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UNCERTAINTY FROM “ABOVE”

Diverse understandings, politics
and implications

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FIGURE 2.1 Flooding in Mumbai during the monsoon (Photo credit: Wikimedia commons).

Introduction

Uncertainty is often considered to be a *super wicked problem* or a *monster* by scientists and policymakers (van der Sluijs 2005; Curry and Webster 2011). In climate change policymaking, approaches to handle uncertainty have been dominated

by efforts to minimise and control it, and “attempts to quantify it in one way or another” (Hallegatte *et al.* 2012: 10). This approach has been increasingly critiqued for neither providing a useful basis for meaningful policy responses nor reflecting the lived realities of people (Wilby and Dessai 2010). Alternative perspectives have emerged over recent years that have focused on embracing uncertainty through “robust” decision-making (Lemos *et al.* 2016; Kirchhoff *et al.* 2015) or engaging with and integrating local or indigenous understandings through citizen science (Panda 2016; D’Souza and Kale 2018) (Figure 2.1).

While there is now quite a rich literature focusing on indigenous experiences and knowledges of climate change and uncertainty (Crate and Nuttall 2009; Carey 2010; Rudiak-Gould 2013), there are still gaps in how uncertainties are understood across a range of actors involved in envisioning climate scenarios and models and translating them into policy. In this chapter, we examine how uncertainty is understood by climate scientists and policymakers at national and sub-national levels considered the “above” in this volume. This complements studies of how individuals, households and organisations at local levels (the “below”) understand uncertainty and climate change, which is the focus of most of the chapters in this volume. We are particularly interested in how uncertainties are represented in policy debates and whether conceptualisations of climate-related uncertainties from the “below” are taken into account in scientific assessments. To do this, we draw on insights from existing literature, complemented by data from semi-structured interviews and roundtable discussions in Norway, India and the United Kingdom.

As discussed in the introduction to this volume, conceptualisations of uncertainty are varied and are embedded in different realms of knowledge and disciplinary traditions. Three types of uncertainties are relevant for our discussion (see Mehta and Srivastava 2020 and Chapter 1, this volume). Firstly, aleatoric uncertainties referring to natural fluctuations, high degree of variability and disequilibrium dynamics having unknown effects (cf. AchutaRao 2016); secondly, knowledge or epistemic uncertainties, which refers to indeterminate knowledge about changes and their impacts (Field *et al.* 2012; Scoones and Stirling 2020); and thirdly, uncertainties linked to larger political economy conditions, including unanticipated outcomes due to socio-political interventions and how they are experienced by diverse groups (Wynne 1992; Mehta *et al.* 1999). All these uncertainties are experienced, framed and interpreted differently by different actors and are linked to relations of power that justify different institutional practices and responses (Rein and Schön 1993).

Uncertainty is at the core of the climate change problem. The IPCC has slowly changed its stance on uncertainty. From a preoccupation with **reducing** and **mastering** uncertainty, it is now focusing more on how to **manage** and **cope** with uncertainty and defines uncertainty as “[a] state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable” (IPCC 2014b: 128). Hawkins and Sutton (2009) distinguish three main sources of uncertainty in climate projections: firstly, the

natural fluctuations or internal variability of the climate system; secondly, the fact that different models give different climate projections to the same radiative forcing¹; and the third is scenario uncertainty, which are uncertainties around future demographic change and emissions pathways. These are sometimes referred to as aleatoric, epistemic and policy uncertainty, respectively (Hallegatte *et al.* 2012). For shorter timescales, the two former dominate, whereas for longer timescales of many decades, model and scenario uncertainty are dominant. From a climate science perspective, the potential to reduce uncertainties in climate projections is seen to be only in internal variability and model uncertainty; the former only over a decade or so through the integration of observational data (Hawkins and Sutton 2009). While aleatoric uncertainty over the longer term is, by its very nature, something that cannot be “dealt with” in any meaningful sense of the word, epistemic uncertainty can be identified, acknowledged and reflected on in policy processes.

Hallegatte *et al.* (2012: 4) describe climate change as a situation with “deep uncertainty”, namely, where one of the following conditions is met: “(1) a range of possible futures without known relative probabilities; (2) multiple divergent but equally-valid world-views, including values used to define criteria of success and (3) decisions which adapt over time and cannot be considered independently”. They argue that as these uncertainties cannot be eliminated, in either the short or most likely longer term, new approaches to deal with these uncertainties are needed. This has given rise to a growing “family of approaches” focused on providing robust outcomes in the face of a range of possible changes, ranging from large computer-based models to qualitative assessments (Interview with a climate scientist, UK, January 2017). Approaches include a focus on “no regrets”, reversibility and flexibility in the face of uncertainty, building safety margins and reducing decision-making time horizons (Hallegatte *et al.* 2012). Common to these approaches is that they acknowledge and “embrace” uncertainty, rather than trying to avoid or minimise it and building in planning responses that are robust and resilient in the face of a range of possible future climates.

How climate change uncertainty is understood from the “above” matters because it is experts, policymakers and scientists who frame how we see climate change and related policy decisions and funded priority actions. Decisions are made today that will affect future vulnerabilities – and, in turn, impacts – from climate change and decisions will have to be made and, indeed, are made, based on incomplete information. This chapter, thus, explores how uncertainty is understood and represented by the “above”, by whom and how decisions are made. We draw on over 30 interviews in India (Delhi, Mumbai, Kolkata and Gandhinagar) and 10 in Norway and the United Kingdom. Additionally, we also draw on insights generated from four roundtable events carried out with scientists, policymakers as well as representatives from academia and civil society, including their reflections on issues concerning inter- and transdisciplinary working and social science perspectives (see Chapter 7, this volume). While the roundtables had a good mix of men and women, apart from about four women scientists,

all the other interviewees were men, highlighting the need for more women in climate science/climate decision-making. The findings are organised around the following broad questions: (1) how is uncertainty understood by climate scientists and experts? (2) how is uncertainty presented and represented in policy debates, including the integration of local knowledges and understandings? and (3) what are the possible options for generating a more social understanding of uncertainty?

We hope to demonstrate that while the “above” is deeply aware of the challenges of integrating uncertainty in scientific understandings, most groups in the “above” are largely wedded to conventional scientific assessments such as modelling and predictions and “mastering” uncertainty instead of embracing uncertainty. The “above” is of course very diverse and this chapter teases out this heterogeneity. We also focus on the challenges and frustrations that many scientists and experts have with the politics of uncertainty and the challenges of communicating uncertainty to decision-makers who do not care for such nuances and seek predictability. Finally, despite some attempts to bridge gaps between the “above” and “below”, we found that in the Indian context, there is significant resistance to construct alternative approaches and systems that embrace plural knowledges and experiences from “below”.

Understandings of uncertainty

The question of how uncertainty is understood by climate scientists, policymakers and boundary workers relates not only to whether it is considered as an epistemic or ontological issue but also if, and to what extent, local understandings of uncertainty are incorporated. We discuss these themes first by looking at issues concerning modelling and parameters and then by investigating the sources and nature of uncertainty at different spatial and temporal scales. This includes challenges concerning downscaling models to finer resolutions as well as dealing with uncertainties in long-term projections.

Uncertain models

Climate change has traditionally been conceived as a global phenomenon and conventionally one of the pervasive ways to understand it has been through computer models. The “globalising instinct” in knowledge making and the tendency to focus on the global scale can, in part, be attributed to the fact that the climate system is hugely complex and efforts to gain an understanding of the dynamics have largely been driven by the construction of General Circulation Models or GCMs (Edwards 2010). Because Greenhouse Gases (GHGs) influence systems of circulation, modellers argue that it is a tricky exercise to scale down models to lower levels such as the regional or the local. This is the premise on which the algorithms and parameters underpinning GCMs are based (Lahsen 2005).

All models, including GCMs, are simplified representations of complex systems and as such are never the “real” thing, a fact that is often ignored (Pollack *et al.*

2005). At the centre of the scientific practice is the creation of boundaries and distinct binaries (Douglas 1986) between the subjective and the objective, between the abstract climate and the particularities of weather (Hulme 2016; Heymann 2018). The abstract and supposedly “objective” is represented by the hard science of modelling which can ignore or externalise the subjective dimensions of uncertainties or neglect their political dimensions (Jasanoff 2009). Such scientific approaches are just one of the many ways people anticipate and prepare for the future and need to be viewed together with the day-to-day strategies of people who live with the uncertainties of climate (Hastrup 2013, see Chapters 3–6, this volume). However, a certain politics of knowledge results in particular domains with so-called hard science gaining authority over the others. Yet, all forms of knowledge (including so-called expert knowledge) are culturally and socially embedded and moulded by particular social, power and gender relations (as demonstrated in previous chapters). Models are also embedded in narratives and storylines about a future based on certain assumptions (Hajer 1995) but gain authority over other forms of knowledge through a range of political practices and boundary-ordering devices (Shackley and Wynne 1996; Heymann 2018).

These models, however, are ridden with uncertainty as it is a fraught exercise to represent the complexity of processes and climate in future. For example, GCMs aim to represent the relationship between two fluid and chaotic systems: the oceans and the atmosphere. Characterising such systems is virtually impossible using current theories of non-linear dynamic systems, particularly in situations involving transient changes of parameter values (Dyson 2015; Curry 2017). Sources of uncertainty include the structure of the model, the selection and function of particular parameters included in models as well as uncertainties related to the data used which are also derived from a variety of sources. In climate change, much uncertainty derives from imprecision, also through attempts to deal with disparate sources and sets of data. Furthermore, measuring devices and instruments can be unreliable or change over time and these are themselves models of a kind. Only 10% of the information gathered is raw data, and the rest has been processed through some sort of model, a phenomenon Edwards (2010) describes as “shimmering”. Added to these sources of uncertainty is technical uncertainty regarding the computational implementation of these models.

The challenges of modelling such fluid and complex interlinked systems are exemplified by what Dyson (2015) terms “fudge factors” such as clouds and, to some extent, aerosols. The stochastic nature of clouds makes it extremely hard to incorporate cloud behaviour into models. This was reflected in several interviews with Indian scientists working on climate change models, who stated that even “one cloud in a model is difficult to model” (Interview with scientist, New Delhi, May 2017, NCMRF). By contrast, a scientist in the Ministry for Earth Sciences was optimistic about gaining knowledge about how “how clouds react, develop and interact. While these processes need to be understood from a range of disciplines including physics and mathematics, I am optimistic about it” (Interview May 2017). Another such “fudge factor” and notorious

source of uncertainty is aerosols. These are “tiny particles in solid/liquid phase ubiquitously dispersed in the atmosphere” (Moorthy *et al.* 2016, 53) and have climate forcing potential due to their optical, microphysical and chemical properties (*ibid.*). Aerosols impact climate directly by interacting with incoming solar and outgoing terrestrial radiations. They also have indirect effects as they alter cloud properties (Srivastava 2017). Their dispersion and effects on climate are extremely challenging to model, not least due to lack of data on emissions that are a significant source of aerosols. According to a scientist in Kutch (Gujarat), models have a weak emission inventory in India because emission inventories have mainly developed in Europe. In Kutch, for example, industrial expansion has led to an increase in aerosols, which, in turn, can increase cloud cover but not necessarily more rain. It could influence the incidence of extreme weather events such as tropical cyclones (Srivastava 2017). A scientist from Kutch argued:

Aerosols are challenging in the Indian context. They are difficult to understand and need more time and computational models. How are these particles parametrized with rainfall? If this is not done, predictions are not possible. The dangers of ignoring this is that prediction reliability is less than 40% [...]. Clouds for example may exist according to meteorological parameters but if aerosols are not taken into consideration, predictions could fail.

(Scientist October 2016, Kutch)

As stated earlier, the challenge according to the IPCC is to learn to manage uncertainty. In the *Fifth Assessment Report*, the IPCC (2014a) acknowledges that there are uncertainties that we will never know and that the best response is to understand and cope with them. For the IPCC,

uncertainties arise at the level of observations (measurements for natural phenomena and some socio-economic statistics, possibly survey data for other socio-economic, political and cultural issues) and from how the data from observations are turned into indicators used in the assessment (e.g. by combinations of variables, statistical methods) (Swart *et al.* 2009: 4).

Scientific assessments and results are weighed across this spectrum of confidence, but here too, there is room for bias and value judgements (Curry and Webster 2011). Computer simulations are used to represent “aspects of the climate that are extremely difficult to observe [...] and explore the system that would otherwise be impenetrable” (Curry and Webster 2011: 1668).

The challenges of modelling uncertainty

Nobody we interviewed denied the problem of climate change. All interviewees acknowledged climate change as a major global challenge and recounted their

own observations of climate change examples. A meteorologist in Norway observed that:

The main characteristic of the weather in Norway is variability and temperature differences can be rather large. From our measurements and data over a span of 50 years we see that the temperature is rising, and that precipitation generally has increased. Flash flooding and intense precipitation over limited areas for 1–3 hours causing a lot of damage has also increased. These need to be taken into account for future planning, e.g. in cities, drainage etc. The trends we are observing were not there earlier, and they are in tune with what is coming out of the IPCC reports.

(Expert from the Norwegian Meteorological Institute August 2016, Oslo)

A central question is what can – and cannot – models cover? A crucial choice that modellers have to make is to choose what parameters to include and how. Given that modellers cannot capture the whole range of issues and uncertainties in their models, how do you accommodate the effects of land use changes, for instance? There are diverse sources of epistemic uncertainty which may cascade into other types of uncertainty related to models, parameters and assumptions. A climate researcher in a government institution in Gujarat highlighted this as follows:

In research, all predictions are based on projections. My research is on Greenhouse Gases (GHGs) and how uncertainty is accounted in emissions. The IPCC’s emission scenarios are based on the natural course of emissions in the atmosphere and energy (direct fossil fuel burning) accounts for 70 percent of GHG emissions. But there is a lot of uncertainty in these emission scenarios due to the limitations of models and the baselines. So, if there is so much uncertainty in the data, methodology and also emission factor (e.g. the ash contents are different for different resources and depend on how they are burnt, namely, aerobically, anaerobically or incomplete burning), how does it influence and guide our projections?

(Interview September 2016, Gujarat)

Another modeller based at a research institute in Norway told us that the uncertainties associated with physiographic parameters, affected by socio-economic factors such as urban development plans and patterns of land use change, will affect modelling; however, tackling them remains challenging:

We have no idea how different development scenarios take place – for example, if a hotel will be built on the coast in Greece and how will it affect land use changes? All the uncertainty I can deal with is reduced to the distribution of non-probability [...] We don’t capture change when it comes to land/water change or changes due to infrastructure and

population dynamics. We make large-scale global assumptions; we don't capture these kinds of (socio-economic) changes.

(Modeller August 2016, Oslo)

In India, climate models are a relatively recent development. India's nodal department for weather- and climate-related information and analysis, the Indian Meteorological Department's (IMD) models have only evolved relatively recently which limits their applicability in terms of establishing baselines and useful, long-term trends. According to two scientists from a forecasting institute in New Delhi:

We want to predict everything, but our models are old and hence our predictions are based on old models. We are using information from old satellites from the 1980s and 1990s. Only recently do we have better data and improved models. Before the 1990s, the IMD only used observational data and charts, hence the experience of IMD with models has been very limited. Currently there is a cult like faith in modelling and hence there is a major demand for our models. However, there will always be uncertainty. For example, if data is collected within 1 and half hour and it is 150 km away from Delhi there will be uncertainty. Even with the best model, surprises can happen even with the best input/data. I am sure even in 200 years there will be uncertainty. Modelling is not a perfected science.

(Interviews May 2017, New Delhi)

For a climate scientist in Norway, uncertainty stems from models (and parameterisation), natural variability and social systems. "Some uncertainties can be narrowed down but there are limitations in the modelling exercise. Even though models have improved a lot over the past 20 years and are now finer in scale, there is still a lot of complexity" (Interview August 2016, Oslo). Despite acknowledging these complexities, most climate scientists we interviewed hoped that with better knowledge, better modelling and better parameters uncertainties could be reduced or addressed since they are keen to provide certainty and data to make decisions. Our interviews suggest that many modellers in practice remain committed to reducing and mastering uncertainty rather than aiming to have models that speak to coping and learning to live with uncertainty.

The challenge of downscaling

Climate change models are associated with a cascade of uncertainties that increase with downscaling (Wilby and Dessai 2010). These relate to uncertainties of future emissions of GHGs and sulphate aerosols as discussed above; uncertainties of the response of the climate system to these changes at global and national scales and the spatial and temporal distribution of these impacts (Dessai

and Sluijs 2007). In a scalar view of uncertainty, the cascade of uncertainty proceeds from different demographic and socio-economic pathways and then translates into GHG emissions, gets picked up by models by way of outcomes, which then translate into various human and natural impacts that further trickle into the adaptation responses (Wilby and Dessai 2010). However, socio-economic pathways are particularly hard to capture. Thus, the socio-political unknowns of climate change are massive, and these often intersect with other “uncertain” drivers of change and may exacerbate or snowball into existing problems related to environmental conditions such as water quality, health and food and energy security (Hastrup 2013). The chapters that follow demonstrate this cascading view of uncertainty in Mumbai, Kutch and the Sundarbans. As noted earlier in this chapter, there has been a distinct “globalising instinct” in climate change science, as scientists working on constructing GCMs have mainly been preoccupied with the global dynamics of CO₂ emissions, circulation and effects (Curry 2017). There is another dimension to scaling down as well, what Schneider and Walsh refer to as the “politics of zoom” (2019). This emphasises how downscaled visualisations of the impact of climate change tend to replicate the “hegemonic dynamics of their global sources” and tend to “cancel out conflicting local data” (Schneider and Walsh 2019: 5). Scaling down to lower spatial scales is, therefore, considered challenging.

The temporal scales in climate change models are another challenge. The climate models are made to look at the effects of emissions or scenarios, and these differences only come into play after about 30 years so every uncertainty before that is not really dealt with. The models often also do not capture all the changes and uncertainties at the local level. There is a fundamental misconception that climate models can do anything in the here and now, locally.

Interviews reflect that uncertainties are particularly problematic at regional and local scales. For the most part, uncertainties are described in epistemic terms, for example, that models and science are “not up to it yet” or that science still needs to improve. Uncertainty in models, therefore, can potentially reduce the veracity of claims around climate change and limit the potential to meaningfully inform policy (see “below”). Most of the scientists we interviewed acknowledge the uncertainties associated with downscaling. This is especially true in dense urban settings. A hydro-climatologist from Mumbai stated:

Downscaling from global circulation models to finer resolutions is a failure because the science is not properly understood. At a finer resolution they are failing at a miserable scale. For example, take Mumbai. There is much talk about links between urban island heat effect and extreme rainfall. But there are so many multiple factors: the buildings and city structure have much to do with this. That Mumbai is getting more extreme rainfall due to the urban heat island is actually a wrong hypothesis and scientists have started to realise this. When the monsoon starts there is nothing, all temperature goes down, so urban heat island doesn't really level up.

What is exactly happening is that there is huge flux of moisture [coming in from the Arabian sea and that creates lots of problems because of the urban structure (i.e. very tall buildings that change the patterns of wind and rainfall). Even two buildings between roads can have an effect on urban precipitation. The resolution will be in the range of 2–5 km. But in climate models the resolution is more than 100 km. Even if we are going for regional models and the range is 4 km there will still be huge uncertainty. These phenomena are not really captured in models and even if we have the scientific understanding it is very difficult to represent that understanding into models. Different models try and parametrize these cases in a coarse scale and when we use different parameter scales, this also leads to sources of uncertainty whilst looking at the urban scale.

(Interview with scientist April 2016, Mumbai)

Singh and AchutaRao (2018) highlight the aleatoric and epistemic uncertainties inherent in modelling rainfall, especially monsoon (see below) behaviour and emphasise the challenges of downscaling especially since GCMs are coarse in resolution since they cover up to 200 kilometres in grids. Regional Climate Models (RCMs) are supposed to address some of these challenges; however, they also add further to the uncertainty existing in GCMs due to the “high computational costs resulting in a limited number of simulations being available. Also, downscaling further adds to the uncertainty that already exists in the global coupled model simulations” (Singh and AchutaRao 2018: 2). For example, a scientist from Gandhinagar told us that in India, Gujarat is one state that has produced an inventory of regional-level emissions. But she concurs that planning regarding adaptation and mitigation can be difficult based on regional-level data, as these are not communicated to global bodies. The international organisations rely on national-level data and this can be misleading. For instance, the state of Gujarat has a different emissions scenario from the rest of the country. The per capita consumption of electricity is almost double that of the national average due to the high number of industries and the very industrialised and developed coastline (Scientist September 2016, Gandhinagar).

These challenges of uncertainty come clearly to the fore in drylands such as Kutch, which are characterised by high variability in precipitation and where rainfall patterns vary every few kilometres. Global projections on climate change are not particularly helpful when it comes to state-level planning, argues an IMD scientist in Gandhinagar:

Though it is projected that there would be an average rise of 1–1.5 degrees in the global temperature, that is not helpful for decision-making when you have to plan for this kind of warming at local stations. You need to make a proper strategy, probably to make people aware of the grilling heat that is likely to affect people in coming future.

(Interview January 2018, Gandhinagar)

Automatic Weather Stations (AWS) can help provide more locally attuned forecasts, but there are only three in a large district such as Kutch that function well (Interview, October 2016, Kutch), while there are about 60 in Mumbai (Interviews with Bombay Municipal Corporation official, January 2016, Bombay). Due to the massive weather variability and massive changes happening every 10 kilometres, a dense network is required every 10–15 km to record variability. However, in remote places in areas like Kutch, poor internet connectivity and limited funding impede the efficiency of AWS. This discussion highlights that global and RCMs have limits when it comes to predicting impacts at the local level and managing with local-level uncertainties and variations, especially in highly variable locations such as drylands. India, at least, is still far off in having robust systems at the local level to improve weather and climate forecasts in order to provide predictions and support to agencies working on the impacts of climate change in areas such as water security, food security and vector-borne diseases (Interview, October 2016, Kutch).

Forecasts and projections: uncertainty in the short, medium and long term

While climate modellers are concerned with the long-term projections of what is likely to happen in the future, the science of weather forecasting is dealing with the short-term, day-to-day predictions of precipitation patterns, temperature changes, wind speeds and other weather features. For meteorologists, weather and climate are often considered to be a seamless continuum. An expert from the Norwegian meteorological office told us: “When scientists talk about climate change, they talk about the past and they talk about the future. Weather forecasting is a few days in between”. By contrast, lay people rarely distinguish between “weather” and “climate” (see quote below). The same meteorologist discusses the temporal aspect of climate change and the distinction between weather and climate change:

I talked with a taxi driver some weeks ago. He did not know that I was a meteorologist, so he told me that they had had three different climates that day. It is difficult for lay people to distinguish between weather and climate, and I don't think it is necessary to expend much effort to make people see the difference. I think we should rather look at it as a continuum, a sort of seamless change between the past climate, the current weather, and future climate projections. Of course, we are providing the weather forecasts, as professionals, we are distinguishing very much. But in fact, it is a seamless change. For me, the analysis of climate change, the weather and climate projections for the future are part of the seamless production of information and services.

(Interview August 2016, Oslo)

While short-term weather forecasting is a less uncertain endeavour than speculating about long-term effects of GHG emissions, uncertainty looms large. In particular, the problem of resolution is a key issue for many weather forecasters. As discussed above, rainfall is intrinsically tricky to predict, due to the stochastic nature of cloud cover. Several interviewees also mentioned particular challenges in forecasting rainfall, both due to extremes and also the uncertainties around the monsoon in the Indian context. The following quote from a Mumbai-based scientist captures this nicely:

There are two challenges when we talk about India: The monsoon is one and the second one is extremes in rainfall patterns. Temperature is not so difficult and we get good projections on forecast, but precipitation is tricky. When we heat corns we know when the temperature is high, we know what will happen, but we don't know what will pop up. up[...] Rainfall is like popcorn [...] Over and above the challenges of resolution and parametrization, we just don't know which corn will pop up or not. With temperature there is less uncertainty but with moisture we never know when it precipitates and how. It could precipitate here or there, now or after 12 hours and these patterns can disturb the entire balance. So from a climate/ weather perspective these are the uncertainties we are talking about.

(Scientist October 2016, Mumbai)

This often makes forecasting difficult for the IMD, given the challenges in predicting the Indian monsoon. The same scientist stated that climate

models are failing to simulate the monsoon trends and climate projections thus often do not work. It perhaps makes sense to focus on a shorter scale for models so that they can be more of user and also lead to decision making.

(Scientist October 2016, Mumbai)

This implies, thus, the need to cope and manage uncertainties around the monsoon and also communicate them appropriately rather than assuming that there is confidence in predicting the longer scale.

Uncertainty in policy and public debates

The science–policy interface, that is, how scientific practice/projections are translated into decision outcomes also has implications for how uncertainty is addressed. While scientists work with uncertainty in terms of probability, decision-makers often like to be certain about the outcomes (Bradshaw and Borchers 2000) and governments are typically very unresponsive to uncertainty, see Chapter 4 for the case of senior bureaucrats in Gujarat. As discussed earlier, decision-making is less about mastering uncertainty prerogative of natural science and more about managing uncertainty (Schneider and Kuntz-Duriseti 2002). In

real terms, there could be two kinds of paradoxes that policymakers encounter: excess of information and the lack of time to determine policy options, or the time scale lag between resolution of uncertainty and policy decisions (Schneider and Kuntz-Duriseti 2002).

No one disputes that effective communication between science and policy is necessary to make informed choices regarding decisions on climate change (Dessai and Sluijs 2007). One of the foremost challenges of climate change decision-making is to “translate” and make sense of the models and integrate this into policy- and decision-making and justify such decisions. As Dosi and Egidi (1991: 152) argue that – “with uncertainty, information is imperfect and possibly asymmetric, agents hold different beliefs and ‘priors’, and their knowledge of the future is limited. They can interpret correctly the signals that they receive (and try to do so), but they do not [and cannot] receive all the signals necessary to make those optimal choices that would have been taken under perfect information”. This point relates to the epistemic uncertainty whereby imperfect knowledge leads to uncertainty. However, these decisions are often located and embedded in structures and contexts that function, harness and use information in particular ways. These may be (1) the epistemic networks, (2) financial networks, (3) political networks, (4) discursive networks and (5) performative networks (Hulme 2013). The focus on quantitative and statistical uncertainty most often hides or ignores the “policy relevant uncertainty information about the deeper dimensions of uncertainty that cannot be quantified” (ibid.: 5). The uncertainties in forecasting and modelling lead to difficulties in translating these issues into policy and public debates. Several patterns emerged from the interviews that we outline below. These include:

- The conflation of variability and climate change in popular discourse
- Critique of relevance of models to policymaking
- Decision-makers may not accept the forecasts from scientists, especially if they are uncertain
- The media may not present the nuances inherent in the forecasts
- Approaches like ‘robust decision-making’ or similar tend to be more at the academic level and do not seem to be gaining much traction in India

We now examine these issues in depth with the help of the interview material. An important distinction, which is often conflated in popular discourse as well as decision-making, is between climate variability and climate change (Hulme 2016). Local people and decision-makers tend to focus on “the here and now” and on the variability that they experience, rather than long-term climate change. This can be frustrating for scientists as expressed by a climate scientist in Kutch:

Climate change and variability are often conflated. We need at least 30 years of data to talk about climate change and one cannot talk about climate change with a few years of data.

(Interview October 2016, Kutch)

Many of the scientists interviewed spoke of the problems in translating scientific knowledge to decision-making.

Ministers and others always push scientists for estimates and figures regarding climate change impacts. Climate change science gives you a range but they want a figure for planning crops, breeding programmes etc. This is a problem for us working in climate change. How to deal with the complexity in models?

(Scientist January 2015, Kolkata)

Largely, policymakers tend to focus on what's happening in microclimates in order to be able to act accordingly. For example, they look at predictions for agriculture so that they can provide inputs to farmers regarding decisions to plant crops (Social scientist 2014, UK). However, they seem to want a lot of certainty which is often not possible due to the reasons mentioned above.

This often leads to difficult relationships between scientists and officials. Officials complain when forecasts are wrong and fail to understand that uncertainty is always embedded in forecasts and that we need to live with it and work around it. In part, the problem is also that scientists have failed to communicate issues concerning uncertainty to the public, the media and the government and the probabilistic nature of forecasts.

In the roundtable held in Oslo, observations in a similar vein were made:

We often represent research on climate change as a flower, with the climate system and changes in the climate system, in the middle. Then the next circle is about impacts on nature and society, and then there are the petals of the flower, where we get into more sectoral research – adaptation and mitigation in transport, adaptation and mitigation in agriculture, things like that. There is a danger that this view leads to climate research being a bit like a drunken man who has lost his keys – he will look under the light of a lamppost, because that is where he can see something, but it is not necessarily where the keys are. In the same way, climate science can say something about probabilities of extreme rainfall, average temperatures, and so on, but that may not necessarily be what matters to people.

(Roundtable discussion August 2017, Oslo)

A geologist working on climate change in the Sundarbans feels very frustrated by policymakers who only focus on short-term gains, whilst ignoring climate change and also completely lack long-term thinking and planning:

In 2002, I started talking about sea level rise in the Bay of Bengal and vanishing islands but nobody listened to me. The government said: “it’s

under control so the sea cannot rise”. Now with all the plans and data in place, they are saying: “let it rise”. Despite sea level rise, islands are still forming but this is due to geological factors. Everything is unknown and we cannot quantify uncertainty. The monsoon forecasts for the Sundarbans have failed miserably since 2008. Farmers are now committing suicide all over India due to floods and droughts combined. We cannot fight with the sea and nature. Even in Japan the tsunami wall failed. Why are cities being built in such vulnerable coastal areas, e.g. Bombay? There is no proper long-term planning. The government only thinks 10 km around Delhi. They focus on scenarios and on lowering costs and less on benefits. Which dams or embankments in the country have given the desired results? Has anybody been punished for wasting public money?

(Interview January 2014, Sundarbans)

He also argued that mainstream science in India, including engineering, has tended to ignore uncertainty. This is because Indian science tends to focus on modifying and controlling nature rather than accepting that “we don’t know enough [...]”. Observing and experiencing nature are both very important. This training is absent in Indian science. To understand a place like the Sundarbans, one needs a different orientation or mindset” (Interview January 2014, Sundarbans).

Most scientists also complained that there is a marked lack of political and bureaucratic will to engage with climate science and research. The scientist working in Gujarat comments:

Our research will always have recommendation for the government but they keep it and forget it! Even in Gujarat which has all the policies in place around climate change, integration is not happening – I think the Climate Change Department operates only as fund managers, but the policy has not yet come (See also Chapter 4 on Kutch, this volume).

We also interviewed social scientists who work on climate change who feel that the problem is that policymakers are always looking for easy solutions and that natural scientists and social scientists also often cannot agree about uncertainty. In a group discussion with natural and social scientists, a social scientist contended that

Natural and social sciences ask completely different questions. Natural scientists want to provide information to economists, whereas economists ask what decisions to take under uncertainty [...] It is very difficult to translate a natural scientists uncertainty formulation into decision making.

(Interview August 2016, Oslo)

They all acknowledged that communicating uncertainty is difficult, especially when you begin to quantify uncertainties:

There are cascading uncertainties and we can't quantify all of them. In climate change temperature forecast ranges from 2.5 C – 5 C. We need to ignore some uncertainties in order to say anything and don't want to live completely in an uncertainty scenario. Of course, a lot depends on communicating what we put in our models and quantification is only one aspect here. We need better communication.

(Modeller August 2016, Oslo)

We try to work within standard errors but there exists a dilemma of how much uncertainty one should communicate. Natural scientists bring facts-based observations. Economists interpret information and we tell policymakers what to do. Too much of focus on whether it is 3, 4 or 5 degrees (i.e., uncertainty) can distract attention from key issues.

(Economist working on climate change, August 2016, Oslo)

Natural scientists told us that social scientists tend to focus too much on complexity which does not allow decisions to be taken and does not help problems to be solved ultimately. By contrast, social scientists said that natural scientists have a too narrow view of what uncertainty is and that there is a need to work around “uncertainty” as a problem of communication. In the Oslo roundtable, a participant, with experience from the IPCC, argued that there are a lot of scientists who think we should just ban the word uncertainty altogether and instead talk about “how certain are you”?

Attribution and the uptake of forecasts and projection

An issue that came up in most interviews concerned problems in attribution, over and above the complexity and uncertainty in forecasts and projections. We have already discussed the problems of forecasts around the monsoon; however, there are little long-term data and trends that provide sufficient evidence that the monsoon has changed in response to climate change in terms of average precipitation as evident in this statement from a meteorologist at the IMD.

We do not see long term trends linking climate change with the monsoon. Of course, in different Indian states, there are differences in rainfall patterns, e.g. Rajasthan has seen changes in rain frequency. There is an increase in monsoonal heavy rain and an increasing number of days with heavy rain with lighter and moderate rain decreasing. But still on average the totals are still roughly the same.

(IMD expert, May 2016, Delhi)

India has organised events related to attribution which are attended by delegates from other countries in the global South. However, attribution can also be harnessed for political uses. The attribution of heatwaves and other climatic events is increasingly becoming a contested area as it deals with questions of responsibility, equity and justice as well as adaptation (see below). In an interview with two officials at the Ministry of Earth Sciences (MoESs), we were told:

We need more research on how to do attribution, at present it is experimental. We recently had an African Development Bank meeting in Ahmedabad looking at attribution of heatwaves and floods. Attribution involves use of all available models and assesses historical data over a period of time plus different variables related to specific climate events. For example, the recent heat waves are attributed to climate change. India is leading research on the question of attribution. The use of outputs from attribution science can be deployed also in the global arena. India wants to use attribution science in climate negotiations.

(Officials Ministry of Earth Science May 2016)

Attribution issues, however, seem to matter less at the national, state and district level. Policymakers and politicians in India are not necessarily concerned about whether a certain weather event is attributable to climate change or not in the first place. What matters is the type and nature of response and displaying that the prevailing government/state is in control. Largely, the cause of the event does not matter to the local electorate (IIT climate scientist January 2018). This again underscores the disconnect between the “above” that still has a tendency to reduce and master uncertainty v/s the “below” that is finding ways to live with and manage climate and other related uncertainties.

Also, in dynamic environments like Kutch and the Sundarbans, attribution is more difficult because climate change is one of the many issues that people have to grapple with in their daily struggle for survival (see Chapters 4 and 5). According to a social scientist working on climate change:

Usually it's best not to rush to conclusions regarding climate change though of course much depends on how ecosystems change and adapt and a lot of other relationships. Locals tend to have a far more nuanced perspective [...] But NGOs tend to attribute and relabel lots of things as climate change in order to access money. All development work is now climate change. By contrast, people at the forefront of climate change are less likely to label it as such.

(Social scientist UK, July 2014)

Scientists also struggle with dealing with simplistic views from NGOs.

Local NGOs are foolish to blame local people for all the problems in the Sundarbans, e.g. ‘overfishing’ and forest loss. Locals cannot be blamed for salinity and flooding [...] Sea level rise is the main reason why the islands are disappearing. Even tigers are getting homeless in islands where there are no people. We need to convince NGOs that local people cannot be blamed for a lot of these changes.

(Scientists January 2014, Kolkata)

From a development point of view, such simplistic perceptions are also unhelpful because local people are vilified and often not allowed to pursue their traditional livelihoods in the name of climate change, often increasing their vulnerabilities and insecurities.

On a positive note, with respect to disaster management, some government scientists are happy about the scope for forecasting and are optimistic regarding the potential for further improvements. This is especially the case with respect to the usefulness of narrowed down uncertainty (scenario bands), in particular predicting cyclones:

We have done well in disaster prediction and threats are detected even though there can be some difference between actual intensity compared to prediction. With cyclone Aila in 2009, the trend was different from prediction though with cyclone Phailin in 2013 we did very well. The science has improved a lot and is now part of a co-ordinated system and network with disaster management authorities. Disaster management cells co-ordinate functioning and there are now far lower casualties than 20 years ago. Of course, we can still improve the models and forecasting but overall, I am optimistic about our progress.

(Scientist at MoES May 2016)

Hybrid knowledges and social understandings of uncertainty

As discussed in this volume, approaches are growing that focus on embracing rather than seeking to avoid uncertainty. They are based on the realisation that uncertainty should not, and need not, lead to paralysis in action. Thus, while the traditional view of uncertainty that we have described so far persists both globally and in the Indian context, there is now an emerging alternative framing that is gaining ground. According to one of the leading researchers working in this field:

We are looking at frameworks and what options we have that are immune to uncertainty. [It] is supported by institutions such as the World Bank, Rand corporation and so on (...) there are obstacles still in costs, data availability etc., but it is developing.

(UK Researcher January 2017)

The “Decision-making under uncertainty society”² consists of political scientists, modellers and others actors who are trying to move away from the “predict and act” framework. Robust decision-making is a group of tools, anything from “back of the envelope” tools to RAND corporation’s big dataset approaches (UK Researcher January 2017; see also Bhavé *et al.* 2016). From a methodological perspective, the alternative framing has come a long way in changing the focus of adaptation planning away from scenario-led approaches and towards decision-led approaches that emphasises the need for flexibility in future planning (echoing responses that we have described from the “below” in many chapters of this volume). But it is less clear whether and how much traction these approaches have beyond academia. Some argue that approaches like “robust decision-making” have very little traction among governments who tend to revert to familiar and dominant frameworks based on risk assessment. Another UK researcher put it this way: “Climate change is not special [...] policy makers are not interested if you say you do not have an answer, [you] have to pick a model or a scenario and go with that” (Interview, February 2017, UK).

Heymann (2018) contends that the discursive trend to concentrate on global models and averages runs counter to the history of climatology as a discipline anchored in local experience of climate and weather. The importance of downscaling and validating local knowledge is to “humanise” climatology, making it accessible and link it to everyday life, knowledge and practice. We now turn to focus on the scope to include forms of knowledge that are often overlooked or undervalued by the “above”. These include embodied, emotional and tacit ways of knowing and representing the world which requires a pluralist sensitivity and appreciation for a persistent diversity of understandings (Stirling *et al.* 2018). Social scientists studying the “social life of models” tell us that climate modelling takes place according to diverse reasoning and across different scales (Hastrup 2013). While this so-called hard science has largely gained authority over other forms of knowledge, all forms of knowledge (including so-called expert knowledge) are culturally and socially embedded and moulded by particular social, power and gender relations. Indeed, the preceding sections have focused on the different scientific and socio-political rationalities that have moulded the “above’s” understandings of climate-related uncertainties. Historically, local communities have developed practices and strategies to plan for and live with ecological uncertainty and variability (Hastrup 2013). Hastrup (2013) argues that dealing with climate change involves practices of anticipation, that is, how people anticipate the future and prepare for it. For her, scientific approaches are just one of the many modalities of this anticipation alongside the day-to-day strategies of people who live with uncertainty or make decisions regarding changes in climate. These could be seasonal mobility, crop diversification or risk-averse behaviours to cope with resource fluctuation.

According to Berkes and Berkes (2009), many indigenous systems have developed highly appropriate ways to deal with complexity and uncertainty. Indigenous knowledge (IK) evolves through adaptive learning based on

developing a complex knowledge base of the environment and lessons from past mistakes and is thus a kind of post-normal science (Funtowicz and Ravetz 1993). According to Berkes and Berkes (2009), both kinds of knowledge are desirable because they have different relative strengths and a potential for complementarity. IK can also complement more macro perspectives by filling in the local scale. However, as argued in Chapter 4 on Kutch, climate change and new radical uncertainties profoundly alter previous indigenous anticipations and often test tested indigenous system might not help in tackling the new range of unpredictability and unknowns.

Indeed, climate scientists we interviewed working in an interdisciplinary institution in Norway acknowledged the limitations of engineering and technologically oriented solutions which cannot solve everything.

Unfortunately, ‘techno-management’ and pipe thinking are very problematic and there is too much faith in technological solutions to ‘rescue us’. Instead, we need to have more learning and mutual, exchanges across different groups and levels of expertise. For example, scientists could learn from farmers at what temperature it is when crops die and then improve threshold scenarios. Policy makers could also make use of this information and give guidance to farmers to change their cropping patterns. But it is difficult for humans to grasp all of this complexity and learning processes embracing uncertainty are key.

(Discussion with scientists August 2016, Oslo)

Plural knowledge systems can act as the “bridge”. Historical work by Carey (2010) demonstrates how scientific knowledge about glacial changes in the Andes is moulded by power dynamics, economic outcomes, local worldviews and social relations. Thus, even the so-called modern forms of knowledge based on western science are thoroughly dynamic and imbued with local culture and practice (Feyerabend, 1996; Wynne 1996). Thus, neither scientists nor local people are homogeneous. The dynamic view of the nature of uncertainty from “below” and “above” that we have pursued in this volume opens up the possibility of identifying convergences between certain actors and perspectives in local and scientific worlds. Hybrid knowledges can, thus, be a suitable way to tackle uncertainty challenges, and a growing number of scientists are seeking to work in transdisciplinary and interdisciplinary ways (see also Movik *et al.*, Chapter 7). As argued by a professor from Kolkata:

I have moved out from the conventional academic domain. When we started only 2% of fishers used GPS, now 60% use it. Scientists are now working with farmers in Kutch and the Sundarbans to revive local crops that are resistant to droughts, salinity etc and can survive better in the face of cyclones, droughts etc In Mumbai, IIT researchers are developing

a flood forecasting system. Different experts from tidal, atmospheric and hydrological sciences will work together and develop a model which will have a probabilistic forecast on floods. It will be opened up to community (urban people) to get their feedback on what way they can improve it further.

(Interview, January 2014, Kolkata)

The Met office in Norway works in close co-operation with different authorities – for example, roads, water, energy, agriculture, fisheries, transport and coast – who all depend on the weather for their work. They also consult the public about how best to provide weather forecasts and information (e.g. mobile apps). The 90-minute weather forecast is based on user feedback. We did not find this same level of user engagement in the IMD in Delhi even though there was acknowledgement of the strengths of local weather information and traditional knowledges:

Yes, they [local weather forecasts based on perceptions] are useful in many respects, we can find out whether local people understand our ‘language’. We can also learn how to prepare better, how our information is used and what the local confidence in our warnings is. Traditional knowledge can be useful for some situations, e.g. a local person based on understanding of cloud formation can predict whether there will be thunderstorms etc. Farmers through this knowledge can utilise historical evidence, memory and observation. This knowledge can work but not always. Animal behaviour is similarly to have shown ability to react/predict weather but similarly cannot be used much or relied on. But traditional knowledge can be use especially for wider communication.

(Scientists at IMD, Delhi, Interview May 2016)

Clearly, despite appreciating local traditions and knowledge, this official did not see an integration of this knowledge/and perceptions into models as feasible. By and large, the scientists we interviewed seemed to imply that scientific knowledge was perhaps better or of a higher level.

[...] ordinary people may be also decision-makers but it is our duty as scientists to explain about the possibilities for the future. The possibilities are based on historical records that you really have to take into account that the future will not be like the past. I think that is a sort of mission we have as scientific people, to try to explain that. I do not think we will manage to convince everybody Religion is something you believe, that is good for many people, but science is not a religion, it is about good hypotheses for the future, which are based on scientific work.

(Interview with scientist in Oslo Met office, August 2016, Oslo)

A scientist working in Gujarat says he has learnt a lot from farmers regarding the agriculture–climate interface. His organisation has organised “listening sessions” with farmers and training programmes with farmers, however, with the aim to educate the farmers about climate change and also to improve forecasting “so we can help farmers”. Even though he acknowledges limits to modelling exercises, he thinks local knowledge is in itself difficult if not impossible to quantify and feed into models. In that way, rather than hybrid knowledges, most of the scientists we interviewed see an unbridgeable epistemic and ontological divide between expert and lay knowledge. Scientists in the MoESs plainly stated that local knowledge is “not useful in modelling. I don’t think local people can give feedback on weather/climate related information [...] and don’t think it is possible to use local knowledge to further develop models” (Interview with MoES Scientists, Delhi May 2016). This was echoed by scientists from the National Centre for Medium Range Forecast (NCMRF) on the issue of local knowledge and its integration into modelling exercises: “No, they cannot be integrated. Model development is very different from local perceptions. There is so much subjectivity when it comes to observed weather. We are scientists want some objectivity and can’t rely on sentiments or emotions” (Interview with NCMRF Scientists May 2016).

Similarly, scientists from a national research institute in Delhi said that it was difficult to integrate sociological dimensions in climate models since it was not possible to bring narratives together with quantification of data, with the exception perhaps of Representative Concentration Pathways (RCPs) which can incorporate development aspects and integrate different data sources, for example, scientific data with socio-economic aspects (Scientists interviewed May 2016, Delhi). Most of our interviewees expressed similar reservations although one US-based scientist said that bringing in local-level field information is very challenging but might be viable. By contrast, scientists did appreciate that interdisciplinary research (especially in the natural sciences) is vital to “connect the dots’ and improve scientific findings and models across fields, though here too it depends on “what skills can tolerate other skills” and the ability of models to be re-examined with respect to incorporating feedback” (US-based scientists interviewed January 2018, Mumbai IIT).

In the political realm, a top-down structuring of governance seems to be an impediment towards local perceptions making their way into decision-making processes, as a former Minister of Environment and Forests in India highlights:

No, it is not possible at the moment to include local perceptions though NGOs as mediators are important. When I was minister, we listened to the people and civil society organisations but currently 95% of the information flow is top down especially at the centre.

(Interview with former Minister of Environments and Forests May 2017, Delhi)

This highlights the importance of instituting structural processes at the political level if local climate information were to be of greater relevance in macro- as well as micro-level decision-making.

In sum, while the experts we interviewed seemed to acknowledge limits to their models and approaches, most of them seem to imply that science or scientists have a “mission” regarding climate change. Barring a few exceptions, we did not see much evidence of scientists actively trying to incorporate local-level knowledge and history into their models and methods. In fact, while doing the research, we did not find much evidence in the Indian context of climate scientists working closely with local communities and their indigenous knowledge systems to understand climate change-related uncertainties. This is unlike emerging alliances in the Arctic and beyond, where scientists are working closely with local communities and indigenous peoples to co-produce knowledge and understandings of climate change in a bottom-up and democratic manner.³ There are growing attempts to create plural climate studies frameworks to embrace place-based experiences of local people and insights from the critical social sciences (see Chakraborty *et al.* 2021) and also attempts to decolonise climate sciences by using indigenous peoples’ experiences and knowledges as the starting point (Johnson *et al.* 2021). We hope these will gradually make their way into mainstream climate science and climate policymaking.

Conclusions

This chapter has explored how uncertainty is understood by scientists, decision-makers and boundary workers and how it is presented and represented in models and scientific understandings. We also discussed the science/policy interface and the challenges in communicating uncertainty before discussing the possibility of integrating local knowledges and understanding in order to generate a socially grounded understanding of uncertainty. We found that despite an acknowledgement of the problems of modelling in capturing and understanding uncertainty, particularly at regional and local scales, there is a major drive to improve modelling and predictions to embrace uncertainty and complexity. Scientists also struggle due to the conflation of uncertainty in weather and climate in popular discourse and the media and the fact that the media do not portray the nuances of forecasting well, which also impedes future work. Many scientists were also constrained because their work on forecasts and models was often not taken seriously or because the probabilistic nature of the models is not deemed relevant to policymaking.

The chapter also discussed the growing community of natural and social scientists, boundary actors and policy actors, working to develop approaches to better reflect the “deep uncertainty” in relation to climate change and some efforts on the part of a growing community of natural scientists, social scientists and policy actors trying to bridge the gap between the “above” and “below”.

However, our interviews show that while there has been significant progress in developing concepts, large gaps exist in the understanding across the different groups, due, in part, to different starting points, languages and priorities (UK researcher, March 2017).

We also discussed how the scientific models and scientific data largely focus on biophysical factors. However, as the case studies in this book demonstrate, biophysical changes interact with socio-economic and other trajectories of change causing new vulnerabilities for people and their ecologies. Thus, models may lack the local perspectives, socio-historical components and human dimensions that confront communities at the forefront of climate change as they adapt and respond to climate change. It is, thus, important to validate models with micro-level detail, local perceptions and histories in a way that is non-instrumental in order to fill crucial gaps in knowledges and understandings of uncertainty. As we have discussed in this chapter, scientists are clearly aware of the political nature of climate change and the limits to their knowledge and also the problems with translating their knowledge into policy and practice. However, they still appear to be resistant to construct alternative models and approaches that are more plural and draw on other skill sets and repertoires. Most of the scientists interviewed were men. In general, there are fewer women in senior roles in climate science and policymaking, but the few women we interviewed in all three countries, acknowledged some of the limitations of perspectives from “above” and the need to take on board local perspectives and realities in their work. This highlights the importance to have more plural and gendered perspectives in, otherwise, very male-dominated research and policy environments.

In conclusion, while the scientists we interviewed acknowledge uncertainty and there are signs of increasing appreciation of “deep uncertainty”, traditional approaches to uncertainty still dominate in the understandings and policy debates among the “above”. There remains a tension between the “above” still trying to master and reduce uncertainty through modelling and scenario building and the “below” that is seeking to cope with and live with uncertainty. While most of the scientists we interviewed acknowledge local understandings of uncertainty and the need for local expertise to inform climate models, and hybrid engagements emerging, there is as yet not much evidence of mainstream climate science or policymakers in India embracing alternative knowledges.

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Notes

- 1 Radiative forcing is defined as “the net change in the energy balance of the Earth system due to some imposed perturbation (...) and quantifies the energy imbalance that occurs when the imposed change takes place” (Myhre et al., 2013).
- 2 <http://www.deepuncertainty.org/>, accessed July 2021.
- 3 See http://www.unesco.org/new/en/media-services/world-heritage-37th-session/whc37-details/news/global_change_in_the_arctic_and_co_production_of_knowledge/, accessed March 2020.

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