the option of moving to academia/industry (Met Office Scientist 11, Interview). Publishing or being involved in new research is a perfect opportunity to do this. Projects that fail to offer these rewards are less attractive (cf. Jacobs et al 2006; Lemos & Morehouse 2005). Including Bayesian probabilities, on top of the Met Office's new climate modeling setup, fulfilled this criterion:

> 'from a methods point of view the goal just seemed right and it was something that should be done. [What] really gives me confidence is the Bayesian framework... we've put our own interpretation on it... but it's all written down in the maths, it's there to debate... you can see it in black-and-white. *It's just good science*' (Met Office Scientist 3, Interview).

The appeal of Bayesian probabilities stemmed from it's perceived usefulness both intellectually and institutionally. First, tacit assumptions and experiential knowledge once hidden from view in climate modeling are made explicit in an effort to improve the transparency and accountability of the science. It can be difficult to trust the work of climate modelers 'when they stand up, make all these bold statements but they haven't presented their assumptions, they haven't talked about the limits of their knowledge' (Met Office Scientist 3, Interview). It was believed that this commitment to mechanical objectivity - the adherence to impersonal rules as a method to minimize the influence of subjective bias (Daston & Galison 2007; Porter 1995) - would make the new projections more useful, and therein, usable. Second, by showing the relative degree to which changes in climate variables are supported by current evidence, the roles and responsibilities of scientists and users are redefined through the application of institutional risk management (Rothstein et al 2006; Porter & Demeritt 2012). Now scientists are responsible only for producing the model outputs and evaluating their robustness. By contrast, the onus is on users to decide what level of risk they are willing to accept when applying the projections, rather than 'rely on' the Met Office for a 'single, definitive, answer' and blame them if it's 'proves to be wrong' (Met Office Scientist 5, Interview).

Not all users shared the Met Office's vision for assessing uncertainty. When UKCIP surveyed users of the previous climate scenarios, in 2006 they voiced a number of concerns. They said it was a 'mistake' to 'produce [probabilistic] information [as] there is still no evidence to suggest that people will make better decisions with [it]', especially as 'so few people know how to interpret [it]' (Respondent 6, UKCIP 2006b: 14). But even 'if they were capable of understand[ing] this probabilistic [information]' it was noted that it would fit poorly within the decision processes and contexts of users as 'they would not have the time to absorb it!' (Respondent 8, UKCIP 2006b: 14). These concerns came too late. Modeling decisions had already progressed beyond the point of being reversed. Despite the science being strongly perceived as useful whether it was usable, or would even be used, was unclear. Different institutional priorities for the Met Office to produce world-leading science, alongside a political mandate to create policy-relevant knowledge, have pulled scientists in opposite directions. Ambiguity over how uncertainty should be assessed left it to be defined by those able to reap the professional rewards for doing so.

4.2. When Usable Isn't Useful Science

Where institutional priorities and user preferences once clashed over the meaning and application of usable climate information, they now came together via a common goal: the need to improve the spatial resolution of the climate projections. Simply put, the geographical scale of the UK's previous climate scenarios, UKCIP02, was considered 'too coarse' by many users. This made it 'difficult to bring [the findings] down to a local enough level to apply [them]' (UKCIP 2006a: 7). Met Office scientists agreed. In response, they increased the spatial resolution from 50km to 25km by downscaling the outputs from the Met Office's global climate model, HadCM3, using a complex statistical method and a regional climate model, HadRM3 (Jenkins et al 2009). The UK's land surface was broken up into 434 grid cells, each 25km in size. On the advice of the user panel, these grid cells were aggregated into 23 river basins and 16 administrative regions to improve the decision relevance of the data (Steynor et al 2012). Yet, in so doing, tensions between the Met Office and other researchers in the field rose over whether the 'science had been stretched too far' and how useful it is for decision-making (Met Office Scientist 1, Interview).

Met Office scientists have long understood that users 'are interested in their local patch' (Met Office Scientist 9, Interview). For instance, water managers are often interested in how water flows through their catchment and where it ends up

(Prudhomme et al 2012). 'Climate inputs' such as precipitation are needed for 'different parts of the catchment' if river responses are to be modeled as accurately as possible (Translator 6, Interview). Model outputs at a 50km scale fail to meet these water-modeling requirements. By contrast, higher spatial resolution data can help improve the fit between climate science and decision-making processes/contexts as well improve its relevance and salience (Cash et al 2003; Lemos et al 2012). Indeed, the Met Office 'doesn't just want to do science for science's sake... we want to do something useful, good science', which involves thinking 'about users and what they want, and crikey with regional climate projections this all fits' (Met Office Scientist 3, Interview). Yet the Met Office's commitment to giving users what they want is predicated on aligning a wider set of institutional priorities. One of the main deliverables for the Climate Prediction Programme is to 'develop a finer [spatial] resolution... [climate] model to improve regional predictions for impact and adaptation studies' (Defra 2007a: 10). This political goal enables original research to continue unabated. Met Office scientists are able to 'add in greater complexity into the models through new feedbacks and interactions' at higher spatial scales or gain greater control over them 'by turning some things on or off' (Met Office Scientist 9, Interview). In addition, extra details provided by the new projections offer a visual cue about improvements, forestalling questions about added-value:

> 'Because we'd provided high-ist resolution climate data [50km] before [with UKCIP02] we certainly couldn't do anything worse than that. Obviously we wanted to do something better than that, and that naturally meant going down to 25km' (Met Office Scientist 12, Interview).

How reliable these 25km model outputs are became a hotly debated topic. An opening salvo came from a respected atmospheric physicist Myles Allen, University of Oxford, in an interview with the BBC. He told them, 'the IPCC explicitly stepped back from making probabilistic projections on [the] sort of scale' used by the Met Office (Ghosh 2009). Whereas the new projections provide probabilistic outputs on a 25km, the IPCC's fourth assessment report stated that outputs of this kind were only reliable on a scale of 1,000km (Solomon et al 2007: 87). In private, others voiced similar concerns:

> 'There is really a gut feeling, an instinct… when talking about the small scales at which UKCP09 tries to say something… when you ask reasonably sensible academics: do you think you can represent what the climate will be in 80 years at a 25km scale, it's easy to persuade them you can't because it feels as though you shouldn't be able to, and there are lots of reasons why with our current understanding and technology that you can't' (Climate Scientist 5, Interview).

Concerns grew that the projections’ regional detail meant 'the science was being pushed a little further than it was ready to go' (Climate Scientist 4, Interview). Aware of these concerns, the Met Office inserted a caveat in the text: the 'cascade of confidence' (Jenkins et al 2009: 22). That is, confidence is highest in the model outputs at continental scales but gets lower and lower as the scale reduces, and at 25km is only 'indicative... [of] large-scale changes modified by local conditions' (ibid). Whether users understand that the data's reliability varies - greatest at the national scale and less so at the local scale - is unclear as there is a temptation for 'people to just flick pass the caveats and dive into the high-resolution data' (Met Office Scientist 1, Interview). If users are unaware of these potential limitations they could be given a false sense of certainty when applying this climate information (Bradley et al 2014; Frigg et al 2013; 2015).

Questions, in turn, were raised about the respective role and responsibilities of scientists towards users. Should Met Office scientists have said "no" to making the projection data available at smaller scales? Responding to these concerns, the Met Office's Chief Scientist, John Mitchell, wrote a letter to the New Scientist journal. He argued that 'government and industry' cannot wait for 'nearly perfect' regional climate projections and prefer to make 'decisions on current imperfect models rather than no information at all…' (Mitchell 2007; see Schneider's 2009 analogy of climate models as dirty crystal balls). If climate information is not made available as quickly as possible to decision-makers it will lack pertinence, and will be ignored irrespective of how useful or usable it may be (Ford et al 2013). Others disagreed:

> 'Do we need a 25km [spatial] resolution when the distributions are so similar? A couple of decimal points apart. You might as well have two points: one in the north and the other in the south [of the country] frankly, otherwise you run the risk of overselling [the science]' (Climate Scientist 9, Interview).

Any decision that is this sensitive to the level of data precision is one that may prove too risky (reputationally) for the climate community to endorse. Indeed, an official government review concluded that 'tensions exist in meeting users' desired information requirements with the development of credible and defensible science' (Hoskins 2009: 1). A subtle distinction is revealed here between what users may want and what they really need (Tang & Dessai 2012). Judging this can be tricky as it may bring scientific and institutional priorities into conflict. Met Office scientists are, for instance, reluctant to tell users what they can and cannot do (Met Office Scientist 6, Interview). This has led to a perception that the Met Office 'listened too much to users, [and] responded to their requirements too strongly. That we'd done something a lot of scientists would have said "no", sorry that's going too far' (Met Office Scientist 3, Interview). Some have even suggested that Met Office staff are powerless to say "no" to users or their funders:

> 'If modelers are asked for detailed projections about what will happen say in a corner of England in 2080, some feel, and I'm thinking of those in the Met Office that it's their job to provide an answer. And whatever the computer spits out, they feel obliged to report it' (Climate Scientist 7, Interview).

Met Office scientists deny this. They explained that they would never sign-off on anything that was not ‘scientifically sound’ or could damage the ‘Met Office’s reputation’ (Met Office Scientist 2, Interview). In fact, the new projections were 'delayed for two years whilst a bug in the data was fixed' (Met Office Scientist 11, Interview). Since then, an independent review panel has verified the science behind the projections (Hoskins 2009) and the method has been published in high-impact scientific journals (Collins et al 2007; Harris et al 2013; Sexton et al 2012). But doubts remain. ‘Just because something is technically possible doesn’t necessarily mean that’s what you should do’ (Climate Scientist 2, Interview). Not only do scientists and users understand usable science differently, *a la* Lemos and Rood (2010), but scientists distanced from the process understand and respond to it differently as well. Given the politically furor surrounding climate change, others in the field have urged the Met Office to think carefully about how they present climate information, knowing skeptics will use anything to cast doubt.

4.3. When Usable Science Shouldn’t Be Used

In 2009, the UK's climate projections were released online, free-of-charge. Within 'a few clicks of the mouse' users could generate customizable outputs, from figures, tables, maps to factsheets, for places of interest to them 'now until the end of the century' (Met Office Scientist 1, Interview). Where some praised the projections for improving the confidence of the data, and for individualizing the management of risk, others expressed concerns over the complexity of the outputs and their usability (Kelly 2014; Tang & Dessai 2012). As debates remained over the exact meaning of useful vs. usable science, a much bigger concern facing the research community came into view, namely that the use of the projections 'poses a serious risk to the credibility of the field' (Climate Scientist 7, Interview).

Met Office staff were aware of researchers’ concerns. But they felt this reflected they 'small philosophical differences... where different problems are tackled in slightly different ways' (Met Office Scientist 3, Interview). No changes were needed. Others disagreed, as a cultural preference for scientific reticence was reluctantly cast aside. As efforts to discuss their concerns behind closed doors yielded 'little or were ignored', several researchers did so again but this time in a public forum: a scientific workshop (Government Official 4, Interview). Listening to the exchanges, a writer from the New Scientist journal published a piece asking if climate scientists were overselling their models (Pearce 2007; 2008). The Met Office's Chief Scientist, John Mitchell, wrote back defending the work (Mitchell 2007). Yet as David King, the Government's Chief Scientific Advisor, told the BBC ‘civil servants are very sensitive to scientists disagreeing in public’ as it can lead to policy paralysis and inaction (Ghosh 2009; see Lemos & Rood 2010; Shackley 2001). Researchers were sympathetic but felt caught in a catch-22. They did not want to derail progress towards implementing new climate policies but felt the reputations of the scientific and policy communities were being put at-risk:

> 'There was a feeling that we shouldn't be arguing about what we can do or can't do [scientifically] as that'll undermine the need for action. I was sympathetic with that view when UKCP09 started [in 2003] but I'm much less so now [2013]. I think the public needs to hear scientific disagreements, especially for serious things like climate change' (Climate Scientist 5, Interview).

Met Office staff, users, and other researchers understand and respond differently to useful/usable science, due in part to how involved they were in defining the work and how much effect it has on their professional lives; but an institutional and cultural preference also persists for critical debates to be held away from public view to avoid misunderstandings. Such misunderstandings, often reflecting epistemic differences over how climate science should be done, can offer 'skeptics fresh ammunition' to cast doubt (Climate Scientist 1, Interview; see Brysee et al 2014; Lewandowsky et al 2015; Orestes & Conway 2010). The Global Warming Policy Foundation - a think-tank critical of human-induced climate change research - has used Nicolas Lewis' work to claim that there is a warming bias in the modeling used for the projections and have called on the Government to withdraw them (Lewis 2013; Montford 2013). A fear of stifling policy action, or undermining public support, sits alongside another concern: namely, that criticism will be confused with skepticism. This can be damaging to the credibility of the those involved as well as deter open and frank debate about the limits of climate modeling or how things could be done differently:

> 'Back in 2007, Judith Curry said 'we have to be really careful about what we attribute to climate change and what we attribute to natural variability, which we don't understand'... She was accused of being a denier... when its a very reasonable thing to say from a scientific point of view but apparently you risk your reputation if you're too vocal about it' (Climate Scientist 1, Interview).

Government efforts to reassure the public have not always worked. For instance, when the BBC interviewed the Secretary of State for the Environment, Hillary Benn, he played down any scientific disagreement, noting 'there are always a few mavericks' (Government Official 3, Interview). This remark split the scientific community into two camps: 'serious scientists' and 'skeptics'. The institutional structure of UK climate research can add further complications. 'Shouting too loudly' in a small, centralized, research network like the UK, 'wouldn't be a good career move' for the funding prospects of junior researchers who need to be taken 'seriously as scientists', and are often (in)directly reliant on access to Met Office resources (Climate Scientist 5, Interview; cf. Pearce 2013). Whereas Brysee et al (2013) observe how climate scientists err on the side of caution, preferring to understate atmospheric responses to growing greenhouse gas emissions, to avoid being labeled alarmists; by contrast, a similar culture of scientific reticence is alive and well in the UK but plays out differently as a united front is presented to the public. Concerns, if any, are expressed privately. Judgments and values that shaped the projections are closed-off from public view, leaving users with a skewed impression of the work, and little option but to trust in the authority of science. This can be risky because:

> 'if these presumptions are not acknowledged more openly, the risk is run that, when they are eventually exposed through open debate, the resulting acrimony will make negotiation and mutual accommodation even more difficult' (Demeritt 2001: 328; see Beck's 2012 work on climategate).

Trust can be easily lost but difficult to restore. The complexity of the projections intensifies this problem. Users are now more dependent on scientists, not less. An initial survey of users of the projections found that less than half (43%) were satisfied with them, believing they had neither the technical competence nor capacity to make sense of them (UKCIP 2009). The projections were seen as 'so complex' that they 'push people towards complete rejection, or more dangerously, complete acceptance' (Climate Scientist 7, Interview). A concern here is that if users 'learn five years down the line that the probabilities were immature and we [the community] knew but didn't say anything', trust in the field would be damaged (Climate Scientist 5, Interview). Met Office staff downplayed these concerns noting that the 'limitations of the projections are very clear' in the text and if users 'struggle to understand them' they can always speak directly to the Met Office or contract-in a consultancy to interpret it for them (Met Office Scientist 2, Interview).

Another concern is the projections are perceived to blur the line between what is ‘a valuable research programme which advances science [and] a trustworthy operational risk management tool for decision-makers' (Frigg et al 2015: 27). The Met Office's raison d'etre of producing policy-relevant knowledge, that also makes an original contribution to science, means the two are inevitably intertwined. Where this can be problematic is when different demands are placed on usable science compared to curiosity-driven research (Irwin et al 1997). The latter prioritizes scientific aspirations to push the field’s boundaries whilst the former speaks to the needs of users for reliability, especially when decisions taken affect people's lives and livelihoods. Although Stokes (1997) argues that basic and applied science can be pursued simultaneously, without one necessarily compromising the other, in the case of the Met Office's projections achieving both goals meant the ‘methods were developing as the project went along’, and therefore, went largely untested by peer-review (Met Office Scientist 3, Interview). On the one hand, this can cast doubt over the reliability of the outputs. It can also be seen as quite 'dangerous... because other governments are asking their agencies to repeat' the work without first scrutinizing it, on the other (Climate Scientist 5, Interview). As yet, no other country has adopted the UK's approach.

An international panel was convened late in the process to review the projections after scientists met privately with government officials to voice their concerns (Hoskins 2009). This was off the back of realizing 'that the way [critics] presented their arguments probably hadn't helped... as they can be quite confrontational' (Government Official 4, Interview). In the end, responses to the projections were mixed. Few contested that the Met Office's had tried to improve the confidence in data, or given users greater control over the level of risk they manage, but the complexity of the projections had impacted upon their usability. Users, as a result, are left with little alternative but to trust the science. A concern here is that this could backfire on the field's credibility if scientific disagreements, once hidden from view, are revealed (Beck 2012; Demeritt 2001). This points to an inherent tension within the heuristic of co-producing usable science, particularly the balance in power over who defines it (Klenk & Meehan 2015). Only a small number of actors can be actively involved before the process becomes unmanageable. Yet those excluded still have a stake in the final output, especially in contentious fields like climate change, where compromise is a hard fought exercise.

5. Discussion: Is co-producing science for adaptation decision-making a risk worth taking?

Over the last decade, researchers have repeatedly sought to understand why adaptation planning and decision-making have failed to progress as quickly as once hoped (Barnett et al 2015; Eisenack et al 2014; Moser & Ekstrom 2010). A major concern is that policy paralysis and inaction are due to scientists failing to deliver climate information that can actually be used for adaptation decision-making (Hanger et al 2013; Moss et al 2013), and in turn, users failing to specify what exactly makes climate information usable for adaptation (Dilling & Lemos 2011; Kirchhoff et al 2013). Non-scientific actors are now being called upon to help reverse this trend by deliberately co-producing science with scientists (Lemos & Morehouse 2005; Nowotny et al 2001). Co-production promises to give users more socially-responsive and decision-relevant climate science (Lemos et al 2012). It also promises to enrich the lives of scientists, both intellectually and materially, through greater research-impact, publications, and reflexivity (Hegger & Dieperink 2015). A growing body of literature is now dedicated to identifying the barriers to co-producing science and finding ways of overcoming them (Briley et al 2015; Cvitanovic et al 2015a; 2015b; Meadows et al 2015).

Despite the initial reluctance of Met Office staff to meet users face-to-face, and find out what they need; scientists soon realized that they could squeeze these new activities into their working practices without sacrificing their publishing commitments (Jacobs et al 2006; Lemos & Morehouse 2005), or giving up their 'serious scientist' status (Porter et al 2012). One activity did not negate the other. Indeed, Met Office scientists showed a determination to see their work used in the real world. They praised how meeting users allowed a greater appreciation of the needs and challenges faced by each to develop and helped identify where small changes could be made to the UK's climate projections, UKCP09, with a big impact for their usability and uptake. For instance, the delivery of the weather generator, release of spatially coherent Regional Climate Model runs, and add-ons in the form of extreme events, all speak to the commitment of the Met Office to give users what they need and how the level of trust and familiarity between the scientific and user community has grown.

But our research shows that co-production is far from a neutral activity as 'friction, antagonism, and power' imbalances can develop between those involved and 'innovative and experimental ways of understanding and adapting to climate change' are excluded (Klenk & Meenhan 2015: 161). 'Who' is involved in co-producing science for adaptation decision-making, and 'how' they do it, shapes not only the final product but also affects how others respond to it.

First, co-production can preserve, rather than challenge, the status quo over who decides how climate science is done. As a result, this creates the very real 'intellectual risk of partiality and complicity' (Castree et al 2014: 764). Partiality because the diversity of voices, particularly critical ones, are often missing from the small, centralized, research network built around the Met Office; and complicity because the full range of human responses, values, and ways of knowing climate change, are excluded from debates over how climate projections should be produced. A risk here is prevailing rules of thumb, or tacit assumptions, over what makes climate science usable for adaptation are accepted uncritically, 'which can lead to inefficienc[ies], inefficac[ies], and maladaptation' (Preston et al 2015b: 482). If the spatial resolution of climate data is improved it's assumed that decision-making will naturally be improved as well (Mearns 2010). Yet the value-added by this data, and importantly its reliability for decision-making, are highly contested (Dessai et al. 2009). If users become aware of errors in the projections or disagreements in the scientific community, after long-term and potentially irreversible investments have been made, trust in the field could be lost (see Demeritt 2001; Beck 2012). Skeptics may also use these concerns to cast doubt about 'alarmist' scientists, impeding future efforts to adapt (Brysee et al 2013; Lewandowsky et al 2015; Oreskes & Conway 2010).

Second, scientists faced a series of practical constraints, both institutional-political and socio-technical, that affect how they co-produce science. For instance, Met Office scientists are required to deliver policy-relevant science, which also makes an original contribution to knowledge, for inclusion in the IPCC process as part of their funding agreement with Government (Defra 2007a). Likewise the pressure to produce world-leading science is also felt on an individual level as scientists publish high-impact journal articles to further their careers. These factors can shape how scientists see and respond to users and their needs (Porter & Dessai 2016). Not only do scientists and users understand useful/usable science differently, *a la* Lemos and Rood (2010), but the technical nature of debates over the meaning and assessment of uncertainty places users in a fairly passive position whereby scientists retain the power for defining how science should be done: keeping the linear-model of science alive and well. The UK's latest climate projections are a prime example. Modellers assumed that introducing Bayesian probabilities would give users greater confidence and control over how outputs are used to make risk-based decisions (Jenkins et al

2009). But probabilistic projections demand more from users. Lacking the time, resources, and capacity, users may struggle to assess their vulnerability to climate change and decide how best to adapt (Frigg et al 2015; Heaphy 2015). They become more reliant on scientists, not less.

6. Conclusion

Our research highlights some concerns over the risks involved for scientists, and the field more broadly, when deliberately co-producing climate science for adaptation decision-making. If scientists respond too strongly to user needs there is the risk of antagonizing peers and creating disagreements over whether climate science is being farther than it’s ready to go. Such concerns speak to the idealized and contested roles scientists can adopt, and the tacit assumptions they reflect about the nature of science and decision-making (Pielke 2007; Shackley et al 1999), as the perceived inability to say “no” to users needs sits in stark contrast to the more detached and disinterested norms advocated by purist scientists. If scientists don’t respond strongly enough to user needs, however, there is the risk that users will not adapt or may make poor decisions instead. Such concerns stem from providing climate information that is either too complex to use and understand or fails to meet the specific requirements of decision-makers (Lemos et al 2012). Steering between these extremes is far from easy. To do this, scientists will need the right skills. They will need to communicate effectively with different actors, manage and resolve competing needs (institutional, political, intellectual and social), and have the humility to recognize the limits of their own knowledge and be open to other ways of thinking (Preston et al 2015a). Unless scientists develop these skills, there is a real risk that co-production could become yet another barrier to climate change adaptation.

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References

Agrawala, S, 1998. Structural and process history of the Intergovernmental Panel on Climate Change. Climatic Change 39, 621-642.

Amundsen, H.; Berglund, F.; Westkog, H. (2010) Overcoming barriers to climate change adaptation - a question of multilevel governance? Environment and planning C, 28: 276-289.
Archie, K.M., Dilling, L., Milford, J.B., Pampel, F.C. (2014) Unpacking the ‘information barrier’: Comparing perspectives on information as a barrier to climate change adaptation in the interior mountain West. Journal of environmental management 133, 397-410.
Barnett, J., Evans, L. S., Gross, C., Kiem, A. S., Kingsford, R. T., Palutikof, J., Pickering, C., and Smithers, S. From barriers to limits to climate change adaptation: path dependency and the speed of change, Ecology and Society, 20(3), 5. http://dx.doi. org/10.5751/ES-07698-200305.
Baxter, J.; Eyles, J. 1997. Evaluating qualitative research in social geography: establishing ‘rigour’in interview analysis. Transactions of the Institute of British Geographers 22:505-525.
Beddington 2010. Review of Climate Science Advice to Government and Met Office Hadley Centre: Role, Governance and Resourcing, Government Office for Science.
Beck, S., 2012. Between tribalism and trust: The IPCC under the “public microscope" Nature and Culture 7(2), 151-173.
Bierbaum, R., Smith, J.B., Lee, A., Blair, M., Carter, L., Chapin III, F.S., Fleming, P., Ruffo, S., Stults, M., McNeeley, S., (2013). A comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitigation and adaptation strategies for global change, 18, 361-406.
Biesbroek, R., Klostermann, J., Termeer, C., Kabat, P. 2011. Barriers to climate change adaptation in the Netherlands, Climate law, 2, 181–199.
Bradley, S.; Frigg, R.; Du, H.; Smith, LA. 2014. Model Error and Ensemble Forecasting: A Cautionary Tale. in Guichun G, Liu C (eds.) Scientific Explanation and Methodology of Science. World Scientific, Singapore.
Briley, L., Brown, D., Kalafatis, S. E. 2015. Overcoming barriers during the co-production of climate information for decision-making. Climate Risk Management.
Bruno Soares, M., Dessai, S. 2015. What are the barriers and drivers to the use of seasonal climate forecasts in Europe?, Climatic Change.
Brysse, K.; Oreskes, N.; O’Reilly, J.; Oppenheimer, M. 2013. Climate change prediction: Erring on the side of least drama? Global Environmental Change 23:327-337.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B. (2003) Knowledge systems for sustainable development. Proceedings of the national academy of sciences 100, 8086-8091.
Castree, N., Adams, W., Barry, J., Brockington, D., Buscher, B., Corbera, E., Demeritt, D., Duffy, R., Felt, U., Neves, K., Newell, P., Pellizzoni, L., Rigby, K., Robbins, P., Robin, L. Rose, D., Ross, A. Schlosberg, D., Sorlin, S., West, P., Whitehead, M., Wynne, B. Changing the intellectual climate. Nature Climate Change 2014, 4:763-768.
Collins, M. 2007. Ensembles and probabilities: a new era in the prediction of climate change. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 365:1957-1970.
Cvitanovic, C.; Hobday, A. J.; van Kerkhoff, L.; Marhsall, N. A. 2015a, Overcoming barriers to knowledge exchange for adaptive resource management: The perspectives of Australian marine scientists, Marine policy, 52, 38-44.

Cvitanovic, C.; Hobday, A. J.; van Kerkhoff, L.; Wilson, S. K.; Dobbs, K.; Marshall, N . A. 2015b, Improving knwoledge exhcnage among scienists and decision-makers to faciliate the adaptive governance of marine resources: A review of knoweldge and research needs, Ocean and coastal management, 112, 25-35.
Daston, L.; Galison, P. 2007. Objectivity, Zone Books: New York.
Department for the Environment, Food and Rural Affairs, 2010. Adaptation Reporting Power: Frequently Asked Questions and Answers. in Department for Environment, Food and Rural Affairs.
Department for the Environment, Food and Rural Affairs, 2007a. Climate predictions programme: Research project final report, PECD 6/12/37 GASRF 21.
Department for the Environment, Food and Rural Affairs, 2007b. UKCIP08 group terms of reference and communication channels, 15th January, Internal document.
Demeritt, D., 2001. The construction of global warming and the politics of science. Annals of the Association of American Geographers 91(2), 307-337.
Dessai, S., Hulme, M., Lempert, R., Pielke, R.. (2009) Climate prediction: a limit to adaptation?, In W.N Adger, I. Lorenzoni and K. O'Brien (eds.) Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press, 64-78.
Dilling, L. Lemos, C, 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Global Environmental Change 21, 680-689.
Eisenack, K., Moser, S.C., Hoffmann, E., Klein, R.J., Oberlack, C., Pechan, A., Rotter, M., Termeer, C.J., 2014. Explaining and overcoming barriers to climate change adaptation. Nature Climate Change 4, 867-872.
Ekstrom, J.A., Moser, S.C., (2014). Identifying and overcoming barriers in urban adaptation efforts to climate change: case study findings from the San Francisco Bay Area, California, USA. Urban climate, 9, 54-74.
ESYS 2004. Review of UKCIP - Final Report. ESYS plc, Guildford.
Feldman, D. L., & Ingram, H. M. (2009). Making science useful to decision makers: climate forecasts, water management, and knowledge networks. Weather, Climate, and Society, 1(1), 9-21.
Ford, J.; Knight, M.; Pearce, T. 2013, Assessing the 'usability' of climate change research for decision-making: A case study of the Canadian international polar year, Global environmental change, 23(5), 1317-1326.
Frigg R, Smith LA, Stainforth DA 2013. The myopia of imperfect climate models: the case of UKCP09. Philosophy of science 80:886-897.
Frigg, R.; Smith, L. A.; Stainforth, D. 2015, An assessment of the foundational assumptions in high-resolution climate projections: The case of UKCP09, Synthese, 1-30.
Gawith, M., Street, R., Westaway, R., Steynor, A., 2009. Application of the UKCIP02 climate change scenarios: reflections and lessons learnt. Global Environmental Change 19, 113-121.
Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994. The new production of knowledge: The dynamics of science and research in contemporary societies. Sage.
Glaser, B., Strauss, A., 1967. The discovery grounded theory: strategies for qualitative inquiry. London, England: Wiedenfeld and Nicholson.
Goffman, E., 1959. The presentation of self in everyday life.

Ghosh, P. 2009. Climate warning's error margins, BBC News, 18th June 2009, [Available from: http://news.bbc.co.uk/1/hi/8106513.stm Accessed 11th August 2015]
Hardoy, J., Hernández, I., Pacheco, J.A., Sierra, G. (2014) Institutionalizing climate change adaptation at municipal and state level in Chetumal and Quintana Roo, Mexico. Environment and urbanization 26, 69-85.
Harris GR, Sexton DM, Booth BB, Collins M, Murphy JM 2013. Probabilistic projections of transient climate change. Climate dynamics 40:2937-2972.
Heaphy, L. 2015. The role of climate models in adaptation decision making: The case of the UK climate projections 2009, European Journal for Philosophy of Science, 5(2), 233-257.
Hegger, D., Dieperink, C. 2015, Joint knowledge production for climate change adaptation: What is in it for science? Ecology & society, 20(4), doi.org/10.5751/ES-07929-200401
Hjerpe, M., Storbjörk, S., Alberth, J. (2014) “There is nothing political in it”: Triggers of local political leaders' engagement in climate adaptation. Local environment, 1-19.
Hilgartner S 2000. Science on stage: Expert advice as public drama. Stanford University Press.
Hoskins, B. 2009. Report from the review of the methodology used for the UKCP climate change projections, [Available from: http://ukclimateprojections.metoffice.gov.uk/media.jsp?mediaid=88445&filetype=pdf Accessed 14th August 2015].
Hulme, M., Jenkins, G., Lu, X., Turnpenny, J., Mitchell, T., Jones, R., Lowe, J., Murphy, J., Hassell, D., Boorman, P., McDonald, R. Hill, S. 2002. Climate change scenarios for the United Kingdom: The UKCIP02 scientific report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK.
Hulme, M.; Dessai, S. 2008. Negotiating future climates for public policy: a critical assessment of the development of climate scenarios for the UK. Environmental science & policy 11:54-70.
Irwin, A., Rothstein, R., Yearley, S. 1997, Regulatory science - towards a sociological framework, Futures, 29(1), 17-31.
Jenkins, G,; Murphy, J.; Sexton, D.; Lowe, J.; Jones, P.; Kilsby, C. 2009. UK climate projections: Briefing report, Met Office Hadley Centre, Exeter, UK.
Kelly, N. 2014. The scientific and political legacy of the UK climate projections (UKCP09): An undergraduate perspective, Area, 46, 111-113.
Kiem, A.S., Austin, E.K. (2013) Disconnect between science and end-users as a barrier to climate change adaptation. Climate research 58, 29-41.
Kirchhoff, C.J.; Lemos, M.C.; Dessai, S. 2013. Actionable knowledge for environmental decision making: Broadening the usability of climate science. Annual review of environment and resources, 38, 393–414.
Klenk, N.; Meehan, K., 2015, Cliamte change and transdisciplinary science: Problematizing the integration imperative. Environmental science & policy, 54, 160-167.
Lawton, J. 2009. The 2009 Sir John Lawton Review of the Met Office Hadley Centre: A report for the Department for the Environment, Food and Rural Affairs and the Department of Energy and Climate Change, October 2009, Report reference: D7112.
Lemos, M.C., Kirchhoff, C.J., Ramprasad, V. 2012, Narrowing the climate

information usability gap. Nature climate change 2, 789-794.
Lemos, M.C., Morehouse, B.J. 2005, The co-production of science and policy in integrated climate assessments. Global environmental change 15, 57-68.
Lemos, M.C., Rood, R.B. 2010, Climate projections and their impact on policy and practice. Wiley interdisciplinary reviews: climate change 1, 670-682.
Lewandowsky, S.; Oreskes, N.; Risbey, J.; Newell, B.; Smithson, M. 2015. Seepage: Climate change denial and its effect on the scientific community, Global environmental change, 33, 1-13.
Lewis, N. 2013, An objective Bayesian improved approach for applying optimal fingerprint techniques to estimate climate sensitivity, Journal of Climate, 26, 7414-7429.
Lovbrand, E., 2011, Co-producing European climate science and policy: A cautionary note on the making of useful knowledge, Science and public policy, 38(3), 225-236.
Mahony, M.; Hulme, M. 2012. Model migrations: mobility and boundary crossings in regional climate prediction. Transactions of the Institute of British Geographers 37:197-211.
McKenzie-Hedger, M.; Cornell, M.; Bramwell, P. 2006. Bridging the gap: empowering decision-making for adaptation through the UK Climate Impacts Programme. Climate policy, 6, 201-215.
McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. Environmental Science & Policy 10, 17-38.
Meadows, A. M.; Ferguson, D.; Guido, Z.; Owen, G. 2015, Moving towards the deliberate co-production of climate science knowledge, Weather, climate and society, 7, 179-191.
Mearns, L.O. (2010) The drama of uncertainty. Climatic change 100, 77-85.
Meyer, R. (2011). The public values failures of climate science in the US. Minerva, 49(1), 47-70.
Mitchell, J. 2007. Climate uncertainty. New Scientist 2620.
Montford, A. 2013. The climate model and the public purse, The Global Warming Policy Foundation, briefing paper 8.
Moser, S.C., Ekstrom, J.A., (2010). A framework to diagnose barriers to climate change adaptation. Proceedings of the national academy of sciences, 107, 22026-22031.
Moss, R., Meehl, G. A., Lemos, M. C., Smith, J. B., Arnold, J. R., Arnott, J. C., Behar, D., Brasseur, G. P., Broomell, S. B., Busalacchi, A. J., Dessai, S., Ebi, K. L., Edmonds, J. A., Furlow, J., Goddard, L., Hartmann, H. C., Hurrell, J. W., Katzenberger, J. W., Liverman, D. M., Mote, P. W., Moser, S. C., Kumar, A., Pulwarty, R. S., Seyller, E. A., Turner, iI, B. L., Washington, W. M. and Wilbanks, T. J. 2013, Hell and high water: Practice-relevant adaptation science, Science, 342 (6159), 696-698.
Mukheibir, P.; Kuruppu, N.; Gero, A.; Herriman, J. (2013) Overcoming cross-scale challenges to climate change adaptation in local government: A focus on Australia, Climatic change, 121: 271-283.
Murphy JM, Booth BB, Collins M, Harris GR, Sexton DM, Webb MJ 2007. A methodology for probabilistic predictions of regional climate change from perturbed physics ensembles. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 365:1993-2028.

Murphy JM, Sexton DM, Barnett DN, Jones GS, Webb MJ, Collins M, Stainforth DA 2004. Quantification of modelling uncertainties in a large ensemble of climate change simulations. Nature 430:768-772.

Murphy JM, Sexton DMH, Jenkins GJ, Boorman PM, Booth BBB, Brown CC, Clark RT, Collins M, Harris GR, Kendon EJ, Betts RA, Brown SJ, Howard TP, Humphrey KA, McCarthy MP, McDonald RE, Stephens A, Wallace C, Warren R, Wilby R, Wood RA 2009. UK Climate Projections Science Report: Climate change projections. . Met Office Hadley Centre, Exeter.

Nonaka, I. 1994. A dynamic theory of organizational knowledge creation. Organization Science. 5, 14–37.

Nowotny, H., Scott, P., Gibbons, M., 2003. Introduction: Mode 2' revisited: The new production of knowledge. Minerva 41, 179-194.

Oreskes, N.; Conway, E. 2010. Merchats of doubt, Bloomsbury Publoshing: London.

Parker WS, 2013. Ensemble modeling, uncertainty and robust predictions. Wiley Interdisciplinary Reviews: Climate Change 4:213-223.

Pearce F, 2007. Climate tipping points loom large. New Scientist, 2617.

Pearce, F. 2008, Are climate scientists overselling their models?, New scientist, December 2008.

Pearce, W. 2013, Are climate sceptics the real champions of the scientific method? The Guardian, Tuesday 30th July 2013, http://www.theguardian.com/science/political-science/2013/jul/30/climate-sceptics-scientific-method

Pielke, R. A. Jr.; Prins, G.; Rayner, S.; Sarewitz, D. 2007, Climate change 2009: Lifting the taboo on adaptation, Nature, 445, 597-598.

Porter, T. 1995. Trust in numbers: The pursuit of objectivity in science and public life, Princeton University Press: Princeton, NJ.

Porter, J. J.; Dessai, S. 2016, "The usual suspects": Climate scientists' perceptions of users and their needs. Environmental research letters.

Porter, J. J.; Demeritt, D.; Dessai, S. 2015, The right stuff? Informing adaptation to climate change in British local government, Global Environmental Change, http://dx.doi.org/10.1016/j.gloenvcha.2015.10.004

Porter, J. J.; Dessai, S., Tompkins, E. 2014, What do know about UK household adaptation to climate change? A systematic review, Climatic Change, 127(2), 371-379.

Porter, J. J.; Demeritt, D. 2012. Flood risk management, mapping and planning: The institutional politics of decision support in England, Environment & Planning A, 44(10), 2359-2378.

Porter, J. J.; Williams, C.; Wainwright, S.; Cribb, A. 2012. On being a (modern) scientist: Risks of public engagement in the interspecies embryo debate, New Genetics & Society, 408-423.

Preston, B., Rickards, L.; Funfgeld, H.; Kennan, R., 2015a, Toward reflexive climate adaptation research, Current opinon in environmental sustainability, 14, 127-135.

Preston, B.; Mustelin, J.; Maloney, M. 2015b, Climate adaptation heuristics and the science/policy divide, Mitigation & adaptation strategies for global change, 20, 467-497.

Prudhomme, C., Dadson, S., Morris, D., Williamson, J., Goodsell, G., Crooks, S., Boelee, L., Davies, H., Buys, G., Lafon, T., 2012. Future Flows Climate: an ensemble of 1-km climate change projections for hydrological application in Great Britain. Earth System Science Data Discussions 5, 475-490.

Rayner, S., Lach, D., Ingram, H. 2005. Weather forecasts are for wimps: why water resource managers do not use climate forecasts. Climatic change 69, 197-227.
Rice, J.; Woodhouse, C.; Lukas, J. 2009. Science and decision making: Water management and tree-ring data in western United States, Journal of the American water resources association, 45(5), 1248-1259.
Risk Solutions, 2007. Hadley Centre Review 2006: Final Report, Produced for the Department for the Environment, Food and Rural Affairs and the Ministry of Defence. Report No. D5149.
Rothstein, H.; Huber, M.; Gaskell, G. 2006. A theory of risk colonisation: The spiralling regulatory logics and societal and institutional risk, Economy & society, 35(1), 91-112.
Sarewitz, D., Pielke, R.A., 2007. The neglected heart of science policy: reconciling supply of and demand for science. Environmental science & policy 10, 5-16.
Schneider, S.H., 2009. Climate change science and policy. Island Press.
Sexton, DM, Murphy JM, Collins M, Webb MJ, 2012. Multivariate probabilistic projections using imperfect climate models part I: outline of methodology. Climate dynamics 38:2513-2542.
Shackley, S.; Risby, J.; Stone, P.; Wynne, B. 1999. Adjusting to policy expectations in climate change modelling: An interdisciplinary study of flux adjustment in coupled atmospheric-ocean general circulation models, Climatic Change, 43, 413-454.
Shackley S, 2001. Epistemic lifestyles in climate change modeling. Changing the atmosphere: Expert knowledge and environmental governance: 107-133.
Steynor, A.; Gawith, M.; Street, R. 2012. Engaging Users in the Development and Delivery of Climate Projections: The UKCIP Experience of UKCP09. UKCIP, Oxford.
Stocker, T. 2004, Climate change: Models change their tune, Nature, 430, 737-738.
Stokes, D. 1997. Pasteur's quadrant: Basic science and technological innovation, Brookings Institution Press.
Street, R.; Steynor, A.; Bowyer, P.; Humphrey, K. 2009, Delivering and using the UK climate projections 2009, Weather, 64(9), 227-231.
Swart, R.; Biesbroek, R.; Capela Lourenco, T. 2014, Science of adaptation to climate change and science for adaptation, Frontiers in environmental science, 2, 1-8.
Tang S, Dessai S 2012. Usable Science? The UK Climate Projections 2009 and Decision Support for Adaptation Planning. Weather Climate and Society 4:300-313.
Tompkins, E.L., Adger, W.N., Boyd, E., Nicholson-Cole, S., Weatherhead, K., Arnell, N. 2010, Observed adaptation to climate change: UK evidence of transition to a well-adapting society. Global environmental change 20, 627-635.
Tribbia, J., Moser, S.C. (2008) More than information: what coastal managers need to plan for climate change. Environmental science & policy 11, 315-328.
United Kingdom Climate Impacts Programme [UKCIP] 2004. UKCIPnext climate change scenarios – what do users want?, February 2004.
United Kingdom Climate Impacts Programme [UKCIP] 2005. UKCIPnext climate change scenarios – user forum, November 2004.
United Kingdom Climate Impacts Programme [UKCIP] 2006a. Expressed preferences for the next package of UK climate change information: Final report on the user consultation, December 2006.

United Kingdom Climate Impacts Programme [UKCIP] 2006b. Expressed preferences for the next package of UK climate change information: Appendices to the final report on the user consultation, December 2006.
United Kingdom Climate Impacts Programme [UKCIP] 2009. UKCP09 user feedback survey, September 2009.
United Kingdom Climate Impacts Programme [UKCIP] 2014. The development of UKCP09, November 2014.
Wilby, R.; Keenan, R.; 2012, Adapting to flood risk under climate change, Progress in physical geography, 36(3), 348-378.