COMMUNICATING CLIMATE RISK
A TOOLKIT

A publication of the **Analysis Under Uncertainty *for* Decision Makers Network**

COP26 UNIVERSITIES NETWORK

AU4DM Network

COMMUNICATING CLIMATE RISK: A TOOLKIT

A PUBLICATION OF THE ANALYSIS UNDER UNCERTAINTY *for* DECISION MAKERS NETWORK

Written by
Jo Lindsay Walton and Polina Levontin

With additional contributions from
Martine J. Barons, Mark Workman, Erik Mackie, and Jana Kleineberg

Layout and design by
Jana Kleineberg | Kleineberg Illustration & Design

Published in 2021 by AU4DM, London, UK

ISBN: 978-1-912802-06-7
DOI: 10.25377/sussex.16823260

The **Analysis Under Uncertainty for Decision Makers Network** (AU4DM) is a community of researchers and professionals from policy, academia, and industry, who are seeking to develop a better understanding of decision-making to build capacity and improve the way decisions are made across diverse sectors and domains. For further details about the network, visit www.au4dmnetworks.co.uk/.

Recommended citation
Walton, J.L., Levontin, P., Barons, M.J., Workman, M., Mackie, E., and Kleineberg, J. *Communicating Climate Risk: A Toolkit* (London, UK: AU4DM, 2021).

COP26 UNIVERSITIES NETWORK

CAMBRIDGE ZERO

Imperial College London

AU4DM Network

SUSSEX HUMANITIES LAB

Warwick Statistics

Disclaimer
The opinions expressed in this publication are those of the authors.
They do not purport to reflect the opinions or views of the COP26 Universities Network.

COMMUNICATING CLIMATE RISK:
A TOOLKIT

FIRST EDITION

TABLE OF CONTENTS

EXECUTIVE SUMMARY

AR6 continues to demonstrate the IPCC's commitment to quantifying and communicating uncertainty in order to support transparency in science and inform robust decision-making. AR6 also includes greater emphasis on deep uncertainty, e.g. in domains such as tipping points and cascade risks. Risk assessment and risk management are assumed in AR6 as key frameworks that underpin global mitigation and adaptation efforts. However, more needs to be done to connect scientific understandings of uncertainty to risk-based decision-making by policymakers, NGOs, industry, and other actors spanning diverse epistemological, cultural and social contexts. Specific kinds of uncertainty such as model uncertainty and deep uncertainty are challenging to communicate and are typically not well-understood by decision-makers, even those who are risk-literate. Key concepts and methodologies differ across and within different domains of science and policy, creating the potential for information to be lost or misinterpreted.

This Communicating Climate Risk Toolkit ('the Toolkit'), from the COP26 Universities Network (COP26 UN) and the Analysis under Uncertainty for Decision-makers network (AU4DM), seeks to narrow the gap between climate science and climate action, by providing insights, recommendations, and practical tools to support dialogue between scientists, decision-makers, and many diverse communities. The Toolkit also endeavours to identify open problems and pose questions for further study and debate. Topics covered include varying conceptions of uncertainty and risk, best practice in visualising uncertainty data, case studies on tipping points and model uncertainty. Based on close collaboration across decision science, climate risk modelling, statistics, the environmental humanities, and science communication, the Toolkit seeks to drive a step change in achieving holistic, joined-up, and participatory climate action, equal to the scale of the task of the decade ahead.

The Toolkit was developed as part of the COP26 Universities Network Climate Risk project in 2021, and is usefully read in conjunction with the project's other outputs: Climate Action Unit's **Communicating Climate Risk Goodybag** (bit.ly/theGoodyBag), which explores the science / policy interface, informed by neuroscience, climate journalism, and other fields, and which provides practical tips for writing and engaging in dialogues around climate risk; and the **Climate Risk Papers series**, which summarises recent research in the areas of tipping points, cascade risks; coastal flood hazard modelling; compound hot-dry events such as heatwaves, wildfires and droughts; and attribution of extreme events.

COMMUNICATING CLIMATE RISK: KEY MESSAGES

1. Taking an integrated, whole-economy approach to decision-making means **connecting scientific practices around uncertainty** to other understandings of risk across policy, business, the third sector, and communities affected by climate risk, within a just transition framework.
2. **When uncertainty is appropriately quantified and communicated, it can deepen collaboration between experts, decision-makers, and other stakeholders.** However, many kinds of uncertainty are challenging to quantify and/or communicate.
3. **Quantifying uncertainty is not always possible,** e.g. where there is deep uncertainty or data poverty.
4. **Attempting to quantify uncertainty is not ethically and politically "neutral,"** and may sometimes be undesirable, e.g. incompatible with the goals of transparency, inclusion and justice, or unduly disadvantaging to particular stakeholder groups.
5. Improving transparency and equity means **considering proportionality when communicating uncertainty.** Comprehensive and prominent uncertainty information will be appropriate for some contexts but not all.
6. Narratives and communicative practices around **model uncertainty** need to be strengthened, and lack of diversity in the modelling community needs to be addressed.
7. **The regional disparities in modelling are also problematic.** Data and research-poor regions are often the ones for which model predictions are least informative. Yet these same regions are often the most vulnerable, while lacking both forecasts that could support decision-making or means to implement adaptation and risk mitigation measures.
8. **Climate risk communication implies not only technical questions but also political ones,** because it is inherently concerned with the representation and weighting of the voices of diverse societal stakeholders.
9. **More can be done to deepen the participatory character of climate action. Real transfer of decision-making power needs to be improved.** Comparative studies and peer-to-peer learning allow different countries and localities to benefit from one another's experiences of strengthening participatory action.
10. Well-established terminology for actors at the science-policy interface, including *expert, decision-maker, stakeholder,* and *public,* remains indispensable; better attention can be paid to such terms' presuppositions and their potential to limit inclusivity and participation. In particular, **the interconnected nature of climate risk tends to expand the meaning of stakeholder.**
11. The context in which we are communicating is always being shaped by **social movements** that help draw attention to the historical, economic and cultural politics of climate change. Societal backlash will occur if climate mitigation and adaptation is imposed top-down.
12. Climate risk communication is a field with many open problems, and **there is clear value to interdisciplinary collaboration** across science, social science, and arts (e.g. graphic design) and humanities (e.g. environmental humanities). However such collaborations also demand significant time and energy, and in most national contexts **the pace of academic funding, research and impact is unsuited to the urgency of climate risk.**

*What if those who are most willing to listen are **not** those who most need to hear?*

Chapter 1 INTRODUCTION

OVERVIEW

What you'll find in this toolkit (and what you won't)

This Toolkit aims to improve the communication of climate risks. It has been guided by a few principles:

- The need to **improve dialogue between climate scientists, policymakers, and other stakeholders,** to rapidly reduce net emissions to zero and to build resilience to climate risks.
- The fact that climate risks are faced across society and around the globe, and the need for **holistic and participatory** approaches to communication, with strong regard for equity and inclusion.
- The many **uncertainties** associated with climate risks, and the need for robust understandings of and communication about those uncertainties.
- The **urgency** of climate change, and the need for immediate action of unprecedented type and scale, even given imperfect information, tools, experience, and terminology.

Where policy and climate science intersect, things can get complicated fast. The UK Government Office for Science (GO-Science) recommends policymakers adopt a joined-up and participatory approach to integrating scientific and other expert advice into policy. GO-Science advises that issues which need input from experts and communities should be identified early. Policymakers should seek advice from a wide range of experts; the more uncertainty there is, the stronger the rationale for widening the variety of experts consulted. These processes should be made as transparent and participatory as possible, to permit scrutiny by key stakeholders and the public (The Government Chief Scientific and Adviser 2010; Garb, Pulver, and VanDeveer 2008).

These are all sensible principles from GO-Science. In practice they imply **a lot of dialogue involving a lot of different participants. These participants** don't just bring their own expertise and values to these dialogues. They also bring their own ways of talking and thinking about the issues. For example, key terms like *uncertainty* and *risk* often come with different associations. These terms might even be considered examples of the "imperfect terminology" mentioned in the four principles above. What's more, participants bring their own norms about what counts as acceptable or good communicative practice.

Subsections

i

Because these conversations are about climate change—or "everything change", as the speculative fiction author Margaret Atwood aptly put it—they need to include an unprecedented variety of participants. That means that effective communication is more challenging than ever. The scope for **misinterpretation and information loss** is vast. Sometimes, participants may even struggle to find the right kinds of questions to ask. At other times, participants may leave feeling satisfied, without recognising they have been speaking at cross-purposes.

There is also scope for **disengagement,** and disintegration of the spaces where dialogue might occur. Policymakers tend to have many pressures on their time. A policymaker may sense that a scientist has something important to tell them—about extreme weather events, about knock-on effects, about the uncertainty in upscaling novel technology—yet not be able to connect it to their everyday decision-making. The policymaker may suppose the scientist has good reasons for saying 'extreme precipitation' rather than 'floods,' or for saying 'it is unequivocal' rather than 'we are completely certain.' But the policymaker may not understand what those reasons are, and may not have the capacity to figure it out in the time available.

And of course, it's not just science that has its own technical vocabulary and norms. The wider world of policy, industry, and society can present as opaque and inaccessible to scientific experts. Despite the extensive resources devoted to realising policy impact, many scientific experts still lack the necessary knowledge of policymaking to communicate in ways that make it "harder for climate policymakers to evade the practical consequences of the knowledge base they already accept" (Geden 2018). Because climate risk is so ubiquitous, and involves impacts that can cascade right through society, experts even face challenges in prioritising *which* decision-makers to seek out—let alone learning to speak their languages. What if those who are most willing to listen are *not* those who most need to hear?

To effectively address climate risk, we need to communicate effectively about climate risk. This Toolkit has been assembled by experts from decision science, statistics, modelling, neuroscience, the environmental humanities, and climate journalism backgrounds. It contains recommendations and insights for improving dialogue between scientific experts and the many decision-makers dealing with climate risks. We don't have all the answers—the Toolkit also identifies challenges and open problems, and provides case studies to inspire you to form your own views. The Toolkit won't tell you exactly what word or what visual to use in every context to get your point across. But it will help us all to start asking one another the right questions.

To effectively address climate risk, we need to communicate effectively about climate risk.

UNCERTAINTY AND CLIMATE RISK COMMUNICATION

Why it's hard to talk about uncertainty, and why we should talk about uncertainty

> *"I was telling a client that the likelihood had been estimated as one in fifty. But then the scientists said, 'That doesn't mean anything without the uncertainty.' I asked them, 'What do you mean, uncertainty? I thought one in fifty was already uncertain?'"*
> *(Interview Respondent, September 2021)*

It is not enough to understand what is happening to our planet. Climate experts need to communicate what they know to non-experts—to people with power to do things about it. This means climate experts often need to communicate what they know about what they *don't* know. In other words, **climate experts need to communicate the *uncertainty* that is an inherent part of scientific expertise.**

To someone from a non-scientific background, the word *uncertainty* is associated with hesitancy, doubts, and indecisiveness. When a person from a non-scientific background tells you they are uncertain about something, they are usually implying, "I'm not really the right person to ask. Don't rely too heavily on my advice." But to scientists, uncertainty means something different. Uncertainty isn't just an absence of information: often uncertainty is its own kind of information, and it can be useful for making better decisions (Morgan 2009).

Nonetheless, when it comes to climate change, it can be hard to talk about uncertainty. When uncertainty is mentioned, experts may be seen as lacking faith in their own science.

When uncertainty is carefully quantified and communicated, it can deepen understandings and strengthen collaborations between experts, decision-makers, and other stakeholders.

They may be suspected of merely trying to save face, in case they turn out to be wrong about something. Or they may be perceived as being too wrapped up in the details, too out of touch with reality to ever give a straight answer, or the type of answer that is being sought.

Uncertainty may also send the message that we should wait until we can be more certain. This can be exacerbated by the continued spread of climate change disinformation, by powerful incumbent interests or by malicious rogue actors (Boykoff 2008; Supran and Oreskes 2017; McCright and Dunlap 2003). As Maxwell Boykoff puts it, "Uncertainty can be reframed as scientific incompetence" (in Liverman et al. 2008).

Quantifying uncertainty is not always possible (see **Chapter 3:** Tipping Points) or desirable. For example, relying on quantitative forms of risk assessment might be incompatible with the goals of transparency and inclusion, in some cases disadvantaging indigenous voices and other relevant epistemologies and methodologies (Russill and Nyssa 2009).

For all these reasons and more, it can be hard to talk about uncertainty. But sometimes we need to talk about uncertainty. In particular, climate change is characterised by

> *multiple intersecting and uncertain future hazards to natural and human systems, that are expected to unfold over a very large range of spatial and temporal scales, and whose probabilities may be difficult, or in some cases impossible, to quantify precisely (because of intrinsic and/or irreducible uncertainties about the future). It is a risk multiplier that interacts with other stressors to create new or alter existing risks[.]*
> *(Weaver et al. 2017)*

Just as climate change is characterised by many uncertainties, so too are our efforts to mitigate and to adapt. Uncertainty can be "represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts)" (AR6 WGI 2021). When uncertainty is carefully quantified and communicated, it can deepen understandings and strengthen collaborations between experts, decision-makers, and other stakeholders. **Uncertainty communication can underpin more robust decisions,** decisions that make sense across the whole range of possible futures — not simply the future that is most likely, or the one that strikes the imagination most forcefully. Scientists who communicate uncertainty can also "demonstrate the trustworthiness of their science by showing a commitment to transparency" (Padilla et al. 2021).

Uncertainty is also significant in **interdisciplinary collaboration.** Experts in the social sciences and humanities sometimes criticise physical scientists rather sweepingly for "scientism," a dangerous conviction in their own objectivity and comprehensiveness of scientific knowledge; better communication of uncertainty can enhance interdisciplinary understanding of existing scientific practices of self-reflection and self-governance, and explore concrete opportunities for improvement.

Finally, uncertainty is important for **participatory decision-making,** since areas of uncertainty can be areas where parties with different interests or perspectives can find space for mutually acceptable solutions[1]. Even more broadly, by embracing uncertainty, we also remind ourselves that the future is still open, and can still be fundamentally shaped by the choices we make today.

Just as there is equivocation on the word *uncertainty,* so too is there equivocation on the word *risk.* What does the word ***risk*** mean to you? Does *risk* mean the same thing to those with whom you are communicating, or those whose lives you seek through your research, decision-making, and/or advocacy? How confident are you that you know these answers? This topic is explored in greater depth in the next subsection.

1 It has been argued that "most policymakers and political leaders are not keen to reduce uncertainties and overcome ambiguities — these are a source of political flexibility" (Geden 2018).

The headline message of AR6 WGI is crystal clear: we need to cut emissions rapidly, and we need to safely store more carbon.

THE IPCC AND THE AR6

How the global scientific authority on climate talks about uncertainty and risk

The Intergovernmental Panel on Climate Change (IPCC) is an intergovernmental body of the United Nations, which for over thirty years has worked to assess the drivers and impacts of climate change and to formulate policy options. It is the global authority on climate science. The IPCC does not exist to conduct original research, but rather to review and communicate the current state of global climate research. At the time of writing, the IPCC is reaching the end of its sixth assessment cycle (2015-2022), and in the midst of publishing its sixth major report (AR6). At present the first part of this report, *AR6 Working Group I* (AR WGI), focusing on the physical science basis, is available in a near-final form (AR6 WGI 2021).

The IPCC tends to carefully avoid normative language. It tries not to tell us what we 'should' do. Nonetheless, the headline message of AR6 WGI is crystal clear: **we need to cut emissions rapidly, and we need to safely store more carbon;** we need to do this while **shoring up against floods, droughts, heatwaves, wildfires, and many more impacts;** these impacts are happening already, and will get worse. While there have been many advances in science in recent years, the AR6 results are broadly consistent with every Assessment Report ever issued by the IPCC. The greatest difference is that time is more short than ever.

In order to mitigate and adapt to climate change, scientific expertise must feed transformations in policy and strategy at many different levels and scales throughout society. AR6 WGI continues to demonstrate the IPCC's commitment to **quantifying and communicating uncertainty** in order to support transparency in science and inform robust decision-making. AR6 WGI also includes greater emphasis on deep uncertainty, e.g. in domains such as tipping points and cascade risks (see Chapter 4). Furthermore, **risk assessment and risk management** are assumed in AR6 WGI as key frameworks that underpin global mitigation and adaptation efforts. See 'Some IPCC Definitions' for more information (in Chapter 5).

However, **more needs to be done to connect scientific understandings of uncertainty to risk-based decision-making** by policymakers, NGOs, industry, and other actors spanning diverse epistemological, cultural and social contexts. Many kinds of uncertainty such as model uncertainty and deep uncertainty are challenging to communicate and are typically not well-understood by decision-makers, even those who are risk-literate. Key concepts and methodologies differ across and within different domains of science and policy, creating the potential for information to be lost or misinterpreted.

Moreover, to those unfamiliar with climate science and policy, the emphasis on *uncertainty* and *risk* can be perplexing. As described in the last subsection, the everyday meanings of these words may be associated with reluctance to give advice or to take action. For a **lay audience,** references to uncertainty and risk may weaken the cognitive or emotional impact of climate information. **Participation may also be disincentivised**, if stakeholders are made to feel they must acquire technical understandings of uncertainty and risk, in order to legitimately engage with climate science or with the policy it informs.

BUDGETS, BOMBS, AND UNCERTAINTY ABOUT UNCERTAINTY: AN EXAMPLE OF CLIMATE RISK COMMUNICATION

Should we always talk about uncertainty? This mini-case study reveals there are arguments on both sides…

There are many "pragmatic and ethical reasons why communicating uncertainty is critical" (Padilla et al. 2021), and many organizations, including the IPCC, strongly advocate for communicating uncertainty about climate risk (IPCC WGI et al. 2021). There is also evidence that in many contexts uncertainty is currently not being appropriately communicated (van der Bles et al. 2019; Budescu, Por, and Broomell 2012). But are there times where we simply shouldn't talk about uncertainty, or at least not about all uncertainties? For example, Climate Action Unit suggest that attempts to communicate uncertainty all the way down the decision chain may have "hindered rather than helped policy formulation and decision making" (CAU 2021).

This Toolkit focuses on providing decision-makers with climate information, including uncertainty. However, that does not mean we think it appropriate always to fully convey all known uncertainties within any given communication. We recommend that the audience, the aim, the available resources, the opportunity cost, and other relevant factors should all be weighed up, and that **proportionate attempts should be made to convey uncertainty.**

There can be no rigid formula for determining what is proportionate. We also emphasise the strong ethical aspect to such judgments: **"proportionality" should never be used as an excuse to evade obligations to transparency.** However, two sections in the next chapter provide some support for making such judgments: the decision value chain, and the communicating for decision support vs. communicating for storytelling checklist. The decision value chain is there to invite you to think holistically about how beliefs about uncertainty propagate through networks of actors. The communicating for decision support vs. communicating for storytelling checklist recommends that communicators can use an "opt in vs. opt out" framework to uncertainty.

Let's now look at an example of what is arguably very effective climate risk communication, the Mercator Research Institute on Global Commons and Climate Change (MCC) Carbon Clock (www.mcc-berlin.net/en/research/co2-budget.html). This **miniature case study** brings out some of the complexity around deciding whether to include uncertainty information in the first place.

The **MCC Carbon Clock** is a simple animation of our world, as a spinning blue marble suspended in space, with white text superimposed. At the top the text gives a figure for CO2 emissions in tonnes per second, and at the bottom, CO2 budget[2] remaining, also in tonnes. In the top corners, you can toggle between a 1.5 degrees scenario and a 2.0 degrees scenario. In the middle is a set of **rapidly counting down figures**—years, months, days, hours, minutes, seconds—representing the estimated time till we exhaust our carbon budget.

The MCC Carbon Clock effectively conveys a sense of urgency. It takes a subject matter that may feel remote and complex, and it portrays it as a ticking time bomb. At the time of writing, under the 1.5 degree scenario, the Carbon Clock unequivocally tells its audience: we only have seven years and nine months left. Whereas climate science often speaks about the decades or centuries ahead, the Carbon Clock presents a far more relatable timescale. You probably have items of clothing that are older than seven years. A Facebook algorithm might decide to resurface a photograph of you and your friends seven years previously. How time flies: look at him, he looks just the same! The planet doesn't.

Although it aims to convey urgency, MCC Clock also seeks to be

…are there times where we simply shouldn't talk about uncertainty, or at least not about all uncertainties?

2 IPCC AR6 "suggests a remaining budget of about 420 GtCO2 for a two-thirds chance of limiting warming to 1.5°C, and of about 580 GtCO2 for an even chance (medium confidence). The remaining carbon budget is defined here as cumulative CO2 emissions from the start of 2018 until the time of net zero"(IPCC WGI et al. 2021)

transparent in its methodology. It describes the Clock as follows (emphasis in the original), prominently including a link to a key table in the AR6 WGI Summary for Policymakers (SPM) on which it is based:

> ***The MCC Carbon Clock shows how much CO2 can be released into the atmosphere to limit global warming to a maximum of 1.5°C and 2°C, respectively. With just a few clicks, you can compare the estimates for both temperature targets and see how much time is left in each scenario.***
>
> *As to the scientific basis of the carbon clock, we exclusively draw on data from the Intergovernmental Panel on Climate Change (IPCC), which represents the verified state of research. The IPCC last updated its estimate of the remaining carbon budget in summer 2021, with the presentation of the first part of its Sixth Assessment Report.*
>
> *According to a report (see here, table SMP.2), on the 1.5 degree Celsius target, the atmosphere can absorb, calculated from the beginning of 2020, no more than 400 gigatonnes (Gt) of CO2 if we are to stay below the 1.5°C threshold. Annual emissions of CO2—from burning fossil fuels, industrial processes and land-use change—are estimated to be 42.2 Gt per year, the equivalent of 1,337 tonnes per second. With emissions at a constant level, the budget would be expected to be used up in less than eight years from now. The budget for staying below the 2°C threshold, for its part, of 1,150 Gt, would be exhausted in about 25 years. The budgets are calculated in such a way that it is highly likely that the respective temperature target will be met, that is in two thirds of the climate scenarios examined.*

The MCC offers further qualifications and invitations to explore, including this note on uncertainties:

> *While the Carbon Clock appears to be a precise measurement of the time left to ensure climate protection, many uncertainty factors remain, such as different definitions of the 1.5°C target as well as different assumptions about the climate sensitivity, the actually attained degree of global warming, and the future development of other greenhouse gases. Furthermore, for the time being, the calculation is based on the assumption that annual emissions, after a dip in the pandemic year of 2020, will remain at the 2019 level from 2021 onwards.*

Nevertheless, the MCC Carbon Clock can be criticised in at least two ways. First, **the Clock relies on metaphors which can be misinterpreted.** For example, in movies featuring tense countdowns, the hero often snips the wire at the last second—and saves the day, with no harm done at all. Bombs in blockbusters do not gradually explode as their timers tick down. Insofar as these cultural associations may be active in the MCC Carbon Clock, the Clock could convey the sense that sudden, drastic action after about seven years' delay will be adequate to limit global warming to below 1.5 degrees. More subtly, the Clock may carry traces of the 'population time bomb' concept that has thankfully has now largely fallen out of favour. This involved an estimated planetary carrying capacity expressed in terms of global population. (Given different demographic dynamics globally, such anxiety around population growth often had racist undertones).

UNCERTAINTY REBRANDED?
IS THE TERM UNCERTAINTY FIT-FOR-PURPOSE?

THE TERM 'UNCERTAINTY' is deeply embedded in scientific discourse. But is it fit-for-purpose?

Whether or not it is, the term is deeply embedded in scientific discourse. It is unlikely to be going anywhere soon. Nevertheless, in light of the many misleading associations the term can give rise to among non-scientific audiences, it is worth exploring alternative vocabulary for conveying the same information, as a workaround for situations where extensive dialogue to inform such audiences is not feasible. In some contexts it may be more illuminating to use words like "reliability" to qualify forecasts. **But could we go even further in creating more accessible language to talk about scientific uncertainty?**

Furthermore, by bringing vividly to life the carbon budget framework, the MCC Carbon Clock exacerbates the inadequacies of the 'budget' analogy. Financial budgets are for spending; for some budget holders, failing to spend a budget by a particular date means needing to return the unspent funds, and even the threat of a reduced budget the following year. There may also be the implication that the carbon budget is 'what we can safely get away with,' an interpretation which is at odds with the literature on tipping points, for example. From paleoclimate records we know that tipping points exist — profound and irreversible changes in major Earth systems — and there are concerns that several tipping points may be approaching or have already been crossed (see Chapter 3). The less CO2 is emitted, the less likely we are to cross any tipping points which we have not already crossed. Reasoning about probabilities that are largely unknown, as in the case of tipping points, should be very different than contemplating if we want to avoid 1.5 degrees warming with a probability of 0.67 or 0.83.

Although it does seem to be implied that the Clock will be regularly updated to reflect the current rate of emissions, there is no detail about this prominently presented. It may therefore be misconstrued that the Clock is a model offering a *prediction,* i.e. that it *expects* emissions to remain constant because of a failure of mitigation (reducing energy demand, scaling up renewable sources, storing more carbon).

Second, the Clock presupposes the **collapsing or even suppression of uncertainty.** Carbon budget calculations depend on model projections and change as models evolve. The calculated budget is higher in the AR6 than it was in AR5. The budget will be recalculated in AR7 and may be higher or lower depending on new model runs, that will reflect changes in science that moves at a brisk pace, bringing new knowledge and reducing some aspects of uncertainty.

Saying that the budget runs out after seven years implies that the probability of meeting 1.5 degrees becomes zero. In fact, continuing emissions at the current level for twice as long (fourteen years), according to the same set of projections by the IPCC AR6 WGI, reduces the probability of meeting that target (from 67% to 17%), but does not make it impossible. Higher or lower reductions in non-CO2 emissions such as methane may also increase or decrease the values of the estimated carbon budgets by around 220 Gt (or give or take five years, at the current level of emissions).

Not disclosing that its calculations are based on explicitly probabilistic data, the Clock does not prominently mention, nor attempt to justify, basing its countdown on the IPCC table's 0.67 probability column. "Selecting a remaining carbon budget requires two normative choices as a minimum: the global warming level that is to be avoided, and the likelihood or chance with which this is achieved" (Rogelj 2021). The Clock does allow the user to set the level to either 1.5 or 2.0 degrees, but does not reveal anything about the likelihood or chance of achieving that limit, should net zero be reached before the estimated carbon budget is depleted.

The Clock illustrates some of the difficult trade-offs a communicator faces. By mobiling metaphors and by collapsing uncertainty — while also making efforts toward transparency — the Clock creates a sense of urgency without creating a sense of helplessness. But focusing exclusively on the relationship between current emission rates and current estimate carbon budgets creates opportunities for misunderstanding, and sidelines the systemic nature of climate risk — lower chance of staying under the selected target is associated with higher likelihood of extreme events, increasing chances of triggering tipping points, and unleashing cascades of socio-economic disruptions.

One can easily imagine an interactive tool which captures more uncertainty through customizable settings. The user might specify the probability at 0.17 and see the time remaining jump up. The user might set it at 0.83 and watch the time shrink to even less than seven years. Different scenarios for rate of CO2 emissions, and non-CO2 emissions, or for deployment of carbon sinks, could be overlaid. Playing with such a tool might shape an intuitive sense of the estimated carbon budgets and various sources of uncertainty. However, it would also be likely to undermine the urgency of the Clock's message. Global warming would be encountered as a relatively pliable phenomenon, something one can frighten oneself with for a thrill, and then push safely into the remote future with a few altered assumptions. In such interactions, the aggregates of many complex political, social, economic, and ecological processes would be modelled as though they were merely options available to the individual user. Could such a tool really be admired as 'more transparent' than the Clock, despite its greater fidelity to underlying assumptions?

Viewed from the perspective of speculative design, the MCC Carbon Clock is an impactful and worthwhile intervention. It demonstrates the challenges around how and whether to include uncertainty in climate communication when addressing different audiences. **Is the MCC Carbon Clock a proportionate attempt to convey uncertainty in climate risk communication**? We leave it to you to judge.

DESPITE SOME WELL-KNOWN DEFINITIONS, meanings and nuances vary from context to context.

There are no universally accepted definitions of risk and uncertainty, and hence no universally accepted distinction between the two. For the purposes of this Toolkit, we avoid fixed definitions of risk and uncertainty. However, as background, we will briefly outline **some important definitions of risk**, and indicate some of their relations to **uncertainty.**

In everyday speech, the word 'risk' often carries more negative connotations than 'uncertainty' does. This is formalised in the IPCC definition of risk as the potential for adverse consequences. More fully, risk is:

> [t]he potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and wellbeing, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. (Reisinger et al. 2020)

For the IPCC, the uncertainty implied by the word *potential* "does not necessarily have to be quantified," but it is recommended that authors "provide some sense of the nature and degree of uncertainty to allow a meaningful risk assessment and risk management responses to be undertaken" (Reisinger et al. 2020). See 'Some IPCC Definitions' for more on the IPCC's approach to risk and uncertainty.

In other contexts, however, 'risk' is the probability of an event occurring multiplied by the magnitude of its impact, regardless of whether this is positive or negative.

Within finance and some business contexts, a mention of 'risk' may conjure up the association of the risk-return spectrum (also known as the risk-reward spectrum). Very crudely, the higher the return that is sought, the more risk must be accepted. In this respect, the connotations of 'risk' can be exciting, and perhaps positive. An organization that is 'hungry for risk' may be trying out innovative activities, with a relatively high chance of failure, but also a relatively large pay-off. Risk in this usage is something that should be managed, but not all risks should be avoided or minimised. Sometimes risk will be deliberately incurred.

In yet another approach, 'risk' describes conditions where the probabilities of different outcomes are known, and 'uncertainty' (or 'ambiguity') describes conditions where this probability distribution is not known (Knight 1921). Again, the connotations of risk are not entirely negative. Roughly speaking, you don't know what is going to happen, but you know what *might* happen and how likely it is, so you can choose and prepare accordingly.

Universal convergence on a standard vocabulary of risk and uncertainty does not appear feasible, especially not on the urgent timescales required by climate action. Efforts to create greater consistency within a given organisation, project, partnership, network, sector, etc. may be of value. The IPCC definitions provide obvious reference points to which many different actors might align their usage (see also Chapter 5). However, in this respect the Toolkit's key recommendation is: understandings of risk and uncertainty may vary, and clarity should be sought through dialogue on a case-by-case basis.

AUTHOR CONTRIBUTIONS

Conceptualization: *JLW, MJB, PL and MW;* ***Research:*** *JLW, PL, MJB and MW;* ***Writing:*** *JLW, MJB and PL.*

REFERENCES

Climate Action Unit (CAU), 2021. 'Goodybag' of climate risk communication resources provided to participants in Climate Risk Summit (COP26 Universities Network), 1 October 2021.

Bles, Anne Marthe van der, Sander van der Linden, Alexandra L. J. Freeman, James Mitchell, Ana B. Galvao, Lisa Zaval, and David J. Spiegelhalter. 2019. 'Communicating Uncertainty about Facts, Numbers and Science'. *Royal Society Open Science* 6 (5): 181870. https://doi.org/10.1098/rsos.181870.

Boykoff, Maxwell T. 2008. 'Media and Scientific Communication: A Case of Climate Change'. *Geological Society, London, Special Publications* 305 (1): 11–18. https://doi.org/10.1144/SP305.3.

Budescu, David V, Han-Hui Por, and Stephen B Broomell. 2012. 'Effective Communication of Uncertainty in the IPCC Reports'. *Climatic Change* 113 (2): 181–200.

Garb, Yaakov, Simone Pulver, and Stacy D VanDeveer. 2008. 'Scenarios in Society, Society in Scenarios: Toward a Social Scientific Analysis of Storyline-Driven Environmental Modeling'. *Environmental Research Letters* 3 (4): 045015. https://doi.org/10.1088/1748-9326/3/4/045015.

Geden, Oliver. 2018. 'Politically Informed Advice for Climate Action'. *Nature Geoscience* 11 (6): 380–83. https://doi.org/10.1038/s41561-018-0143-3.

IPCC WGI, P. Zhai, A. Pirani, S. L. Connors, and WGI. 2021. 'IPCC, 2021: Summary for Policymakers'. *In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press.

Knight, Frank H. 1921. 'Risk, Uncertainty and Profit'. SSRN Scholarly Paper ID 1496192. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=1496192.

Liverman, D. G. E., C. P. G. Pereira, Brian Marker, and Geological Society of London, eds. 2008. *Communicating Environmental Geoscience.* Geological Society Special Publication, no. 305. London: Geological Society.

Masson-Delmotte, V., P. Zhai, A. Pirani, and S. L. Connors. 2021. 'Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change'. Cambridge University Press.

McCright, Aaron M., and Riley E. Dunlap. 2003. 'Defeating Kyoto: The Conservative Movement's Impact on U.S. Climate Change Policy'. *Social Problems* 50 (3): 348–73. https://doi.org/10.1525/sp.2003.50.3.348.

Morgan, M Granger. 2009. *Best Practice Approaches for Characterizing, Communicating and Incorporating Scientific Uncertainty in Climate Decision Making.* DIANE publishing.

Padilla, Lace, Sarah Dryhurst, Helia Hosseinpour, and Andrew Kruczkiewicz. 2021. 'Multiple Hazard Uncertainty Visualization Challenges and Paths Forward'. *Frontiers in Psychology* 12: 1993. https://doi.org/10.3389/fpsyg.2021.579207.

Reisinger, Andy, Mark Howden, Carolina Vera, et al. 2020. 'The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions'. Intergovernmental Panel on Climate Change.

'Remaining Carbon Budget - Mercator Research Institute on Global Commons and Climate Change (MCC)'. n.d. Accessed 8 October 2021. https://www.mcc-berlin.net/en/research/co2-budget.html.

Rogelj, Joeri. 2021. 'RealClimate: A Deep Dive into the IPCC's Updated Carbon Budget Numbers'. 2021. https://www.realclimate.org/index.php/archives/2021/08/a-deep-dive-into-the-ipccs-updated-carbon-budget-numbers/.

Russill, Chris, and Zoe Nyssa. 2009. 'The Tipping Point Trend in Climate Change Communication'. *Global Environmental Change* 19 (3): 336–44. https://doi.org/10.1016/j.gloenvcha.2009.04.001.

Supran, Geoffrey, and Naomi Oreskes. 2017. 'Assessing ExxonMobil's Climate Change Communications (1977–2014)'. *Environmental Research Letters* 12 (8): 084019. https://doi.org/10.1088/1748-9326/aa815f.

The Government Chief Scientific and Adviser. 2010. 'Guidelines on the Use of Scientific and Engineering Advice in Policy Making'. Department for Business, Innovation and Skills.

Weaver, C P, R H Moss, K L Ebi, P H Gleick, P C Stern, C Tebaldi, R S Wilson, and J L Arvai. 2017. 'Reframing Climate Change Assessments around Risk: Recommendations for the US National Climate Assessment'. *Environmental Research Letters* 12 (8): 080201. https://doi.org/10.1088/1748-9326/aa7494.

There needs to be structural changes in society that allow for easier access to participatory forms of communication.

Chapter 2 UNDERSTANDING AUDIENCES

WHO ARE THE EXPERTS, THE DECISION-MAKERS, AND THE STAKEHOLDERS?

For mainstreaming more participatory approaches, these concepts are indispensable. But who might they leave out?

This chapter shifts the focus to *who* is communicating with *whom*. As Evans et al. (2018) describe,

> *there needs to be structural changes in society that allow for easier access to participatory forms of communication that enable the ordinary citizens, governments and the business sector to discuss and debate issues pertaining to climate change. Climate change communication is central to effective and sustainable mainstreaming of climate change in development policies, mitigation and adaptation policies, collective behavioural change, and more specifically attitudes towards climate change mitigation for improved efforts towards reducing greenhouse gas emissions. (108)*

Within climate communication research, recipients of information are typically imagined as **decision-makers** and **stakeholders,** as well as **policymakers, the public, communities, audiences,** or **individuals.** Sometimes **scientists** and other **experts** are also characterised as recipients of climate information. More granular terms also sometimes appear.

These are all useful terms, and we use them in this Toolkit. Nonetheless these can also be slippery terms. So we open this chapter with some reflections on them. What might such terms presuppose? What do they invite us to imagine about these participants, which may not really be the case? For example, it has been suggested that "[w]hen thinking about the policy relevance of their work, climate researchers tend to address imagined rather than actual policymakers" (Geden 2018). Who concretely belongs to these categories? Who is capable of action that makes a communicator feel satisfied (rightly or wrongly) that they have consulted an expert, supported a decision-maker, engaged a stakeholder? And when participatory mechanisms are devised and implemented using them, do these really connect the lives that will be most affected?

The word *expert* is perhaps the most slippery of the entire list. Governments and organisations often aspire to evidence-based policy creation. This means **experts are routinely consulted for any number of problem-solving activities,** from

Subsections

i

government calls for evidence to consultancy toward bespoke solutions. Typically, expertise is taken into account in **informal or unstructured ways,** even though this type of practice is open to well-known cognitive frailties (Kahneman, Slovic, and Tversky 1982; Burgman 2016), both within the consulted experts and among those who are synthesising their evidence in unstructured or informal ways (Sutherland and Burgman 2015). **Structured approaches** to eliciting expert judgements have been shown to ameliorate many cognitive biases. A broad range of expertise also provides more robust results (Hanea et al. 2018; Burgman 2016).

A strong understanding of the uncertainties within a system is important in generating evidence for policy decisions that are relevant and reliable. **Many uncertainties can be classified and quantified. Experts also develop intuitive understandings of uncertainties.** Relative to a 'well-calibrated' expert, an overconfident expert will tend to underestimate the uncertainties and an underconfident expert will overestimate the uncertainties. Experts become well-calibrated by having frequent feedback on the accuracy of their assessments, which is why surgeons are generally better calibrated than General Practitioners; in the latter case there are many reasons why a patient may not return besides the prescribed treatment being effective.

At what point does someone start being treated as an expert, and by whom? Expertise is often defined by credentials, but highly regarded experts can be no better than so-called novice experts in some situations. **Not all relevant expertise is accompanied by credentials.** Trained scientists are also members of communities, and some citizen groups can develop considerable scientific expertise (Oakden et al. 2021). Furthermore, the expertise of those with lived experience is increasingly being recognised, particularly with regard to social ills and impacts (Gallegos and Chilton 2019). Burgman (2016) recommends seeking broad based expertise and taking measures to avoid groupthink: "Ideally, expert groups should be as diverse as possible, and systems for engagement should encourage people to listen and integrate information from as many sources as possible, and to explore competing explanations. The basic idea is that groups made up of individuals with diverse experiences, backgrounds and contexts will draw on different sources of information, form independent initial estimates and avoid shared professional myopia. They will not anchor on common points nor be motivated by common personal goals."

There are well-established ethical rationales for including the voices of communities in policy formation. This expertise also becomes vital at the point where policy implementation relies on the actions and choices of community members. These community members are experts in their own lives and the lived experiences of their environments. Successful policy implementation needs to mesh with the needs, aspirations and worldviews of those who will either ensure its success, or will game the system to meet their needs, thus undermining policy implementation.

There is not extensive literature on the structured elicitation of lived experience. However relevant insights are available under rubrics such as: stakeholder analysis and engagement, public engagement and citizen participation, participatory policy-making, participatory design, municipalism, participatory democracy, direct democracy, radical democracy. We highlight five points:

- A 'campaigning' mentality risks alienating people. **Genuinely participatory processes allow for emergent scope.** Taking time to understand the motivations and priorities of members of the community has been fruitful in aligning aspirations, for example harnessing rewilding to support tackling rural poverty in the UK.
- As is often the case in climate risk communication, **interdisciplinary collaboration** can yield better results. For example, the Affric Highlands Scheme employed a psychologist alongside conservationists for a rewilding scheme (Weston 2021).
- **More vulnerable groups and individuals may also be those less able to access participatory processes.** Participatory processes can replicate historical patterns of exclusion (McNulty 2019). Practical support should be offered, and more research is needed into eliciting community expertise, taking into account e.g. interactions between cognitive biases, asymmetries in lived experience, payoff structures and strategic interaction, power discrepancies, and cultural and psychological factors.
- **Stakeholder engagement is most effective when stakeholders acquire real influence on outcomes.** This may include joint projects and/or transfer of appropriate decision-making powers and resources to stakeholders; however where this is less than feasible, meaningful influence can still be achieved by 'full stack' stakeholder engagement integrated into the governance, strategy, and operations of relevant entities.

Community members are experts in their own lives and the lived experiences of their environments.

- **International comparative approaches** are invaluable; for example, other countries can learn from the experiences of several Latin American countries which in recent years have taken measures aimed at strengthening participatory governance.

A second slippery term is ***decision-maker.*** It is widely used in decision theory, and it reflects the discipline's aspiration to be relevant to many different contexts. A decision-maker may be an actual person such as a senior executive, an elected official or a civil servant. Or a decision-maker may be an organization or some other entity. **But despite this broadness, the term *decision-maker* may sometimes lead to overly narrow thinking.** For example, we may slide into thinking of a decision-maker as necessarily someone who wields significant political, social, or economic power. But as just touched on, many other categories of actors are constantly making decisions pertinent to the success, and the moral significance, of climate policy.

Furthermore, expecting to find a decision-maker may sometimes close down other possibilities, where agency to drive change does not map neatly onto any individual or organizational unit. Climate risk invites unprecedented depth and speed of organizational and cultural change, and so **the decisions that need to be made may be unlike any decisions made in the past.** To date, studies of decision-making under uncertainty "rarely speak to the organizational and political context in which triggers for evaluative action occur" (Sowell 2019). Within a given management system, the decisions that drive mitigation and adaptation *may* clearly sit with specific roles. But the network of actors best placed to recognise, legitimate, and enact appropriate action may also cut across disparate roles, areas of responsibility, forms of formal and informal power, and even organisations and sectors. Critical threshold may need to be reached where a decision becomes available to collectives that are not available to individuals. In communicating climate information to drive mitigation and resilience, it may not always be appropriate to focus exclusively on the decision-makers who most obviously have their hands on the levers. Especially where such decision-makers prove resistive, it is important to stay open-minded about the nature and origin of positive change within organizations and sectors.

Similarly, the term ***stakeholder*** reflects stakeholder theory and is widely used across government, industry, the third sector and other contexts. Typically a stakeholder is defined as anybody who can potentially impact or be impacted by a given policy, project, product, or other entity of interest. However, where climate policy is concerned, **the highly interconnected nature of climate risk means that it is difficult, and probably undesirable, to completely exclude anybody from stakeholder status.** Furthermore, taking a stakeholder analysis and engagement perspective can sometimes obscure the differences between different concrete individuals belonging to the same stakeholder category, especially when some individuals are more vocal than others. In this way, individuals may be permitted to speak on behalf of those whom they have no legitimate right to represent. Finally, terms like *public, community,* and (to a lesser extent) *audience* and *individuals,* can be used to conflate the membership of a population with whichever subset is most available for dialogue.

These concepts are imperfect but useful. Awareness of their limitations will be helpful in creating processes which are truly participatory, not only in name only. Decision-making in climate risk policy relies on a 'decision value chain' or cascade of information between those who undertake cutting-edge research, through policy design, to those whose everyday lives are affected by the resulting policies. The modes of communication which make this a successful enterprise need to take into account the language, culture, expectations and motivations of the actors involved (Yusha'u and Servaes 2021). Scenarios and storytelling can play a significant role in how information (including uncertainty) is lost, preserved, added, transformed, and/or re-prioritised as it moves through the chain. Ideally participants in this process will also regularly reflect on the limitations of their participatory concepts and mechanisms, draw lessons from historical and international counterparts, and seek options for improvement. We also recommend that where possible, narrower and more concrete terminology should be used to identify participants in dialogues.

THE DECISION VALUE CHAIN

The decision value chain is one way of thinking about evidence-based (or at least evidence-informed) policymaking

The last section indicated the complexity of communicating climate risk. But we also need frameworks for organizing this complexity, even if they mean simplifying things more than we would ideally like. Ultimately, **closer engagement between analytical and policy communities will allow for a more critical interrogation of how decision support is brought into decision-making and policy design** (Sutherland and Burgman 2015). To highlight the issues that need to be considered in the communication of climate risk, we offer the stylised 'decision value chain' (discussed in this section) as well as the 'storytelling vs. decision support' checklist (in the next section).

Communicating climate risk is an integral component to translating decision support into policy, creating traction with relevant audiences, and gaining societal buy-in. However, the extent of research in this area is limited and there is fragmentation amongst different ontologies. The concept of "policy paradigms" (Burns, Calvo, and Carson 2009) highlights that rather than a clear-cut distinction between analytical and decision-making functions in policy design, divergent interests, agendas and values shape policymaking. The role of co-production and boundary work around science and policy in conferring legitimacy on analytical policy inputs is well-documented (Beck and Mahony 2018). However, beyond the politics of climate policy, the psychology as to how decisions regarding policy are actually formulated, the role of detailed analysis and expertise in the process of policy development, and its role in final policy output and decision-making, are not well-understood (Conway and Gore 2019).

What is known is that heuristics and biases are prevalent, particularly around issues involving deep uncertainty. Moreover, dialogue between analytical and policymaking communities is marked by very different cultures, processes and lexica (Kahneman and Klein 2009; Kahneman, Slovic, and Tversky 1982; G. A. Klein 2013; Kahneman and Klein 2009; G. Klein et al. 2007). With so much translation going on, there are many opportunities for useful information to get lost in translation. Dubois et al. (2018) divide the flow from analysis through policy into five phases: **pre-existing knowledge, projection, impact assessment, adaptation strategy, and adaptation plan.** Using content analysis of relevant documents (focusing on uncertainty communication and visualizations), they confirm that "the richness and completeness of the information are reduced" as it moves along the chain.

Nevertheless we stress that the participation of multiple actors in policy formation is also an advantage, with the **potential to integrate plural forms of expertise** and to generate greater legitimacy and buy-in.

Below a circular 'decision value chain' is suggested as a way to schematise the flow of information, while thinking more inclusively about who applies expertise, and where important decisions occur. The decision value chain shows the pattern of information flow from discovery and foresight, to synthesis and insight, to design, to implementation, to impact, then informing later discovery and foresight.

Value in the form of expertise can be introduced all the way around the chain. We would not want to live in a world where scientists made all the decisions. Policymakers have experience and insight about policy

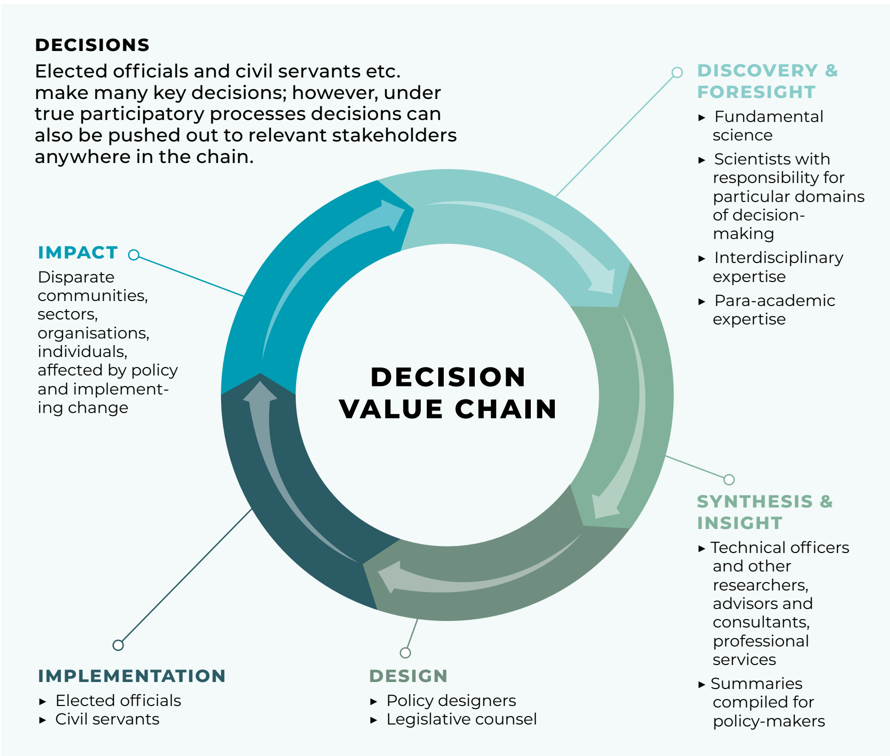


Figure 1. Decision value chain

levers and trends; communities and individuals have a wealth of lived experience and tacit knowledge, and so on. While climate information may degrade in certain respects as it transfers from one participant to the next, it can also be enriched by new expertise, and be subjected to diverse forms of scrutiny and validation.

Just as expertise can be added all the way around the chain, so too can **decisions occur all the way around the chain.** Many key decisions become 'finalised' in the diagram's lower left zone by policy designers, parliamentary counsel, politicians and civil servants (or local equivalents). However, decisions can also be made by other participants, either because there are formal participatory mechanisms to delegate decision-making power, or because participants find the power to take action in ways that are informal or unauthorised.

The sequence of the chain indicates only the broad direction of travel within a network where decision value can potentially also move between any of the participants (including 'upstream' or 'shortcut across' the central hub). Participants may join or leave the chain halfway through the process; the form of connection between them may alter (in terms of bandwidth, responsibilities, etc.); these transformations may be the result of internal evolutionary dynamics, external shocks, and/or deliberate redesign and reconfiguration. Indeed, exploring different connective configurations, giving careful regard to evidence from international comparative democratic politics, is key to strengthening participatory climate policy formation.

UNCERTAINTY AND THE DECISION VALUE CHAIN: EIGHT RECOMMENDATIONS

Dubois et al., focusing on **uncertainty,** make several recommendations for improving the transfer of uncertainty information from science into policy. These include:

1. Encouraging the actors involved in different phases to **work in parallel,** rather than sequentially.
2. Adopting more **participatory approaches,** such as **empowering societal stakeholders** in methodological choices.
3. **Adopting more consistent conventions** for uncertainty representation and the use of visualisations, by:
   a. developing best practice guidelines at the national, local, and/or sector-specific level;
   b. conducting more research into visualisation tools, since the drivers of their efficacy across different contexts are still not well-understood.
4. **Training end users to understand scientists better** (e.g. basics of climatology and decision theory).
5. **Training scientists to understand end users better** (e.g. communication, social and political context of climate policy).

These recommendations appear credible, and we broadly endorse them. This Toolkit may be seen as a small contribution toward the fourth and especially fifth recommendations. We propose three further recommendations to improve the flow of decision value.

6. **Placing participants outside their usual roles** to gain visibility and experience, both upstream and downstream. For example, funding more extended collaborations between scientists, technical officers, policy designers, communications experts from the social sciences (including experts in comparative democratic politics) and from the arts and humanities, and societal stakeholders. Such collaborations can embed a communications orientation from the very start (rather than as an afterthought), can contribute to forming new classes of multi-disciplinary experts, and can improve understandings and transparency on the political and ethical choices that decarbonisation entails. Placements could also contribute to international peer-to-peer collaboration and learning.
7. **Addressing substantive barriers and incentives to participation,** including socioeconomic inequality, linguistic and cultural factors, geographic distance, health and wellbeing inequalities, and traditional patterns of exclusion around gender, class, race, disability, and wealth. Measures to improve the participation of hard-to-reach groups should continue to be implemented, but the need for rapid action also means there may not always be time to wait for the results of such outreach. Where timescales dictate, innovative methods of eliciting community expertise and integrating it into the decision value chain should be explored, alongside more standard outreach.
8. **Multiplying channels for participation and cooperation** via which decision value may transfer among different participants, e.g. (a) public- and community-oriented institutions such as citizens assemblies, democratic engagement platforms, mandated participatory budgeting processes, national council

systems, citizens enquiries, participatory planning and investment processes in local government, village committees, neighbourhood and employee councils, habitat and biodiversity conservation plans, trade unions, and innovative public fora based on models used in issue-specific strategic engagement, as well as (b) more targeted channels between specific segments of the value chain. We recommend bold and exploratory research into the range of connectivity mechanisms, especially around inclusion, equity, and translations of uncertainty and risk information across science, policy, and wider deliberative and participatory contexts.

At the same time, caution is also necessary. In following any of the eight recommendations above, we should be mindful of the following caveats.

- What is **timescale** appropriate? Is it necessary to find a more rapid workaround, perhaps in parallel with longer term structural change?
- What are the **opportunity costs**? Collaboration, translation, and working outside one's niche takes time, energy, and resources. Take the example of **training** (recommendations 4 and 5). What are the opportunity costs of training end users to think more like scientists, and/or scientists to think more like end users? If more time is devoted to training, is less time devoted to other activities? If more skills are added to a role, does it narrow the pool of potential candidates who can feasibly fill that role? If new content is added to a curriculum, what content is dislodged or de-emphasised? How does training also increase the influence of educators within the decision value chain — another set of actors with personal biases who may likewise adapt information, introduce new information, and summarise and synthesise information?

DECISION ANALYSIS: *AN INTERDISCIPLINARY FIELD, ROOTED IN ECONOMICS AND STATISTICS*

IN THIS TOOLKIT, we frequently mention decisions, decision-making, and uncertainty. When we do so, we are speaking principally from within the field of decision analysis. In other words, we are particularly interested in how decisions can be formally modelled, for the purposes of evaluating alternative actions, and how competency in decision-making can be assessed. Decision analysis has its roots in economics and statistics. While it remains closely tied to these disciplines today, it is also an increasingly open and interdisciplinary field, drawing insight from across the sciences, social sciences, and arts and humanities. This rich interdisciplinarity is all the more important when we consider communication, a topic which necessarily includes themes such as authority, trust, interpretation, persuasion, and power.

Even mentioning uncertainty in the context of climate runs the risk, in some contexts, of undermining the confidence in robust scientific findings. Nonetheless, the IPCC has championed transparent approaches to communication of uncertainties, and strived to reflect degrees of confidence in discussing specific elements of assessments of climate risk both in text, graphically, and most recently in its interactive online Atlas. The confidence varies from virtually certain 'facts', that humans are responsible for climate change on a global scale, to high levels of uncertainty regarding specific regional future climate risks, tipping points or cascading risks.

- Participatory approaches should be accompanied by careful attention to **how stakeholders are identified and mapped,** and who is empowered or disempowered by a given participatory process. Stakeholders include stakeholders who may be impacted by a policy, stakeholders who may influence its outcomes, stakeholders of potential alternative policies, stakeholders with whom there are existing or potential tensions, and stakeholders engaged to broaden diversity of perspectives, backgrounds, and lived experience. Other stakeholders include future generations and nonhuman actors. Where stakeholders have influence on one another this influence, including its type, should ideally be taken into account. **Ultimately where climate is concerned, there is nobody who is *not* a stakeholder.** See also above, the section 'Who are the experts, the decision-makers, and the stakeholders?' in this chapter.
- How might the measure be gamed, particularly by those with relatively extensive financial and / or ICT resources?

STORYTELLING VS. DECISION SUPPORT: A CHECKLIST

Popper (2019) draws a broad distinction between two cultures: the numerate, reductionist analytical community, rooted in deductive logic, and the culture of policy, which is more narrative based and framed in the logic of abductive reasoning. Following this distinction, we can think about climate risk communications in at least two ways. Climate risk can **support decisions.** At the same time, they can **tell stories,** transforming attitudes and behaviour in ways that are difficult to directly measure.

For the communicator, decision support and storytelling are not rigid and mutually exclusive categories. Instead they serve as 'lenses' through which you can reflect on and improve your practice. In particular, they can help you to decide how to present uncertainty. When deciding how to do this, consider your purpose and your intended (and unintended) audiences. You can start by answering the following ten questions.

1. Who is this communication for, e.g. what are their background, motivations, needs?
2. Who else might encounter this communication?
3. What are your criteria for successful communication?
4. Are there alternative ways the communication could make a positive impact?
5. Do you expect to receive information to evaluate its success? If so, how?
6. What concepts, frameworks, and methodologies (if any) could be used to talk about uncertainty, and how familiar do you expect your audience to be with these?
7. Can you give specific examples of behaviours, decisions, skills, and/or values you want to influence?
8. Can you give specific examples of how including or excluding uncertainty information (e.g. model uncertainty) could alter the results of your communication?
9. How do your recipients perceive you, and what do they expect from you (if anything) prior to the communication?
10. Do you think these perceptions may change, and if so how?

Remember, these questions are not designed to cover everything you might want to consider as a communicator. They are designed to serve a specific purpose: to help you think about your communication as decision support and as storytelling, and to **reflect on how to frame uncertainty in your communications,** to ensure it is understood accurately and constructively.

Once you have answered these questions, read through the two archetypes below and relate them to your situation. If you wish, you can assign each bolded statement a value between one and ten (1: strongly disagree, 5: neither agree nor disagree; 10: strongly agree).

In reality, **communications don't neatly fit into either archetype,** but always combine aspects of both. For example, scenarios play a prominent role in communication for decision support. Furthermore, even when you are not deliberately using scenario-based methods, your information will still 'tell a story' to the decision-makers who interpret it. On the flip side, any compelling narrative has the potential to influence our future decision-making.

COMMUNICATING *TO TELL A STORY*

1) YOU ARE ENGAGING WITH AN AUDIENCE.

- You may already know who your audience are. Or you may be telling a story in hope of finding an audience.
- You may reach an audience who are mostly similar to one another. Or you may reach an audience with diverse interests, values, perspectives, motives, levels of engagement and agency, and so on.
- If you do reach a mixed audience, you may or may not have the chance to tailor your communications to each segment.

2) YOUR AUDIENCE MAY HAVE MULTIPLE DIFFERENT MOTIVES FOR ENGAGING YOU, SUCH AS:

- acquiring new skills, knowledge, and/or values;
- testing their existing skills, knowledge, and/or values;
- fulfilling their curiosity;
- entertaining themselves;
- acquiring evidence to progress agendas;
- fulfilling obligations to engage.

3) YOU MAY HAVE MULTIPLE MOTIVES FOR ENGAGING YOUR AUDIENCE, SUCH AS:

- raising awareness; seeking alternative perspectives to enhance your expertise;
- encouraging your audience to reassess the importance of the subject matter to themselves;
- encouraging your audience to change behaviours;
- confronting misinformation or common misconceptions about the subject matter;
- improving your audience's literacy for future communications about the subject matter;
- equipping your audience with the conceptual and emotional resources
- to engage with the subject matter in the future;
- giving your audience insights to pass on to their own audiences;
- trying out metaphors and analogies;
- supporting decision-making.

COMMUNICATING *TO SUPPORT DECISIONS*

1) YOU ARE ENGAGING WITH A DECISION-MAKER / DECISION-MAKERS.

- It is mostly clear who is in the decision-maker role. For example, this could be a particular person, or a decision-making process involving various stakeholders.

2) THEY ARE ENGAGING WITH YOU AS AN EXPERT.

- The decision-maker recognises you as an authority in the subject matter and is actively seeking your advice.
- The decision-maker may be relying on you exclusively. Or the decision-maker may be receiving input from other experts in the same domains and/or in different domains, and/or from other stakeholders.

3) THERE ARE MOSTLY GOOD CONDITIONS FOR ANALYSIS, COMMUNICATION, AND DECISION-MAKING.

- For example, it is clear what kinds of decision are relevant. This may be a specific decision, or all the decisions pertaining to a particular area of responsibility or a particular policy aim.
- Experts and decision-makers have enough time and capacity to engage thoroughly in the process.
- There is typically a shared commitment to making the 'best' decision.
- The criteria for evaluating which decision is the best may be fixed in advance. Or such criteria may be transformed or developed in the course of co-production.

COMMUNICATING *TO TELL A STORY*	**COMMUNICATING** *TO SUPPORT DECISIONS*
4) IT MAY OR MAY NOT BE CLEAR WHICH OF YOUR MOTIVATIONS, AND/ OR WHICH OF YOUR AUDIENCE'S MOTIVATIONS, MATTER THE MOST. » You may or may not have clear criteria for what counts as 'successful' communication. » Accountability is mostly informal.	**4) YOUR ENGAGEMENT MAY BE EMBEDDED IN BOTH INFORMAL AND FORMAL ACCOUNTABILITY AND/ OR REPORTING STRUCTURES.**
5) YOU LEAN TOWARD AN "OPT-IN" APPROACH TO UNCERTAINTY. » In this context, you think transparency is best served by clear, straightforward messaging and opportunities for dialogue and further questioning. » There are clear paths your audience can follow to deepen their understanding in various ways, including engaging in detail with uncertainty information, if they elect to do so.	**5) YOU LEAN TOWARD AN "OPT-OUT" APPROACH TO UNCERTAINTY.** » You have integrated uncertainty thoroughly and clearly throughout your communication. » Decision-makers are given support and encouragement to integrate uncertainty into their decision-making.

AUTHOR CONTRIBUTIONS

Conceptualization: *JLW, MJB, PL and MW;* ***Research:*** *JLW, PL, MJB and MW;* ***Writing:*** *JLW, MJB and PL.*

REFERENCES

Beck, Silke, and Martin Mahony. 2018. 'The IPCC and the New Map of Science and Politics'. *WIREs Climate Change* 9 (6). https://doi.org/10.1002/wcc.547.

Burgman, Mark A. 2016. *Trusting Judgements: How to Get the Best out of Experts*. Cambridge, United Kingdom: Cambridge University Press.

Burns, Tom R., Dolores Calvo, and Marcus Carson, eds. 2009. *Paradigms in Public Policy: Theory and Practice of Paradigm Shifts in the EU.* Frankfurt am Main ; New York: Peter Lang.

Conway, Gareth E., and Julie Gore. 2019. 'Framing and Translating Expertise for Government'. In *The Oxford Handbook of Expertise,* by Gareth E. Conway and Julie Gore, edited by Paul Ward, Jan Maarten Schraagen, Julie Gore, and Emilie M. Roth, 1131–52. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198795872.013.49.

Dubois, Ghislain, Femke Stoverinck, and Bas Amelung. 2018. 'Communicating Climate Information: Traveling Through the Decision-Making Process'. In *Communicating Climate Change Information for Decision-Making,* edited by Silvia Serrao-Neumann, Anne Coudrain, and Liese Coulter, 119–37. Springer Climate. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-74669-2_9.

Evans, Henri-Count, Lauren Dyll, and Ruth Teer-Tomaselli. 2018. 'Communicating Climate Change: Theories and Perspectives'. In *Handbook of Climate Change Communication: Vol. 1,* edited by Walter Leal Filho, Evangelos Manolas, Anabela Marisa Azul, Ulisses M. Azeiteiro, and Henry McGhie, 107–22. Climate Change Management. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-69838-0_7.

Gallegos, Danielle, and Mariana Chilton. 2019. 'Re-Evaluating Expertise: Principles for Food and Nutrition Security Research, Advocacy and Solutions in High-Income Countries'. *International Journal of Environmental Research and Public Health* 16 (4): 561. https://doi.org/10.3390/ijerph16040561.

Geden, Oliver. 2018. 'Politically Informed Advice for Climate Action'. *Nature Geoscience* 11 (6): 380–83. https://doi.org/10.1038/s41561-018-0143-3.

Hanea, A.M., M.F. McBride, M.A. Burgman, and B.C. Wintle. 2018. 'Classical Meets Modern in the IDEA Protocol for Structured Expert Judgement'. *Journal of Risk Research* 21 (4): 417–33. https://doi.org/10.1080/13669877.2016.1215346.

Kahneman, Daniel, and Gary Klein. 2009. 'Conditions for Intuitive Expertise: A Failure to Disagree.' *American Psychologist* 64 (6): 515–26. https://doi.org/10.1037/a0016755.

Kahneman, Daniel, Paul Slovic, and Amos Tversky. 1982. *Judgment under Uncertainty : Heuristics and Biases / Edited by Daniel Kahneman, Paul Slovic, Amos Tversky.* Cambridge: Cambridge : Cambridge University Press.

Klein, Gary A. 2013. *Seeing What Others Don't: The Remarkable Ways We Gain Insights.* First edition. New York: PublicAffairs.

Klein, Gary, Jennifer K. Phillips, Erica L. Rall, and Deborah A. Peluso. 2007. 'A Data-Frame Theory of Sensemaking.' In *Expertise out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision Making,* 113–55. Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

McNulty, Stephanie L. 2019. *Democracy from above?: The Unfulfilled Promise of Nationally Mandated Participatory Reforms.*

Oakden, Libby, Gemma Bridge, Beth Armstrong, Christian Reynolds, Changqiong Wang, Luca Panzone, Ximena Schmidt Rivera, et al. 2021. 'The Importance of Citizen Scientists in the Move Towards Sustainable Diets and a Sustainable Food System'. *Frontiers in Sustainable Food Systems* 5 (September): 596594. https://doi.org/10.3389/fsufs.2021.596594.

Popper, Steven W. 2019. 'Reflections: DMDU and Public Policy for Uncertain Times'. In *Decision Making under Deep Uncertainty,* edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper, 375–92. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-05252-2_16.

Sowell, Jesse. 2019. 'A Conceptual Model of Planned Adaptation'. In *Decision Making under Deep Uncertainty: From Theory to Practice,* edited by Vincent A. W. J. Marchau, Warren E. Walker, Pieter J. T. M. Bloemen, and Steven W. Popper. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-05252-2.

Sutherland, William J., and Mark Burgman. 2015. 'Policy Advice: Use Experts Wisely'. *Nature* 526 (7573): 317–18. https://doi.org/10.1038/526317a.

Weston, Phoebe. 2021. 'Planting a Vision: Why the Secret to Rewilding Success Is about People, Not Trees'. *The Guardian,* 27 September 2021, sec. Environment. https://www.theguardian.com/environment/2021/sep/27/planting-a-vision-why-the-secret-to-rewilding-success-is-about-people-not-trees-aoe.

Yusha'u, Muhammad Jameel, and Jan Servaes, eds. 2021. *The Palgrave Handbook of International Communication and Sustainable Development.* Cham, Switzerland: Palgrave Macmillan. https://doi.org/10.1007/978-3-030-69770-9.

'Look at the world around you,' Gladwell argues. 'It may seem like an immovable, implacable place. It is not. With the slightest push — in just the right place — it can be tipped.' (Gladwell 2015)

Chapter 3 COMMUNICATING *around* TIPPING POINTS

WHAT ARE TIPPING POINTS? AND HOW SHOULD WE COMMUNICATE ABOUT THEM?

> *[R]egardless of whether it is being communicated to policy makers or the public […] [u]sing scientific terminology, such as 'tipping points' and 'feed-back loops', is complex and can be difficult to grasp. When climate change is presented in the form of predictions and graphs it can also appear inaccessible, as too big, or disengaging, when not paired with solutions.*
> *(Huxley 2018).*

In this chapter we examine some of the challenges of communicating around **tipping points,** an area often characterised by **deep uncertainty.** Googling 'tipping point' in October 2021, we found that our top results were all about the British game show Tipping Point. Could we take this as one small indication that the science about tipping points has not yet penetrated popular discourse to the extent that we would wish?

A tipping point is a critical threshold beyond which a system reorganises, often abruptly and/or irreversibly. For example, over two million cubic kilometres of ice locked in the Western Antarctic Ice Sheet could collapse and pour into the ocean, causing sea levels to soar by three metres or more. The IPCC believes with medium confidence that it won't collapse this century; Chris Rapley, formerly Director of the British Antarctic Survey, has already said of the Western Antarctic Ice Sheet, "I would argue that this is now an awakened giant" (Rapley et al. 2006).

The probability of triggering a tipping point may be low (or difficult or impossible to quantify) at a given level of global warming, yet with consequences that are catastrophic and far-reaching. Some (not all) potential tipping points of concern include:

1. Collapse of the Western Antarctic Ice Sheet and/or other major ice formations (Arctic sea ice, Greenland ice sheet, Wilkes basin in East Antarctica), leading to much higher sea level rises.

Subsections

i

A tipping point is a critical threshold beyond which a system reorganises, often abruptly and/or irreversibly.

2. Permafrost thaw releasing methane, a powerful greenhouse gas, accelerating global warming.[1]
3. Massive loss of forests including Boreal forests[2] and Amazon rainforest[3] — meaning not only profound loss of biodiversity, but also the release of vast amounts of extra greenhouse gases, accelerating global warming.
4. Mass extinctions of animals, plants and other life forms unable to adapt to rapid climate change (Barnosky et al. 2011).
5. A shutdown of a major system of ocean currents (AMOC) that conveys heat from the tropics into the Northern Hemisphere.
6. Increase in El Niño–Southern Oscillation (ENSO) leading to drought in South East Asia[4] (Lenton et al. 2008).
7. West African Monsoon shift and potential recurring droughts across Mauritania, Senegal, Burkina Faso, Mali, and Niger.
8. Greening of the Sahara leading to greater local biodiversity.[5]
9. Indian Monsoon shift and potential recurring droughts on the Indian subcontinent.
10. More generally, tipping points can occur at regional rather than global levels, and have severe local impacts.
11. Tipping points can also affect marine ecosystems; for example, abrupt West Tropical Indian Oceanic Bloom, caused by a sudden increase in deep water upwelling that brings nutrients to the upper layers of the ocean, leading to gains in productivity from microorganisms to fisheries (Drijfhout et al. 2015).
12. Disappearance of coral reefs, leading to the loss of biodiversity, habitats, greater coastal erosion as well as cultural and economic losses.

Many of these tipping points have implications for **food harvests** and for **extreme weather** such as floods, storms, and wildfires. Other effects could include disintegration of systems that produce and distribute goods and services; and destruction of infrastructures which supply people with energy, food, water, light, heating; infrastructures which store data and carry voices and images around the world; infrastructures which dispose safely of waste and sewage; they could include failures of healthcare, social care, security, finance, housing, transport, education, emergency services; and the unravelling of societies as homes, jobs, and communities are lost, populations are scattered, governance of organisations and institutions weakens or collapses, and wars and conflicts intensify and spread. For those who have been fortunate enough to live under conditions of relative peace, tipping points represent the tearing apart of our taken-for-granted world.[6]

---

1 IPCC AR6 WGI notes that it is "*very unlikely* that gas clathrates (mostly methane) in deeper terrestrial permafrost and subsea clathrates will lead to a detectable departure from the emissions trajectory during this century".

2 "Boreal forest dieback is not expected to change the atmospheric CO2 concentration substantially because forest loss at the south is partly compensated by (i) temperate forest invasion into the previous boreal area and (ii) boreal forest gain at the north (Friend et al., 2014; Kicklighter et al., 2014; Schaphoff et al., 2016) (medium confidence)" (IPCC AR6 WGI).

3 IPCC AR6 WGI puts an upper limit of how much CO2 can be released by Amazon forest dieback as 0.5ppm per year (the current concentration is 442 ppm): "This implies an upper limit to the release of tropical land carbon of <200 PgC over the 21st century (assuming tropical warming of <4oC, and no CO2-fertilisation), which translates to dCO2/dt < 0.5 ppm yr-1 (IPCC AR6 WGI)."

4 "Given also that past climate changes have been accompanied by changes in ENSO, we differ from IPCC and consider there to be a significant probability of a future increase in ENSO amplitude. The required warming can be accessed this century with the transition happening within a millennium, but the existence and location of any threshold is particularly uncertain" (Lenton et al. 2008).

5 "Such greening of the Sahara/Sahel is a rare example of a beneficial potential tipping element."(Lenton et al. 2008)

6 Human history is replete with evidence that dramatic shifts in societies can happen in response to relatively small environmental drivers, an idea popularised by Jared Diamond in Collapse: How Societies Choose to Fail or Survive (Diamond 2011). But social tipping points are also discussed in a positive context: Otto et al. (2020) describe the tipping points they identified that if triggered would enable a radical decarbonisation of society that is currently required.

Many of these tipping points have implications for food harvests and for extreme weather such as floods, storms, and wildfires.

Many tipping points also have implications for the **feasibility of achieving net zero GHG emissions.** For example, shrinking of the Amazon rainforest and Boreal forest through drying, forest fires, pests, habitat loss and other factors, could result in large, swift releases of GHGs.[7] Likewise, carbon release (including methane release) from permafrost thaw may mean that remaining carbon "budgets" are smaller than we think (Comyn-Platt et al. 2018).[8] The range of socioeconomic risks mentioned in the previous paragraph also could deplete our capacity to mitigate GHGs, e.g. climate technologies may be more difficult to develop and deploy at scale in the midst of mass movements of populations, rolling pandemics, famines, wars, and so on. In this sense tipping points are closely associated with dynamics that have been variously imagined as domino effects, cascade risks, feedback loops, vicious circles, cliff edges, points of no return, situations spiralling out of control, runaway processes, and so on.

Now let's take a step back, and focus on **communication.** This list we've given above includes somewhat inadequate summaries of complex topics of interdisciplinary inquiry. It also veils numerous qualifications and interconnections: to take just one example, a warming climate could bring about droughts to the Sahel region of West Africa (#7), or could actually bring more rainfall to the Sahel and the growth of vegetation in southern parts of the Sahara (#8). The list scarcely reflects any disparities in climate vulnerabilities, for example the devastating impact of Amazon die-back on indigenous societies. Interactions between tipping elements are also a source of deep uncertainty: what is expected is that crossing any major tipping point threshold will have implications for other tipping points, and that temporal sequence is important. Overall, the list above also includes some language that may strike many experts as somewhat loose and clumsy.

Despite these drawbacks, this list is also our attempt to **illustrate some good practice in communicating around tipping points.** Tipping points are characterised by complexity and uncertainty. It is easy for experts to become preoccupied with the puzzle of vividly communicating this uncertainty and complexity, and to overlook more basic problems of communication which might be more easily addressed. Audiences may not connect with terms like AMOC, monsoon shift, biome shift, die-back, food security, circulation shutdown. It can be helpful to add words like **rain, fire, snow, hunger, storms, winds, ocean currents, floods, droughts, famines, forests, animals, birds, plants,** and so on—words that connect to the imagination and the senses. Audiences may know that disappearing rainforest, weakening ocean currents, or sea level rises are undesirable, but could benefit from brief discreet reminders why.

Attention to the basics is certainly recommended in communications aimed at policymakers or the public. Furthermore, **experts could also challenge themselves to bring vividness to more technical communications too.** There are three good reasons: (a) to practice these skills; (b) to uncover where experts may actually not share the understandings they assumed they did; (c) texts can often circulate beyond their intended audiences. Interdisciplinary and multi-professional collaboration is also always worth supporting and celebrating: not every scientist should be expected to be a poet as well, and the arts and humanities have much to contribute.

Visualising connections between tipping points might also help communicate complex interactions that increase systemic risks (Figure 1). Here again, experts are encouraged to cater for a wide audience where possible. They can consider visualising some more basic, "core" concepts in climate change, and/or to use visualisations that may allow audiences to connect climate risk with what they already care about or can already vividly imagine.

---

7 IPCC AR6 WGI: "Based on the evidence presented in this section, we conclude that abrupt changes and tipping points in the biogeochemical cycles lead to additional uncertainty in 21st century GHG concentrations changes, but these are very likely to be small compared to the uncertainty associated with future anthropogenic emissions (high confidence)."

8 Recent releases of methane have been impossible to quantify due to the lack of large scale baseline data, and on a larger time scale "several independent lines of evidence indicate that permafrost thaw did not release vast quantities of fossil CH_4 associated with the transient warming events of the LDT, suggesting that large emissions of CH_4 from old carbon sources will not to occur in response to future warming (medium confidence)" (IPCC AR6 WGI 2021).

1. Collapse of Ice Sheets and/or major ice formations → *much higher sea levels.*
2. Permafrost thaw releases methane → *acceleration of global warming.*
3. Massive loss of forests → *loss of biodiversity & release of greenhouse gases → acceleration of global warming.*
4. Rapid climate change → *mass extinctions of animals, plants, other life forms.*
5. Shutdown of A Major system of Ocean Currents (AMOC) → *Cooling of Northern Hemisphere (AMOC conveys heat from the tropics).*
6. Increase in El Niño–Southern Oscillation (ENSO) → *drought in South East Asia.*
7. West African Monsoon → *droughts across Mauritania, Senegal, Burkina Faso, Mali, and Niger.*
8. Greening of the Sahara → *greater local biodiversity.*
9. Indian Monsoon shift → *droughts on the Indian subcontinent.*
10. Tipping points at regional levels → *severe local impacts on all continents.*
11. Changed marine ecosystems → *abrupt West Tropical Indian Oceanic Bloom (sudden increase in deep water upwelling brings nutrients to the upper layers of ocean, leading to gains in productivity from microorganisms to fisheries).*
12. Disappearance of coral reefs → *loss of biodiversity, habitats, coastal erosion, cultural and economic losses.*

Figure 1. Conceptual model for tipping points

Clear, accessible visualisation of GHG emissions and global warming, for example, can be framed as useful context for the narrower topic of tipping points.

Figure 1 shows an interconnected system of potential climate tipping that could have the property where small changes (even below 1.5 degree warming) can trigger outsized impacts that interactively propagate through the system, altering climate drastically and causing large-scale devastation. Such tipping points might have been triggered in the past simply by internal variability (called **noise-induced tipping**), but the risk is higher when external forcings such as human-cased GHG emissions are present. The interpretation of evidence for abrupt changes in Earth's historical record is now accompanied by a greater understanding of possible mechanisms by which a climate might respond to small stochastic variations not with gradual changes but sudden shifts (Wunderling et al. 2021). Further, once some threshold is crossed (in cases of **bifurcation tipping**) and changes are underway, stopping external forcing (e.g. achieving net zero GHG emissions or better) will not impede the transformation to a new state, and a reversal may be difficult or impossible: one term for this is "**hysteresis**."[9] Other tipping points, like the Arctic Sea Ice melt, could be reversible within decades (Masson-Delmotte et al. 2021).

One of the first triggers to be activated is thought to be AMOC, a major system of ocean currents that already has noticeably weakened. It is possible that AMOC is a self-reinforcing system that can switch from one state to another with a relatively small push (it is believed to be an

9 Regrettably recalling the word "hysteria," which Tasca et al. (2012), describe as "the first mental health disorder attributable to women," and which became a highly disciplinary and punitive diagnosis employed by patriarchal medicine in the 19th and 20th century (and also a locus of adaptation and resistance by women; cf. Showalter 1987).

example of noise-induced tipping, e.g. there is no explicit threshold to cross as in bifurcation). Weakening this global ocean circulatory pattern could have an effect of weakening it further, perhaps until the circulation functionally shuts down, as might have happened repeatedly throughout Earth's history. This in itself would be a disaster for agriculture, human health and biodiversity, due to loss of rainfall, rise in extreme cold and heat, and loss of entire habitats. One of the key centers of biodiversity that is especially threatened by AMOC shutdown is Amazon rainforest (Cai, Lenton, and Lontzek 2016). The next domino to fall might be the West Antarctic and Greenland ice sheets[10], whose disintegration would unleash long-term irreversible sea level rises of several meters or more, drowning cities, coastlines and low-lying countries — China, United States, Japan and Netherlands would be especially affected.

THE MANY EMOTIONS OF APOCALYPSE

The science of tipping points can lend itself to apocalyptic storytelling. What are some of the pros and cons?

> *"Are you getting this on camera, that this tornado just came and erased the Hollywood sign? The Hollywood sign is gone, it's just shredded."*
> *— Character in The Day After Tomorrow (2004)*

From the perspective of climate risk communication, tipping points can be associated with **apocalyptic and cataclysmic narratives.** The tipping points session at the COP26 Universities Network Climate Risk Summit, late 2021, provides an illustration (Mackie 2021). The session opened with a slide alluding to the 2004 Hollywood blockbuster *The Day After Tomorrow*. Of course, this movie stretches science in ways that are regrettably familiar. "Scenarios that take place over a few days or weeks in the movie would actually require centuries to occur" (National Snow & Ice Data Center 2004). Nonetheless, *The Day After Tomorrow* does represent a real tipping element: the potential shutdown of AMOC, a large system of ocean currents that conveys warm water from the tropics northwards, which is responsible for the relative warmth of the North Hemisphere.

Movies like *The Day After Tomorrow* vividly communicate the fragility of human lives — as tornadoes tear apart the Los Angeles skyline and toss cars through the airs, as New Yorkers scramble down narrow streets from oncoming tsunami-like waves — in ways that are not always captured by terminology such as "extreme weather events." In the broader context of climate action, is it useful to tug on the heartstrings in this way? Much of the literature on catastrophic narratives and climate storytelling focuses on a distinction between fear and hope. **An overreliance on fear has been quite widely criticised.**

> *[…] some studies suggest that there are better chances to engage an audience by including positive messages in film narratives about environmental risks, especially climate change, rather than adopting the strategy of fear, which would instead distance and disengage them, making them feel overwhelmed and helpless […] (Leal Filho et al. 2017)*

However, one thing we should remember is that apocalypses are about many more emotions than fear and hope. A movie like *The Day After Tomorrow* showcases a range of emotions including exhilaration, confusion, companionship, desire, curiosity, anger, encounters with the sublime, and even moments of humour, both grim and sweet. As many scriptwriters will tell you, an immersive narrative needs emotional variety, or the audience will introduce variety of their own — they

Apocalypses are about many more emotions than fear and hope. ...the end of the world can feel alluring.

10 Referring to repeated abrupt shifts, some associated with AMOC, throughout Earth's history, the IPCC AR6 WGI report notes that the sensitivity of the response to a rise in temperature is uncertain: "The paleoclimate record indicates that tipping elements exist in the climate system where processes undergo sudden shifts toward a different sensitivity to forcing, such as during a major deglaciation, where one degree of temperature change might correspond to a large or small ice sheet mass loss during different stages."

will daydream, feel bored, pick holes in the plot, or find their own things to laugh about. Apocalyptic hearts are full hearts: there is probably no human emotion that cannot find some niche in narratives of disaster and collapse. Indeed, the end of the world can feel alluring. The more dissatisfied people are with their existing lives, the more alluring it may feel. As the recent ASU Apocalyptic Narratives and Climate Change project describes (focusing on the US context):

> *From infectious disease to war, a broad swath of the public has long interpreted social and environmental crisis through the prism of apocalypse, casting potential catastrophes and their causes in religious and moral terms. These apocalyptic visions are often narrated from the point of view of the survivors (the "elect"), thus reinforcing a sense that the end times need to be survived by remaining among the elect, rather than prevented through pragmatic action.*
> *(CSRC 2020)*

Alternatively, an apocalyptic or eschatological idiom can sometimes make climate change feel like nothing special. When has the world *not* been ending? "For at least 3,000 years, a fluctuating proportion of the world's population has believed that the end of the world is imminent" (Garrard 2004). Insofar as apocalyptic framings feel extreme yet in a familiar way, they can be counterproductive, especially with audiences who are already wary. This includes those who are ready to view anthropogenic climate change as a left wing conspiracy (perpetrated by charlatan scientists to secure themselves power and funding, in cahoots with governments that aim to justify increasingly authoritarian, totalitarian, and unjust policies) or as a neocolonialist agenda (perpetrated by the rich countries of the world to impose new forms of domination, indebtedness, and exploitation on the Global South).

De Meyer et al. (2021) offer an intriguing spin on the respective merits of fear, hope, and other emotions: **they suggest that current debates on climate communication have exaggerated the role of emotions altogether.** Instead they advocate for a focus on **practice**, by storytelling (and doing other things) to create spaces where new audiences can experience agency in relation to the climate, at many different scales and in many different circumstances. People should be able to see what they can do.

> *Here, we propose that both place-based, localized action storytelling, and practice-based action storytelling have a role to play in expanding climate agency. As examples of the latter, for creative writers and journalists the required agency would be about knowing how to make action on climate change part of their stories; for architects, how to bring climate change into building design; for teachers, how to teach about climate action within the constraints of the curriculum; for fund managers, how to bring climate risk into their investment decisions; for health professionals, to support the creation of place-based community systems that respond to the health impacts of climate change. These examples of communities of practice provide different opportunities and challenges to expand the notions of climate action beyond the current notions of consumer choice and activism.*
> *De Meyer et al. (2021)*

Let's summarise, then, some approaches to effective climate risk communication. One approach is to focus on **information**. How can information be clearly expressed and tailored for users to easily incorporate it into their decision-making? A second approach (partly in response to perceived shortcomings of the first) places more emphasis on **emotion**. What mixture of emotions should be appealed to in order to motivate action? This focus on emotion is also implicitly a focus on moral normativity, an appeal to the heart rather than the head (there is of course a great body of literature deriding this split between reason and emotion, which in reality are always mutually entangled). More recently we are seeing the emergence of a third approach, not strictly supplanting but rather complementing the other two, which focuses on **practice.**

The distinction between a "practice" focus vs. a focus on "informative and tailored stories" or "stories of hope not fear" is a bit subtle. Of course the three may often overlap. It may be helpful to think about what the "practice" focus means in the longer term. In the longer term, each new representational domain of climate agency will not emerge solely through hopeful portrayals of an agent (e.g. journalist, architect, teacher, fund manager) exemplifying an orthodox version of their role-specific climate action, however cognitively and affectively well-judged. Telling these stories may certainly be the priority in the short term. But what they should hope to kickstart are diverse stories filled with diverse agents, affects, and values: stories which superficially contradict each other in many ways, but whose deeper presuppositions mesh to create fields of imaginable action that can accommodate the particularity and the creativity of real people. "Environmental activist" is a social role that is available for real people to fill precisely because it can be filled in many ways (not just one way) and because it means many contradictory things (not just one thing). The same is true of the figure of the ethical consumer.

Audiences are more likely to engage with stories about the world they live in, than about who they must be in that world. Successful rapid mitigation and adaptation entails shifting to more participatory and equitable societies. Many audiences with centrist or conservative leanings may struggle to see themselves accepted within such societies. They may reject realistic climate narratives as hoaxes, or even welcome the end times: revel in fantasies of courage, ingenuity, largesse and revenge, set amid the ruins of civilisation. More can be done to create narratives that accommodate a range of self-reported aspirational virtues across the political spectrum, in ways that are cohesive with an overall just transition.[11] Storytelling that focuses on multiplying domains of agency also entails interventions beyond representational techniques altogether, transforming the material contexts in which people seek to exercise agency.

WHAT'S WRONG WITH A LITTLE APOCALYPSE?

Are experts sometimes overly wary of apocalyptic connotations?

For reasons described in the previous section, apocalyptic framing and imagery should be used with care. Moreover, it can be difficult to narratively reconcile tipping points with the Paris Agreement target of 1.5 degrees. As already mentioned, with regards to action, there is no contradiction at all. Reducing emissions as rapidly as possible will make crossing tipping points less probable, and will make it more likely to stay under the 1.5 degrees threshold. But with regards to storytelling, it may often feel simpler to give your audience one or the other to focus on.

However, experts can also stray into different problems when they are too averse to apocalyptic associations. Consider another example from the AR6 WG1 report that in trying to distance itself from apocalyptic storytelling, in style, gets semantically tangled up.

> *In summary, while there is a strong theoretical expectation that Amazon drying and deforestation can cause a rapid change in the regional water cycle, currently there is limited model evidence to verify this response, hence there is low confidence that such a change will occur by 2100.*
> *(Masson-Delmotte et al. 2021)*

Firstly, there is an ambiguity about the word 'change' in the last sentence: does it refer to Amazon deforestation on the whole, or to the regional water cycle (the two are also connected, so the uncertainty is not just linguistic but epistemological — would one cause another, and how to interpret 'a strong theoretical expectation' that it would, despite being told that such changes are implausible)? It seems that the epistemological uncertainty over the mechanism for change is low (the theoretical understanding of the process is solid) while modelling uncertainty is high and evidence is lacking, and as a result there is low confidence about the risk of a rapid undesirable change. And how to interpret this? How should we feel as a result of reading this sentence? What are the appropriate ethical or judgment responses?

It is also worth noting that cataclysmic storytelling around tipping points preceded their acceptance within academic circles. The narrative about tipping points within dominant climate science is relatively recent, emerging around 2005. Previously it was considered "too alarmist for proper scientific circles" (Russill and Nyssa 2009), although there was earlier scientific exploration of large-scale discontinuities, especially associated with warming in excess of 2 degrees. Russill and Nyssa (2009) found the timeline disconcerting, asking, "Should we draw any conclusions from the fact that popular discourse on tipping points precedes use of the concept in peer-reviewed climate change science?" But we might also then ask: should we be worried about travelling by air, or using touch screen devices, simply because these practices appeared in science fiction before they became reality? 'Tipping points' are an example of **diegetic prototyping** (Kirby 2010), whereby an idea arrives from the popular imagination to aid the development or articulation of technology or science — in this case, the science of climate risk modelling.

> *The tipping point metaphor is an example of the less common reverse journey, beginning as a rhetorical device to communicate the dangers of abrupt climate change to the public (in 2005–2007) and then developing into a theory-constitutive metaphor in the climate sciences (2007 onwards). While the exegetical function of the metaphor aims at explaining the underlying process to others,*

11 Britain Talks COP26: New insights on what the UK public want from the climate summit (Wang et al. 2021) is one small example of exploring (in the UK context) how climate risk communication might be diversified to appeal to myriad different political and ethical values. It does not (and we should not expect every such study to) engage with the challenging questions about which values fall beyond the scope of those that are compatible with a participatory and just transition.

> *in the theory-constitutive phase, the metaphor starts shaping a subdomain of climate science.*
> *(van der Hel, Hellsten, and Steen 2018)*

Tipping points are now a lot more prominent in both popular and scientific cultures. The context in which we communicate changes rapidly; if it was perhaps true that in the early 2000s that "[t]he desire to increase public urgency is driving the mainstreaming of tipping points in climate change communication, not the reporting of peer-reviewed research" (Russill and Nyssa 2009), then the scientific research in the last decade has matured considerably. However, their research poses questions that are still relevant today, especially since 'climate anxiety' has entered mental health professionals' list of symptoms: "Do tipping points induce unwarranted anxiety and perhaps fatalism […], or, on the other hand, do they help correct for the 'false sense of security' produced by smooth projections of change, which can lull society into inactivity?" (Clayton 2020; Thompson 2021).

WHERE DO WE TALK ABOUT CLIMATE RISKS SUCH AS TIPPING POINTS?

Climate storytelling tends to be siloed, which reduces its impact. How can we help to spread it more widely through our cultures?

Science fiction across various forms (literature, movies, games, etc.) has a long history with climate change themes, and provides one key cultural context for communicating climate risk. Here is a description of tipping points, from Fifty Degrees Below, a novel by Kim Stanley Robinson:

> *They had passed the point of criticality, they had tipped over the tipping point in the same way a kid running up a seesaw will get past the axis and somewhere beyond and above it plummet down on the falling board. They were in the next mode, and coming into the second winter of abrupt climate change.*
> *(Robinson 2006)*

This passage is also quoted by van der Hel, Hellsten, and Steen (2018) who are interested specifically in the physicality of the metaphor, noticing that the "image of the earth on the edge of a cliff, only inches away from tipping over and falling into the abyss" is pervasive in all forms of communication. The researchers combed through a vast array of scientific papers, popular media and journalism around tipping points, and found four linguistic and discursive archetypes:

> *"(1) In the climate sciences, the tipping point metaphor was first introduced from 2005 onwards as a rhetorical device, warning the public and scientific peers for abrupt and possibly irreversible changes in the climate system. This use of the metaphor is characterized by occasionally clearly deliberate metaphorical language use explaining tipping points as motion in space.*
>
> *(2) Meanwhile, journalists adopted and employed the notion of a tipping point in climate change as a metaphorical scientific concept with societal implications, also occasionally exhibiting features of deliberate metaphorical use.*
>
> *(3) From around 2007, the tipping point phrase becomes popular as a theory-constitutive metaphorical model for research in the climate sciences.*
>
> *(4) Finally, from around 2011, notions of tipping points in news media on climate change become used as conventionalized ideas and expressions for important impending change, no longer automatically drawing attention to the metaphorical status of the phrase." (van der Hel, Hellsten, and Steen 2018)*

There is a lack of consensus about the relative roles of metaphors, scientific information and narratives in terms of translating into actions, especially in the face of climate emergency (De Meyer et al. 2020). What is clearly significant in this respect is one's politics (Kahan 2012). Whether scientists like it or not, questions about politics and climate science will be asked. The inclusion of political considerations in discourse about effective climate communication partly reflects a frustration with the use of "the need for better public engagement" to distract from well-attested economic and political obstacles to effective climate action. Furthermore, the example, the extent to which political climate could influence science, especially modelling results (one may question on

The climate storytelling that does exist plays out against a background of intensive cultural production which undermines it and crowds out its perspectives and possibilities.

this basis the extremely low value for climate sensitivity in Russian models) and their interpretations, has to be addressed in some constructive way. The more limited the scientific evidence the greater is the potential for the social and political backgrounds to be reflected in the narrative about climate risks. Assessing that influence can be tricky, since "the standard ways of using probabilities to separate ethical and social values from scientific practice cannot be applied in a great deal of climate modeling, because the roles of values in creating the models cannot be discerned after the fact—the models are too complex and the result of too much distributed epistemic labor" (Winsberg 2012).

The production and circulation of this knowledge is also shaped by (among other things) structural power and by the counterpower of social movements, such as Black Lives Matter and many others, which critically foreground the historical, economic and cultural politics of climate change. In this way the cultural politics of climate change aspire to echo post-colonial discourse in "paying attention to histories of vulnerability and responsibility" (O'Riordan and Lenton 2013). Moreover, recent reframings of climate change in terms of extractivist and neocolonial histories have not yet translated into the effort to redress these historical injustices by cancelling debts, or providing proportionate level of support through grants for adaptation and mitigation in developing countries — or what is referred to be the "compensatory justice" or polluter-must-pay component of climate justice (Okereke 2010). The other important aspect of climate justice is "procedural justice":

> *Despite the elevation of certain 'methods and prescriptions in our epistemologies' and the increasingly 'scientized veneer' of modern climate debate, it is well known that decisions on targets, metrics, emission counting methodologies, and reporting systems all involve both technical and political considerations. Hence, figuring out how to ensure broad and effective participation of all countries in the decision-making process represents another important dimension of justice in the climate regime.*
> *(Okereke 2010)*

O'Riordan and Lenton (2013) propose that "six features — global pervasiveness, uncertainty, interdependency, the reverberations of history, interdisciplinarity, and temporality — form the cultural foundation on which media engagement with climate change has developed and will continue to unfold." Yet one perennial problem with climate risk communication is that it is usually so clearly identifiable as climate risk communication, or nearby discourses like apocalyptic or superdisaster narratives, or science fiction (especially subgenres such as cli-fi or solarpunk). Heavy-handed framing risks limiting the audiences who engage with it, limiting the variety of cognitive and affective resources with which climate risk is construed, and limiting the proliferation of action-based storytelling. At the same time, the climate storytelling that does exist plays out against a background of intensive cultural production which undermines it and crowds out its perspectives and possibilities. It is even tempting to indulge in dubious fantasies of controlling all the stories that are told, to ensure full-bandwidth climate messaging. Setting aside the ethically untenable presuppositions of such fantasies, they also miss the point: the aim should be to encourage climate action themes to spread throughout culture and to hybridise with its preexisting variety in ways that are surprising, generative, and perhaps sometimes discomfiting — even to lose control of the messages. In this spirit, there are strategies that policymakers, third sector, environmental activists and creators, and other stakeholders might explore to help break climate storytelling out of its traditional well-marked boxes.

But Okereke's procedural justice also requires representation not just in the decision-making process or the cultural contexts which broadly inform it, but also in the production of knowledge that feeds it, especially if the knowledge is deeply uncertain.[12] The next sections begin to explore how tipping points, and other kinds of deep uncertainty, tend to expose the polycentric character of knowledge. All knowledge is distributed across specific knowing persons (and the technological systems in which they are embedded). Knowledge about climate change, for example, is embedded across a vast variety of different perspectives, values, interests, and levels and forms of power, all of which inform the nature of that knowledge. So if deep uncertainty is understood as a lack of agreement about how to model a system, it raises the question of who has been invited to agree in the first place — the question of whose voices count.

12 This is not to conclude that the tipping point discourse is always on the right side of anti-racist theory and practice. Consider the following passage that links tipping points to population growth (in Africa and Asia) and frantically calls for 'drastic action': "The Earth is within decades of reaching an irreversible tipping point that could result in 'planetary collapse,' scientists warned yesterday. They called for drastic action, such as rapid curbs on population growth, to prevent food supplies being threatened by major changes to farming caused by climate change. (Dalton, 2012)" in (van der Hel, Hellsten, and Steen 2018).

TIPPING POINTS AND THE IPCC MODEL ENSEMBLE

Do tipping points come with cultural baggage that constrains their integration into climate policy?

Action is the focus with which Chatham House, the well-respected UK policy think tank, introduces tipping points in its 2021 Climate Change Risk Assessment (Quiggin et al. 2021). Overall, the briefing paper is an exemplary piece of communication, whose expression and organisation is lucid, detailed and punchy. However, the paper tends not to communicate uncertainty information. At least, it avoids using the word 'uncertainty,' except for a few occasions — and tipping points is not one of them.

> *Ice sheets are crucial for the stability of the climate system as a whole, and are already at risk of transgressing their temperature thresholds within the Paris range of 1.5°–2°C. A domino-like effect has recently been identified between various tipping points, which can lead to abrupt non-linear responses. Tipping point cascades (two or more tipping points being initiated for a given temperature level) have been identified in more than 60 percent of simulations, for which the initial trigger is likely to be polar ice sheet melting, with the Atlantic Meridional Overturning Circulation (AMOC) acting as a mediator transmitting cascades.*
> *(Quiggin et al. 2021)*

Notice the firm, guardedly urgent tone of phrases like "already at risk," "has recently been identified," and "identified in more than 60 per cent of simulations." There is some important implied uncertainty here, e.g. "60 percent of simulations" sounds like something to be worried about (especially given the magnitude of the impact), but it is nowhere near certitude. But what kind of uncertainty is it? Readers might reasonably mistake "60 percent of simulations" as referring to the main IPCC projections, e.g. those used to calculate the carbon budget. In reality tipping points occur in such projections rarely if at all13.

> *Processes that change on long timescales—particularly AMOC, ocean heat content, and ice sheets—require additional projections beyond the CMIP scenarios to explore longer term commitment, post-forcing recovery measured in centuries rather than years or decades, and potential tipping points and thresholds. There were only a few new studies focussed on longer timescales and none based on CMIP6 models.*
> *(IPCC AR6 WGI)*

The study (Wunderling et al. 2021) cited as a reference, by contrast, creates more space for considering uncertainty. It takes as its premise that these high-profile IPCC models are not able to adequately capture tipping point dynamics. Tipping point dynamics "cannot be fully analysed with state-of-the-art Earth system models due to computational constraints as well as some missing and uncertain process representations of certain tipping elements" (Wunderling et al. 2021). Due to this epistemological uncertainty, the study instead adopts a conceptual network model. This is constructed based on expert judgements about plausible interactions that might trigger tipping points. Such models are suitable for exploring consequences of different scientific beliefs that are not amenable to other methods.

This is not to say that the authors of the Chatham House article are sweeping anything under the carpet. But they have made the pragmatic decision not to lead with the distinction between tipping point conceptual network modelling (and its uncertainties) and other sorts of climate modelling (and their uncertainties). This communicative strategy can be read as symptomatic of the topic's lingering awkward associations, both in terms of the

The IPCC definition of "low-likelihood, high-impact outcome" deserves to be closely examined. Might this term mislead non-experts?

13 IPCC AR6 WGI report notes that abrupt changes do show up in ensemble simulations but very rarely and correlate with less plausible scenarios and narrow regions of parameter space: "At the regional scale, abrupt changes and tipping points, such as Amazon forest dieback and permafrost collapse, have occurred in projections with Earth System Models (Drijfhout et al., 2015; Bathiany et al., 2020; Chapter 4, Section 4.7.3). In such simulations, tipping points occur in narrow regions of parameter space (e.g., CO2 concentration or temperature increase), and for specific climate background states. This makes them difficult to predict using ESMs relying on parameterizations of known processes."

discursive shaping of tipping points within popular culture (see previous section), and the perceived authority of conceptual network models vs. Earth Systems Models (which in turn reflects a lack of strong narratives around model reliability, their groundness in data and experimental evidence; see next chapter).

It is worth exploring ways of conceptual model techniques much more richly into climate decision-making, especially as part of a shift toward more holistic and participatory frameworks. However, the IPCC has yet to figure out how to deal satisfactorily with the more speculative character of such approaches (for example, Wunderling et al. 2021 does not appear in the thousands of articles consulted and synthesised); the AR6 contents itself with describing evidence for tipping point as "limited" and "characterised by deep uncertainty":

> *There is limited evidence for low-likelihood, high-impact outcomes (resulting from ice sheet instability processes characterized by deep uncertainty and in some cases involving tipping points)*
> *(IPCC WGI AR6 2021).*

Excerpts from meeting notes on the approval of text for the IPCC AR6 WGI Summary for Policymakers offer insight into the politics of discussing deep-uncertainty events, as well as the limitations to the capacity of political forces to subvert a scientific process:

> *'C.3: This subsection addresses low-likelihood outcomes. On the Headline Statement on low-likelihood outcomes being impossible to rule out and being part of risk assessment, INDIA objected to such* ***speculative language.*** *SAUDI ARABIA said the* ***uncertainty was unhelpful.*** *DENMARK, supported by NORWAY, LUXEMBOURG, GERMANY, SAINT KITTS AND NEVIS, MEXICO, FRANCE, and SPAIN, underscored that* ***low-likelihood high-impact events are highly policy-relevant.*** *Several countries requested specifying "tipping points," and the DENMARK, LUXEMBOURG, and the UK requested further examples, such as Amazon diebacks. JAPAN preferred "risk to be considered" or "risk" over "risk assessment."*
>
> *'C.3.2: On this paragraph dealing with occurrence of low-likelihood, high-impact outcomes in all GHG emissions scenarios,* ***delegates called for: inclusion of quantitative information; more specificity regarding levels of probability in the different scenarios; and addition of levels of confidence.*** *During discussion, the paragraph was revised to: note likelihood that, high-impact outcomes "could" occur, rather than "may;" specify the reference to tipping points "of the climate system"; and add forest dieback as another example of abrupt response. The paragraph was approved after* ***the authors clarified that "cannot be ruled out" is the best estimate that can be given since no actual likelihood assessment can be made for issues with deep uncertainty*** *such as a strongly increased Antarctic Ice Sheet melt.'*
> *(Bansard and Akanle Eni-ibukun, n.d.)*

Several things can be inferred. Politics clearly is a factor. Uncertainty is disliked, at least in this case: it is found objectionable and unhelpful. Quantitative information is preferred, although the scientists can and do push back, refusing to produce numbers where only words are valid.

COMMUNICATING AROUND DEEP UNCERTAINTY

Tipping points pose special challenges for climate communication. How do we address the deep uncertainty around tipping points?

The forecasting of tipping points, and even the observation of tipping points that may be underway, is associated with deep uncertainty. The IPCC state that "[e]stablishing links between specific GWLs [global warming levels] with tipping points and irreversible behaviour is challenging **due to model uncertainties and lack of observations, but their occurrence cannot be excluded,** and their likelihood of occurrence generally increases at greater warming levels" (IPCC AR6 WGI, 2021). They further emphasise that "[i]t is not currently possible to carry out a full assessment of proposed abrupt changes and tipping points in the biogeochemical cycles," and suggest that the potential for improving such assessments in the future is limited because "[t]he rare nature of such events and the limited availability of relevant data makes it difficult to estimate their occurrence probability" (IPCC AR6 WGI 2021).

The term **deep uncertainty** does not have a precise and universally accepted definition. It may be understood as characterising problems or situations whose uncertainty cannot be quantified, cannot be quantified *given available resources or data,* and/or whose quantification is not desirable. Under deep uncertainty, there is no authoritative model that captures all the relevant driving forces and their relationships—perhaps because there is not enough knowledge

Sometimes (a little paradoxically) uncertainty can simplify the task of communication.

about the processes or parameters to build such a model, or perhaps because there are multiple inconsistent models (Lempert, Popper, and Bankes 2003).[14] Deep uncertainty is also intrinsically linked to themes of **participatory governance** and **just climate transition.**

Strictly speaking, a tipping point refers to a point at which a system reorganises, often abruptly and/or irreversibly. Low probability or deep uncertainty per se are not what characterise the tipping point concept (even though the major climate tipping points of concern have these features, in other areas of science such as epidemiology tipping points are more predictable), but rather this dynamic of reorganisation which is rapid and/or irreversible. It is important to remember this, in order to appreciate the IPCC's approach to tipping points, especially **how tipping points overlap with what the IPCC calls 'low-likelihood, high-impact outcomes.'** Not all low-likelihood, high-impact outcomes involve tipping points, as this quotation demonstrates (our emphasis):

> *There is limited evidence for low-likelihood, high-impact outcomes (resulting from ice sheet instability processes characterized by deep uncertainty and in some cases involving tipping points) that would strongly increase ice loss from the Antarctic Ice Sheet for centuries under high GHG emissions scenarios.*[15]
> *(AR6 WGI 2021)*

The IPCC definition of "low-likelihood, high-impact outcome" deserves to be closely examined. Might this term mislead non-experts? Might it distort the discourse around tipping points? According to the IPCC, the term "low-likelihood high-impact" should be used of events or outcomes whose

> *probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high.*
> *(AR6 WGI Annex VII, emphasis added).*

When asked the probability that a low-likelihood high-impact event will occur, a reasonable respondent might well answer, "Obviously the probability is low!" They may add that it's still worth worrying about. By contrast, what reasonable person would guess that the probability of a "low-likelihood high impact" event occurring is not actually "low"—but rather "low or not well-known"! A closely-related slippage of meaning may also occur, especially when communicating with policymakers or the public: when an expert describes an event as being of low likelihood, audiences may reasonably infer that the expert is confident that an assessment of probability could be made.[16]

It is also important to recognise that the science and evidence around each different tipping element is very different, and undergoing evolution. It is true that the field as a whole offers many forms of deep uncertainty. But we should be careful not to conflate all these uncertainties, nor to forget where potential tipping points have been investigated and ruled out, rather than filed under "deeply uncertain." For example, consider the distinction the IPCC draws between Arctic and Antarctic ice: "There is no tipping point for this loss of Arctic summer sea ice (high confidence)" (AR6 WGI 2021), whereas Antarctic ice is considered a low-likelihood high-impact risk due to instability of the West Antarctic Ice Sheet.

Nor should we jump to conclusions about a given deep uncertainty being permanent; one relevant example here might be statistical time series analyses, which some research suggests may allow observational detection of "early warning signals," where a certain tipping el-

14 In this sense, the concept of deep uncertainty overlaps somewhat with that of wicked problems (Rittel and Webber 1973).

15 We note the linguistic ambiguity of the phrase "there is limited evidence." Should reading such a sentence make one adjust one's perception of risk upward or downward? The intended sense in the quoted passage is that you should adjust it upward slightly: there is evidence for x, although this evidence is limited. But an alternative interpretation might be that the statement is a tacit refutation of x, loosely speaking: "Given the large efforts made to show that x is the case, and the still small amount of evidence in favor of x, in our opinion x is probably not the case."

16 The tipping points explored in this chapter thus fall into the category of 'unknown risks'—risks that are undertaken involuntarily, whose consequences are delayed, and which seem not fully known to science—factors that have been shown to increase risk sensitivity (Fischhoff et al. 1978).

ement has lost stability and may be approaching a tipping point (Boers 2021).[17] The broad point here is that when we communicate about tipping points, conveying uncertainty must not mean downgrading them to speculative storytelling.

Standard Earth System Models can still be useful in identifying and investigating tipping points. The models that were downweighted in the CMIP6 50 model ensemble, because they appear to be less plausible, can actually be useful in constructing narratives around tipping points:

> *A real-world ECS higher than the assessed very likely range (2°C–5°C) would require a strong historical aerosol cooling and/or a trend towards stronger warming from positive feedbacks linked to changes in SST patterns (pattern effects), combined with a strong positive cloud feedback and substantial biases in paleoclimate reconstructions — each of which is assessed as either unlikely or very unlikely, but not ruled out. Since CMIP6 contains several ESMs that exceed the upper bound of the assessed very likely range in future surface warming, these models can be used to develop low-likelihood, high warming storylines to explore risks and vulnerabilities, even in the absence of a quantitative assessment of likelihood (IPCC AR WGI 2021).*

Because of their complexity and deep uncertainty, tipping points pose special challenges for communication. Yet at the same time, **tipping points give us some of the most straightforward messages we are likely to find anywhere in climate science.** We must reduce net carbon emissions to zero as rapidly as possible. We must build resilience around the world as rapidly as possible. Sometimes (a little paradoxically) uncertainty can simplify the task of communication. Because trigger thresholds usually cannot be known with confidence, and because the impacts would be catastrophic, deciding what to do using cost-benefit logic becomes crystal clear: as much as we can, with everything we have. In some respects, we are saved the complexity of the question: but will it be enough?

"PARTICIPATORY UNCERTAINTY"

Low-likelihood high-impact outcomes deserve further study, but our best response is a just and participatory transition

There are many good reasons to change how we think, and how we communicate, about low-likelihood high-impact events. We can reject the priority of quantitative reasoning over qualitative, emphasise conceptual models over Earth Systems Models, and emphasise participatory decision-making under conditions of deep uncertainty. These considerations are relevant throughout this Toolkit, but especially when it comes to tipping points.

> *Deep uncertainty has been used to describe situations where "analysts do not know, or the parties to a decision cannot agree on, (1) the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future, (2) the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or (3) how to value the desirability of alternative outcomes" (Lempert, Popper, and Bankes 2003).*

This definition has the benefit of clarifying what deep uncertainty is. However, it does make it **impossible to definitively say where deep uncertainty begins and ends**. Deep uncertainty tends to draw in other forms of uncertainty. For example, ambiguity may also be relevant, insofar as parties might believe themselves to agree or to disagree, but be mistaken about the state of consensus. Currency may also be relevant, insofar as values and beliefs change over time. Even if everyone who is involved can agree today, beliefs can diverge tomorrow.

More loosely speaking, when we take the perspective of deep uncertainty, we are reminding ourselves to have epistemological humility. We are recognising that, however good we get at thinking about uncertainty, reality is full of surprises: "the long-term future may be dominated by factors that are very different from the current drivers and hard to imagine based on today's experiences" (Lempert, Popper, and Bankes 2003).

So for almost any domain (perhaps any domain), deep uncertainty becomes a lens which may be used. When some decision seems to be demurely contained within neat models to everybody's satisfaction and de-

17 However, other studies have indicated that due to the stochastic behaviour of tipping points, such as AMOC, detection of warning signs is not possible (Ditlevsen and Johnsen 2010).

light, it is simple to reintroduce deep uncertainty merely by expanding the scope of 'everybody'—to include, for example, the participation of those with profoundly different political or ethical views. But for some domains, including tipping points, deep uncertainty is something else: a lens which cannot reasonably be refused. And for such domains, we might speak of "operating under conditions of deep uncertainty."

Deep uncertainty resists quantification and any type of modelling, even loose conceptual modelling. However, **many measures have been suggested to accommodate deep uncertainty.** Among the most important are:

- improving the participatory, deliberative, and democratic qualities of decision-making processes18;
- improving equity to build generic resilience;
- exploring ways to make decisions more flexible to adapt to new information as it arises; and
- finding ways to challenge our presuppositions about the parameters of the decision space, and to discover new potential pathways.

These are overlapping and mutually reinforcing. They further imply that quantification can still be helpful under conditions of deep uncertainty, so long as it is exploratory, and used to clarify reasoning and keep questions open—not shut them down or put precise price tags on uncertainties. In this way, deep uncertainty has inspired new ways of using probability theory in decision support, such as the Robust Decision Making model (RDM) approach. This can include the deliberative integration of multiple plausible probability distributions, based on expert, stakeholder, and/or group judgments.

There are at least four broad rationales to address deep uncertainty by improving participatory decision-making: informational (participatory processes acknowledge that expertise may be generated not only by accredited experts but by all); behavioral (participatory processes improve societal buy-in and mitigate against societal backlash); anticipatory (participatory processes go hand-in-hand with broader socioeconomic equity that has been shown as a form of resilience in its own right); and existential (participatory processes can distribute more widely the moral responsibility for actions whose outcomes are deeply uncertain).

Deep uncertainty has been used to describe situations where "analysts do not know, or the parties to a decision cannot agree on, (1) the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future, (2) the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or (3) how to value the desirability of alternative outcomes" (Lempert, Popper, and Bankes 2003).

18 We would also add a less-well-known term, "agonistic." Agonism is used by democratic theorists to describe participatory processes that express (or "sublimate") real social conflicts, rather than disguise those conflicts under a pretense of rational representative and/or participatory consensus. However, agonism also requires that adversaries are not merely competitors, but deeply and materially acknowledge and support one another's legitimacy in the participatory process, implying strong limits as to how far they would go to score a political win. "While antagonism is a we/they relation in which the two sides are enemies who do not share any common ground, agonism is a we/they relation where the conflicting parties, although acknowledging that there is no rational solution to their conflict, nevertheless recognize the legitimacy of their opponents. They are 'adversaries' not enemies" (Mouffe 2005).

VISUALISING DEEP UNCERTAINTY

Can deep uncertainty be visualised, or perhaps perceptualised in innovative ways?

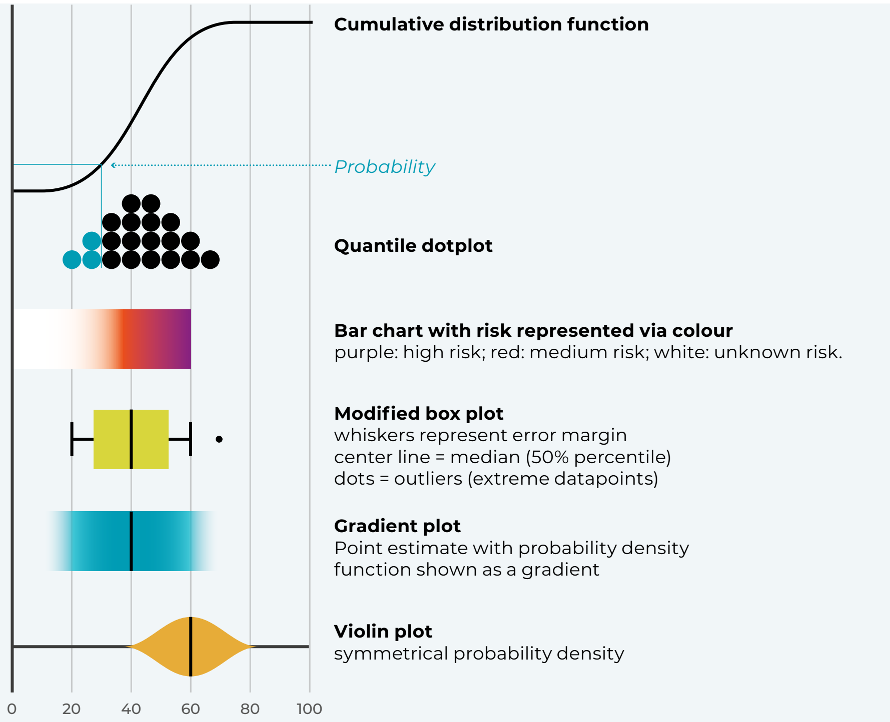


Figure 2. Visualising probabilities and risk.

One of the promising options to communicate the systemic risks potentially hidden at the tails of the distributions is Figure 2. Here the low risk does not fade to the safety of zero but turns into something potentially worse, a whiteness that feels hot and dangerous, perhaps because it invokes a semantic metaphor for lightning—white hot explosion of plasma that reaches 27,000ºC, hotter than the sun. That is the region where risk is labeled 'undetectable' invoking the concept of deep uncertainty (van der Hel, Hellsten, and Steen 2018).

More commonly, deep uncertainty resists visualisation just as much as it resists quantification and modelling. Visualisation is often used in science communication to convey uncertainty information. There is evidence that visualisation of uncertainty affects many aspects of decision-making; for example, choices about the graphical presentation of hurricane forecasts have been shown to influence people's decisions on whether or not to follow evacuation orders. Even when graphics are not used, a user's reasoning around a subject may nonetheless be influenced by both the visual presentation of the information, and the kinds of imagery invoked in the user (whether deliberately or not). In this sense, the visual character of uncertainty can be key to interpretation, decision-making, and action. But deep uncertainty offers serious challenges to visualisation:

> *First, it is assumed that uncertainty, or at least uncertainty of interest, is both knowable and identifiable. Similarly, to be visualized, uncertainty must be quantifiable, such as through statistical estimates, quantitative ranges, or qualitative statements (e.g., less or more uncertain). Moreover, evaluations define effectiveness as an ability to identify specific uncertainty values, which assumes that identifying specific uncertainty values is useful to decision-makers and that the values of interest can be quantified. Lastly, there is an assumption that the quantification of uncertainty is beneficial, applicable to the decision task, and usable by the decision-maker, even if users do not currently work with uncertainty in that way. These assumptions pose a challenge for visualizing uncertainty to support decision making under deep uncertainty, where quantification of uncertainty is not possible or necessarily desirable. In this way, current approaches to uncertainty visualization are more normative in nature, reflecting what researchers think decision-makers need to know about uncertainty.*
> *(Deitrick and Wentz 2015)*

Dynamic visualisations and interactive media may be promising, insofar as interactive media can incorporate their own nonlinear dynamics suggestive of the deep uncertainties of climate risk, and can also act as aids in participatory processes involving many different stakeholders. The development and use of such tools do bring their own special considerations vis-a-vis equity and a just transition to sustainable society. Challenges around filtering and prioritising climate risk communications are pertinent, as communication is likely to multiply and diversify in the years ahead, as transition becomes more central to more societies. Exploring these issues in any detail is outside of the scope of this Toolkit, but we suggest that useful perspectives may be discovered in the literature on structured elicitation as well as in the fields of the philosophy of science and technology and critical data studies, particularly work on metric power and algorithmic governmentality. Democratic theory, e.g. high level conceptualisations of deliberative vs. agonistic democracy (Mouffe 2005), is another important source.

AUTHOR CONTRIBUTIONS

Conceptualization: *PL, JLW and EM;* ***Research:*** *PL, JLW and EM;* ***Writing:*** *JLW and PL;* ***Figures:*** *JK and PL.*

REFERENCES

Bansard, Jennifer, and Tomilola Akanle Eni-ibukun. n.d. 'Summary of the 54th Session of the Intergovernmental Panel on Climate Change and the 14th Session of Working Group I: 26 July - 6 August 2021'. Earth Negotiations Bulletin. https://enb.iisd.org/climate/IPCC/IPCC-54-WGI-14/summary.

Barnosky, Anthony D., Nicholas Matzke, Susumu Tomiya, Guinevere O. U. Wogan, Brian Swartz, Tiago B. Quental, Charles Marshall, et al. 2011. 'Has the Earth's Sixth Mass Extinction Already Arrived?' Nature 471 (7336): 51–57. https://doi.org/10.1038/nature09678.

Boers, Niklas. 2021. 'Observation-Based Early-Warning Signals for a Collapse of the Atlantic Meridional Overturning Circulation'. Nature Climate Change 11 (8): 680–88. https://doi.org/10.1038/s41558-021-01097-4.

Cai, Yongyang, Timothy M. Lenton, and Thomas S. Lontzek. 2016. 'Risk of Multiple Interacting Tipping Points Should Encourage Rapid CO2 Emission Reduction'. Nature Climate Change 6 (5): 520–25. https://doi.org/10.1038/nclimate2964.

Clayton, Susan. 2020. 'Climate Anxiety: Psychological Responses to Climate Change'. Journal of Anxiety Disorders 74 (August): 102263. https://doi.org/10.1016/j.janxdis.2020.102263.

Comyn-Platt, Edward, Garry Hayman, Chris Huntingford, Sarah E. Chadburn, Eleanor J. Burke, Anna B. Harper, William J. Collins, et al. 2018. 'Carbon Budgets for 1.5 and 2 °C Targets Lowered by Natural Wetland and Permafrost Feedbacks'. Nature Geoscience 11 (8): 568–73. https://doi.org/10.1038/s41561-018-0174-9.

CSRC. 2020. 'Apocalyptic Narratives & Climate Change | Center for the Study of Religion and Conflict'. 2020. https://csrc.asu.edu/apocalypticnarrativesclimatechange.

De Meyer, Kris, Emily Coren, Mark McCaffrey, and Cheryl Slean. 2020. 'Transforming the Stories We Tell About Climate Change: From "Issue" to "Action"'. Environmental Research Letters 16 (1): 015002. https://doi.org/10.1088/1748-9326/abcd5a.

Deitrick, Stephanie, and Elizabeth A. Wentz. 2015. 'Developing Implicit Uncertainty Visualization Methods Motivated by Theories in Decision Science'. Annals of the Association of American Geographers 105 (3): 531–51. https://doi.org/10.1080/00045608.2015.1012635.

Diamond, Jared M. 2011. Collapse: How Societies Choose to Fail or Survive. New York, NY: Penguin Books.

Ditlevsen, Peter D., and Sigfus J. Johnsen. 2010. 'Tipping Points: Early Warning and Wishful Thinking: TIPPING POINTS-EARLY WARNING'. Geophysical Research Letters 37 (19): n/a-n/a. https://doi.org/10.1029/2010GL044486.

Drijfhout, Sybren, Sebastian Bathiany, Claudie Beaulieu, Victor Brovkin, Martin Claussen, Chris Huntingford, Marten Scheffer, Giovanni Sgubin, and Didier Swingedouw. 2015. 'Catalogue of Abrupt Shifts in Intergovernmental Panel on Climate Change Climate Models'. Proceedings of the National Academy of Sciences 112 (43): E5777–86. https://doi.org/10.1073/pnas.1511451112.

Fischhoff, Baruch, Paul Slovic, Sarah Lichtenstein, Stephen Read, and Barbara Combs. 1978. 'How Safe Is Safe Enough? A Psychometric Study of Attitudes towards Technological Risks and Benefits'. Policy Sciences 9 (2): 127–52. https://doi.org/10.1007/BF00143739.

Garrard, Greg. 2004. Ecocriticism. London: Routledge.

Gladwell, Malcolm. 2015. The Tipping Point: How Little Things Can Make a Big Difference. Paperback edition. London: Abacus.

Hel, Sandra van der, Iina Hellsten, and Gerard Steen. 2018. 'Tipping Points and Climate Change: Metaphor Between Science and the Media'. Environmental Communication 12 (5): 605–20. https://doi.org/10.1080/17524032.2017.1410198.

Huxley, Anna. 2018. 'Communicating Climate Change Through Narratives: A Cross Pollination of Science and Theology'. In Handbook of Climate Change Communication: Vol. 1, edited by Walter Leal Filho, Evangelos Manolas, Anabela Marisa Azul, Ulisses M. Azeiteiro, and Henry McGhie, 201–14. Climate Change Management. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-69838-0_13.

Kahan, Dan M. 2012. 'Ideology, Motivated Reasoning, and Cognitive Reflection: An Experimental Study'. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2182588.

Kirby, David. 2010. 'The Future Is Now: Diegetic Prototypes and the Role of Popular Films in Generating Real-World Technological Development'. Social Studies of Science 40 (1): 41–70. https://doi.org/10.1177/0306312709338325.

Leal Filho, Walter, Evangelos Manolas, Anabela Marisa Azul, Ulisses M. Azeiteiro, and Henry McGhie, eds. 2017. Handbook of Climate Change Communication. Vol. Vol. 1. New York, NY: Springer Berlin Heidelberg.

Lempert, Robert J., Steven W. Popper, and Steven C. Bankes. 2003. Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis. Santa Monica, CA: RAND.

Lenton, T. M., H. Held, E. Kriegler, J. W. Hall, W. Lucht, S. Rahmstorf, and H. J. Schellnhuber. 2008. 'Tipping Elements in the Earth's Climate System'. Proceedings of the National Academy of Sciences 105 (6): 1786–93. https://doi.org/10.1073/pnas.0705414105.

Mackie, Erik. 2021. 'COP26 Universities Climate Risk Summit Blog: "When Is the Day After Tomorrow?": Tipping Points and Abrupt Climate Responses | Www.Zero.Cam.Ac.Uk'. 2021. https://www.zero.cam.ac.uk/stories/cop26-universities-climate-risk-summit-blog-when-day-after-tomorrow-tipping-points-and.

Masson-Delmotte, V., P. Zhai, A. Pirani, and S. L. Connors. 2021. 'Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change'. Cambridge University Press.

Mouffe, Chantal. 2005. On the Political. Thinking in Action. London ; New York: Routledge.

National Snow & Ice Data Center. 2004. '"The Day After Tomorrow" Q&A Response'. https://nsidc.org/cryosphere/day-after-response.

Okereke, Chukwumerije. 2010. 'Climate Justice and the International Regime: Climate Justice and the International Regime'. Wiley Interdisciplinary Reviews: Climate Change 1 (3): 462–74. https://doi.org/10.1002/wcc.52.

O'Riordan, Timothy, and Timothy Lenton, eds. 2013. Addressing Tipping Points for a Precarious Future. British Academy. https://doi.org/10.5871/bacad/9780197265536.001.0001.

Otto, Ilona M., Jonathan F. Donges, Roger Cremades, Avit Bhowmik, Richard J. Hewitt, Wolfgang Lucht, Johan Rockström, et al. 2020. 'Social Tipping Dynamics for Stabilizing Earth's Climate by 2050'. Proceedings of the National Academy of Sciences 117 (5): 2354–65. https://doi.org/10.1073/pnas.1900577117.

Quiggin, Daniel, Kris De Meyer, Lucy Hubble-Rose, and Antony Froggatt. 2021. 'Climate Change Risk Assessment'. Chatham House. https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021.

Rapley et al., Chris. 2006. 'West Antarctic Ice Sheet: Waking the Sleeping Giant?' British Antarctic Survey (blog). 2006. https://www.bas.ac.uk/media-post/west-antarctic-ice-sheet-waking-the-sleeping-giant/.

Rittel, Horst W. J., and Melvin M. Webber. 1973. 'Dilemmas in a General Theory of Planning'. Policy Sciences 4 (2): 155–69. https://doi.org/10.1007/BF01405730.

Robinson, Kim Stanley. 2006. Fifty Degrees Below. London: HarperCollins.

Russill, Chris, and Zoe Nyssa. 2009. 'The Tipping Point Trend in Climate Change Communication'. Global Environmental Change 19 (3): 336–44. https://doi.org/10.1016/j.gloenvcha.2009.04.001.

Showalter, Elaine. 2011. The Female Malady: Women, Madness and English Culture, 1830 - 1980. Reprint. London: Virago Pr.

Thompson, Tosin. 2021. 'Young People's Climate Anxiety Revealed in Landmark Survey'. Nature, 22 September 2021. https://www.nature.com/articles/d41586-021-02582-8.

Winsberg, Eric. 2012. 'Values and Uncertainties in the Predictions of Global Climate Models'. Kennedy Institute of Ethics Journal 22 (2): 111–37. https://doi.org/10.1353/ken.2012.0008.

Wunderling, Nico, Jonathan F. Donges, Jürgen Kurths, and Ricarda Winkelmann. 2021. 'Interacting Tipping Elements Increase Risk of Climate Domino Effects under Global Warming'. Earth System Dynamics 12 (2): 601–19. https://doi.org/10.5194/esd-12-601-2021.

Decision-makers without an understanding of the uncertainty in a forecast may be underinformed, placing undue levels of confidence in a forecast.

Chapter 4 AR6 AND MODELLING UNCERTAINTY

INTRODUCTION

The IPCC AR6 WGI report represents an extraordinary challenge for climate risk communication.

Three working groups are responsible for AR6, each looking at a different aspect of climate change: The Physical Science Basis (AR6 WGI); Impacts, Adaptation and Vulnerability (AR6 WGII); and Mitigation of Climate Change (AR6 WGIII). There is also a Task Force on National Greenhouse Gas Inventories. In this case study we look at The Physical Science Basis (AR6 WGI) (AR6 WGI 2021). Specifically, we dive into the Summary for Policymakers (SPM) (IPCC WGI et al. 2021), and the new online visualization tool — the IPCC WGI Interactive Atlas — that offers novel ways to explore climate change projections on flexible spatial and temporal scales (Iturbide, Maialen et al. 2021).

The SPM represents an extraordinary challenge for climate risk communication. The complete AR6 WGI report is based on an assessment of over 14,000 scientific publications on topics like greenhouse gases and aerosols in the atmosphere; temperature changes in air, land, and ocean; the hydrological cycle and changing patterns of rain and snow; extreme weather events; the behaviors of glaciers and ice sheets; oceans and sea level rise; biogeochemistry and the carbon cycle; and climate sensitivity. The report runs to nearly 4,000 pages, which the SPM shrinks to just forty.

In this chapter we look at the principles, strengths and weaknesses of how the new IPCC report communicates uncertainty, with some focus on the SPM. Expressions of confidence are attached to many kinds of statements in AR6 WGI, but since the vast majority of findings relate to modelling, **we focus here on model uncertainty.** The next section outlines three major sources of uncertainty in model-based projections.

Subsections

Another motivation for engaging with model uncertainty is that public discourse on this topic is relatively weak. It is a difficult subject (despite being now a bit more familiar to the public, because of recent coverage of epidemiological models by the mainstream media), and is relatively easily exploited by climate deniers. So it is essential to consider ways we can build a narrative about model uncertainty in order to sustain credibility, trust, and action on climate. We will hone in on model uncertainty, exploring a range of models in the AR6 ensemble; how they and other models are evaluated (and the challenges in doing so); and a range of interrelated geographical and socioeconomic disparities.

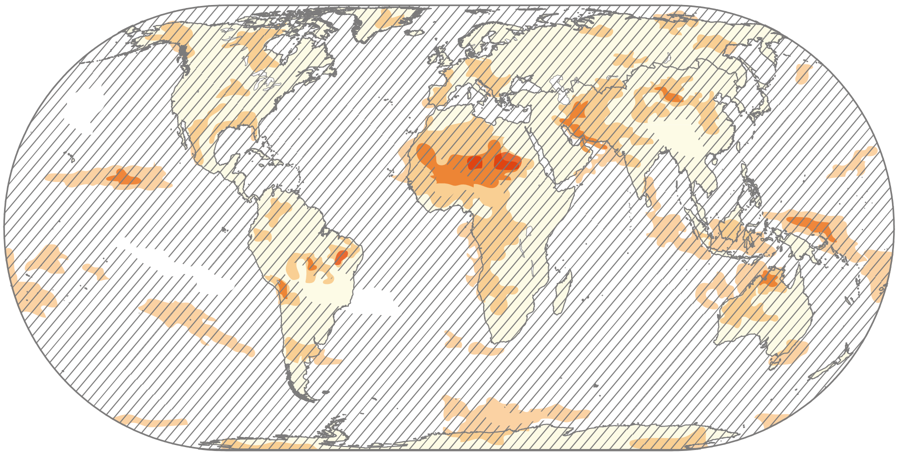


Figure 1. Representing modelling uncertainty as hatched lines overlaid on top of the model-based predictions that are in colour makes it tricky to see where the modelling predictions are reliable and where they are not, as areas free of hatched lines are hard to notice. However, this type of representation of modelling uncertainty is the default option in the AR6 WGI report (print version).

Then we turn to strategies of communication, including language choice, visualisation, and the interactive tools of the AR6. The IPCC is known for its efforts to encourage communication of uncertainty, including standardised terminology (although not yet for modelling), and consistent visualisation conventions (although only in the more widely-read sections). Challenges clearly remain (Budescu, Por, and Broomell 2012; van der Bles et al. 2019; Dieckmann et al. 2017). For example, a look at some of the figures deep in the AR6 WGI report makes it clear that not all authors have followed good practice on visualisations. There are other inconsistencies and choices in design 'language' that are problematic.

For example, in some figures in the AR6 WGI report, hatched lines indicating model disagreement are overlaid on top of colour-coded values *(Figure 1)*. However, at other times the areas that are uncertain are left colour-free *(Figure 2)*. This invites different interpretations: in the colour version, the results might be interpreted as informative but uncertain, whereas entirely removing the colour conveys that reliable regional predictions cannot be made. The lack of a consistent visual vocabulary is not helpful to the audiences that need to relearn graphical conventions for different figures. Visually, the colour-free option is also more legible *(Figure 2)*. Overlaying the lines on the colour background make it very difficult to distinguish areas where the models agree from areas where they don't *(Figure 1)*. The interactive Atlas (mostly) wisely opts for the blank background option.

Trust in climate models is also not independent of trust in other models; comparisons (fair or not) between complex climate models and complex economic models are often made. The inability of mainstream economic and financial modelling to predict the 2008 economic crisis was damaging to the trust people placed in models. Government decisions informed by epidemiological modelling during the Covid-19 pandemic reinforced perceptions of a lack of independence between politics and modelling.

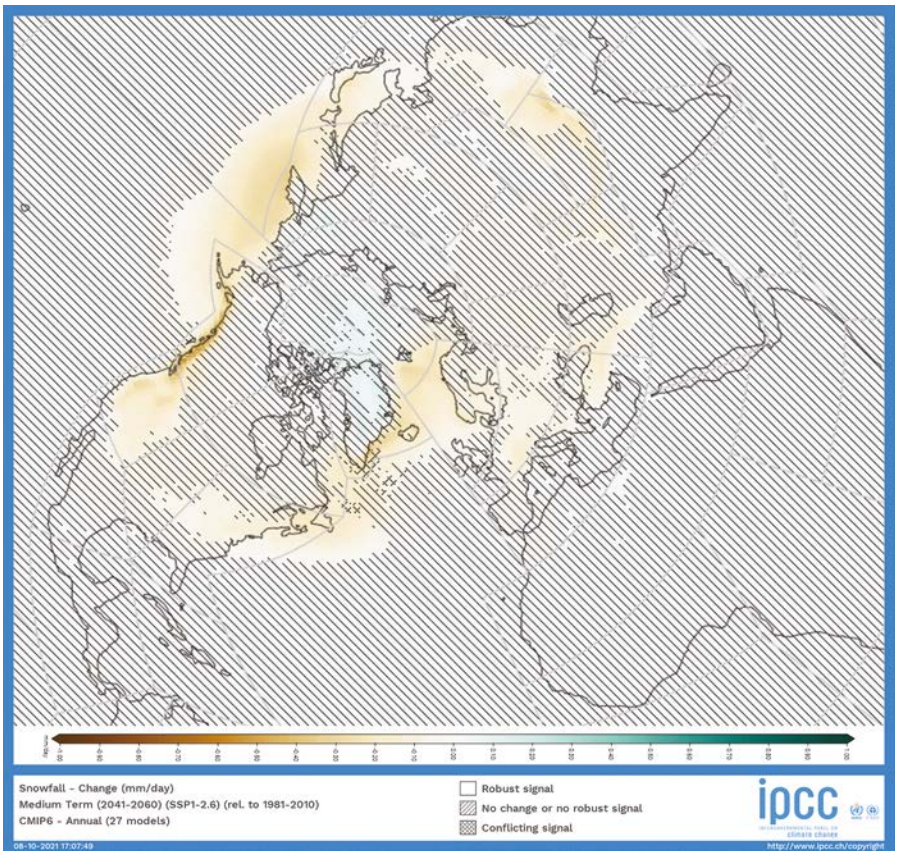


Figure 2. Interactive Atlas example, representing modelling uncertainty. Source: the "Medium Term (2041-2060) SSP1 2.6 (rel. to 1981-2010)-Annual (27 models)" scenario. The darkest colour denotes a change of about-0.5mm per day.

Consistency is clearly to be preferred, all else being equal. Of course, there may sometimes be a rationale for tailoring conventions. The type of uncertainty representation chosen should also take account of the expected size it would be viewed as. Representations of modelling uncertainty are clearer in the interactive online Atlas which, unlike the PDFs, is more likely to be viewed on smaller screens or mobile phones, *Figure 2.*

Beyond the observations of our case study here, research is needed to test the effectiveness of the IPCC's strategies to improve communication of uncertainty. For example, are authors really using uncertainty language consistently? How are such communications being received by different users, and how easily can they translate their information into their own familiar frameworks (e.g. in risk management)? How effectively is uncertainty being communicated in visualisations and interactive tools? Do the conventions that have been devised and discussed with respect to a given data set behave the same when the data changes? Greater consistency and more testing would likely improve user comprehension of these visualisations.

The deeper question remains: how to translate these visualisations into meaningful information about the world? What would it feel like, for example, to live in the world predicted by these snow projections *(Figure 2)*? What would a ½ mm decrease in daily snow precipitation mean for my grandchildren as far as cross-country skiing or snow fights go? Would there be fewer days when they could make snow angels, would they miss a climate they did not know?

SOURCES OF UNCERTAINTY IN MODELLING

There are at least three major types of uncertainty in model-based projection

There are many types of models in the AR6 WGI report. We first consider those in the ensemble — a set of Earth System Models that are run in parallel — to produce key projections for future climate under different emissions scenarios. **Uncertainty in model based projections** is described in the AR6 WGI as arising from three main sources:

- model uncertainty,
- internal variability, and
- scenario uncertainty.

Model uncertainty is also sometimes known as structural model uncertainty or scientific uncertainty. Knowledge may be lacking to choose between different theories of how something works, so different models reflect different understandings of the world. Different Equilibrium Climate Sensitivity (ECS) values emerge as a result of epistemological uncertainties. Model uncertainty is related to model weighting; **some models are downgraded for not performing well according to some criteria, usually in confrontations with observational data.** Ideas of how to weigh models vary. One of the ways to filter models could be to

TYPICAL RELATIVE CONTRIBUTIONS OF
THREE SOURCES OF UNCERTAINTY TO THE VARIABILITY IN FORECASTS

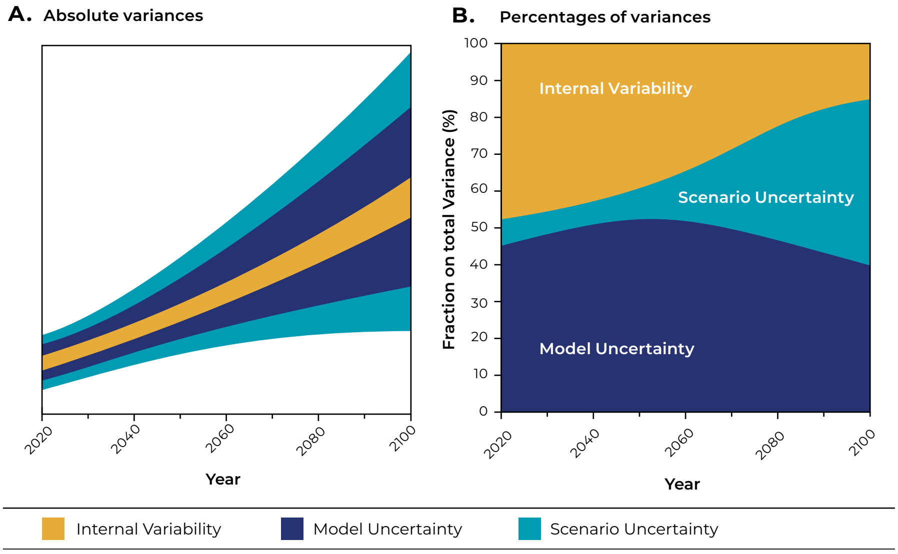


Figure 3. The relative roles of different sources of uncertainty in projections

require them to reproduce specific features that are related to risk, such as the weakening of the Atlantic Meridional Overturning Circulation system of currents (AMOC) that has been detected and that might be implicated in triggering tipping points. Models that don't reproduce these observations could be argued to be unsuitable for assessing future risk of climate change as they are likely to underestimate them.

Internal variability, by contrast, refers to modelled variability in climate behaviour (for example, the Atlantic Multi-decadal Oscillation (AMO), El Niño-Southern Oscillation (ENSO) or The Pacific Decadal Oscillation (PDO)). Other sources of variations might be traceable to exogenous events such as volcanic eruptions (if modelled) or fluctuations in energy received from the sun. Internal variability should mimic natural variability—climate is a complex stochastic system and many perturbations would still be there regardless of how much data we collect and how much better we are able to understand and model various processes.

Finally, **scenario uncertainty** refers to all the uncertainties connected with future human action on mitigation. Additionally, many other sources of uncertainty that don't fall into either of these three categories (e.g. some of those indicated in Chapter 5) may also be relevant.

The impact of these three forms of uncertainty on variability in projections depends on how far along into the future we are looking, on what spatial scale, and also what we are projecting (e.g. the hydrological cycle is an example where the influence of internal variability on the total uncertainty extends to long-term projections, whereas usually internal variability is more influential on the spread in near-term).[1]

Very generally:

- Internal variability and initial conditions account for most of the uncertainty near the start of the forecast and persist throughout projections as an irreducible source of uncertainty. However, it diminishes over time, in most cases, *as a proportion* of the whole variability range, due to the growing prevalence of other sources of uncertainty.
- Model uncertainty is important at all temporal scales, and generally grows over time.
- Scenario uncertainty has little influence at the beginning of the time series, but accounts for a substantial proportion of the variability in the long term.

Two types of visualisations are helpful to communicate relative influence of these main types of uncertainty (Figure 3).

1 As stated in the AR6 WGI: "Internal variability is an irreducible source of uncertainty for mid-to-long-term projections with an amplitude that typically decreases with increasing spatial scale and lead time (Section 1.4.3; Section 4.2.1). However, regional-scale studies show that both large- and local scale internal variability together can still represent a substantial fraction of the total uncertainty related to hydrological cycle variables, even at the end of the 21st century (Lafaysse et al., 2014; Vidal et al., 2016; Aalbers et al., 2018; Gu et al., 2018)" (AR6 WGI 2021).

THE AR6 50 MODEL ENSEMBLE

We should always keep in mind not just what we are communicating, but who is producing the knowledge we communicate ...

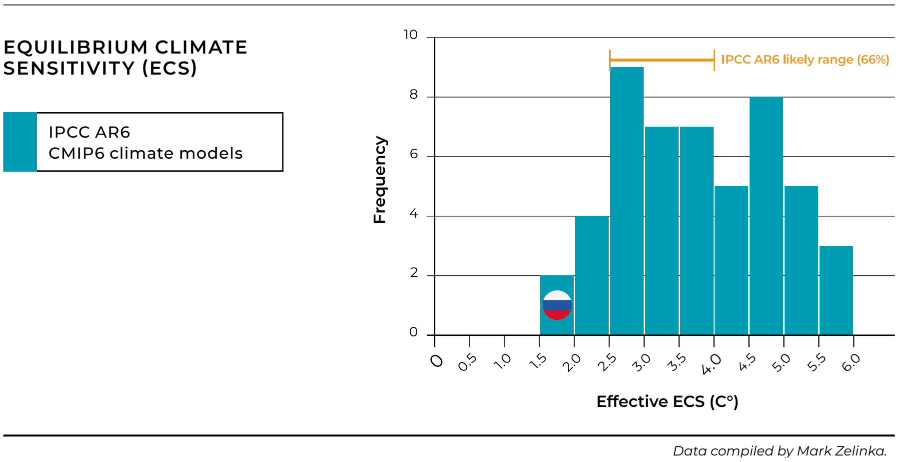


Figure 4. The 50 AR6 ensemble models are characterised by the equilibrium climate sensitivity parameter (ECS).

The AR6 uses an ensemble of 50 main models, each of which imagines temperature responses to an increase in GHGs rather differently. They differ in spatial resolution: climate models divide the world into grid cells, the size of the cell can be coarse (100km length) or very fine (1km length). They differ with respect to exactly what and how they model. They differ with respect to who runs them, and on what computers. Some models describe climates very sensitive to doubling CO2, others less so.

Not all models are treated as equally plausible, so the more extreme versions are given less of a say in the overall results. Figure 3 shows a histogram of equilibrium climate sensitivity (ECS) values from the 50 model ensemble (data available from Mark Zelinka). These values correspond to how much warming each model would predict in a long-term equilibrium if CO2 doubles.[2] The optimistic low values on the left are two Russian models (Schmidt 2021), see also Figure 4. The 66% 'likely' interval bar, above the histogram in Figure 4, refers to the integrated ECS distribution of all 50 models (IPCC WGI et al. 2021). It shows the impact of downweighting extreme models, as it clearly has lower variability than the histogram where all models have equal weight. If IPCC AR6 had treated all models as equally likely (i.e. had not used any model weighting) in its ensemble, its projections (as well as carbon budget calculations) would have come out much more uncertain.

The models are not strictly speaking independent; some of the models have many components in common, share chunks of code, are based around the same theoretical understanding of various processes shaping climates, or use the same assumptions (Abramowitz et al. 2019). There are clusters—some models are more similar than others. All this complicates interpreting the ensemble model mean, and raises concern that all models might be similarly biased.

It is important to keep in mind not only **who we are communicating with** but also **who is producing the knowledge that is being communicated** (van der Bles et al. 2019). The institutes that have produced the 50 models are clustered in Europe, North America, and East Asia (see Figure 5). Location is significant, as the next section explores. The regional disparity within the ensemble also exists in the larger set of models used across the whole of AR6 WGI.

It is important to keep in mind not only who we are communicating with but also who is producing the knowledge that is being communicated.

2 The equilibrium values (ECS) are higher than the transient climate response (TCR) expected under the same models at the time of CO2 doubling (as opposed to after climate reaches a new equilibrium); for TCR, the upper value estimated is 3°C as opposed to 5.6°C for ECS (see ECS values in Figure 4). From a policy perspective, if we are thinking decades ahead then the TCR is more relevant, if centuries then the ECS might be a better guide (Meehl et al. 2020).

REGIONAL DISTRIBUTION OF MODELLING

If you're modelling the whole world, does it matter where in the world you do it? It might …

More research institutions are developing and running climate models than was the case for AR5, but they are not representative. The world is large and detailed, and scientists are relatively few, fewer in some places than in others. Inequities in the distribution of funds available for research, training and data collection contribute to these regional disparities. Despite the fact that nearly 40% of the global population is expected to live in Africa by 2100 (INED 2019), there is a striking lack of models in the ensemble from African research centers. There are not only regional inequalities in the location of CMIP6 institutions (Figures 5 and 6), but also in the availability of data, the scope for evaluating different models, and how informative modelling is for different regions.

Model development has advanced in the world, but Africa still lags as a focus and in its contribution (James et al., 2018). None of the current generation of general circulation models (GCMs) was developed in Africa (Watterson et al., 2014), and the relevant processes in the continent have not been the priority for model development but treated in a one-size-fit-all approach (James et al., 2018) except for a few studies

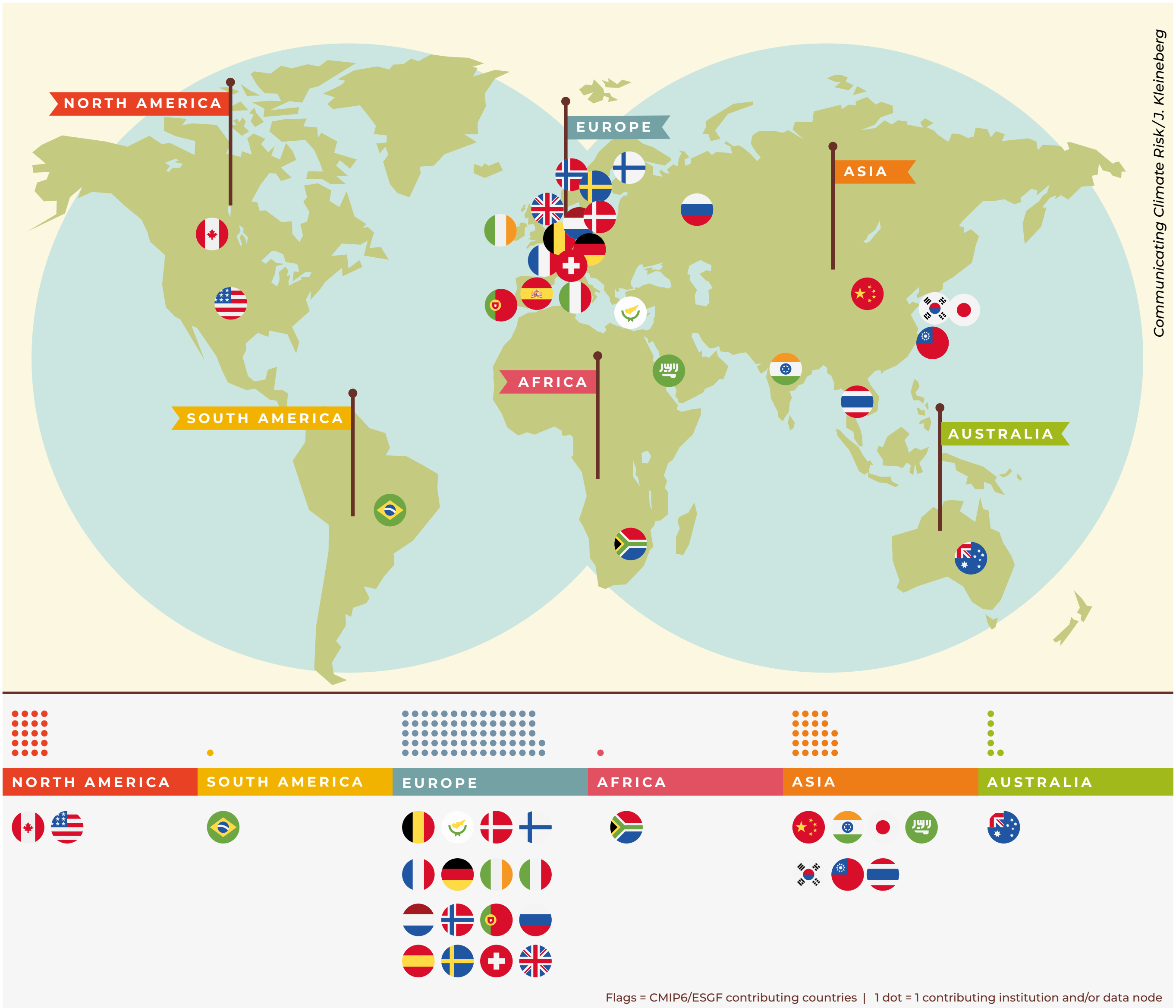


Figure 5. Locations of the institutes contributing to the CMIP6 modelling ensemble that produce projections for IPCC AR6 (data source).

that focused on convective-permitting climate projections (Stratton et al., 2018; Kendon et al., 2019). However, there are growing efforts to boost African climate science by running and evaluating climate models over Africa (Endris et al., 2013; Kalognomou et al., 2013; Gbobaniyi et al., 2014; Engelbrecht et al., 2015; Klutse et al., 2016; Gibba et al., 2019).
(AR6 WGI 2021)

Decision-makers are often interested in predictions for specific regions and for specific climate features. **Data and research-poor regions are often the ones for which predictions are least informative. Yet these same regions are often the most vulnerable**, while lacking both forecasts that could support decision making or means to implement adaptation and risk mitigation measures. Such regions, Central Africa for example, are also the one with the least responsibility for the climate crisis. A lack of well-distributed models also poses the serious risk that some countries will encounter climate mitigation and climate adaptation as an externally-imposed agenda, an agenda freighted with neocolonial significance.

Efforts, such as downscaling, are under way to improve regional forecasts. The new set of models used in AR6 is believed to be more robust in assessing future global surface temperature, ocean warming, and sea-level rise. **In model evaluations, the new ensemble does better than the previous one on many criteria, but not on all.** What does this mean for a more general audience? How do we synthesise and interpret the information on model performance when scientists themselves don't interpret performance metrics in the same way, or always agree on assessments of model skill? If a model seems to perform well in some places but not in others, would the perceived importance (data richness) of one region over another influence our judgment of the overall model's fitness? How can we strengthen narratives and communicative practices around uncertainty in model-based projections? And given that uncertainty can reflect many viewpoints and plausible interpretations of the evidence being brought together, can we recognise the value of increasing uncertainty in some contexts?

Model evaluation, explored in more detail in the next section, is the practice of testing how well a model is performing. **The challenges of model evaluation also vary region by region, in ways which also reflect colonial histories and existing socioeconomic inequalities.** Padilla et al. (2021) imply that the need to communicate the reliability of modelling may be especially strong where there are large humanitarian needs:

the humanitarian sector is increasingly developing standard operating procedures for anticipatory action (Pichon, 2019), including impact-based risk assessments that require policymakers to understand both geophysical and socioeconomic uncertainty (WMO, 2015; Forzieri et al., 2016; Taylor et al., 2021). Decision-makers without an understanding of the uncertainty in a forecast may be underinformed, placing undue levels of confidence in a forecast (Fischhoff, 2012; Fischhoff and Davis, 2014).
(Padilla et al. 2021)

EVALUATING MODELS

Climate models are complex, so they are also complex to evaluate

Lots of data means that the models will fit some historical observations and not others, at some geographical scales but not at others, sometimes preserving the expected patterns of correlations between observations and sometimes not.[3] Given that the observations themselves are uncertain and potentially conflicting (or missing), we should not really expect good models to fit all the data well.

If a model does fit the historical data really well, it may sometimes have no real predictive power. Usually this happens when a model is overparameterized—many parameters enable the fit, but can result in too much noise to make meaningful forecasts.[4] Or it can happen because the processes that shape climate are themselves non-stationary, and structural assumptions are either inconsistent with historical data or invalid for the future. Getting around the fact that external data is lacking when your model makes forecasts on a 100 year scale is not easy: the

3 "In fact, when using observations for model evaluation, there are multiple examples where inter-observational uncertainty is as large as the inter-model variability" (AR6 WGI 2021).

4 "There is high confidence that an ensemble of multiple observational references at a regional scale is fundamental for model performance assessment"(AR6 WGI 2021).

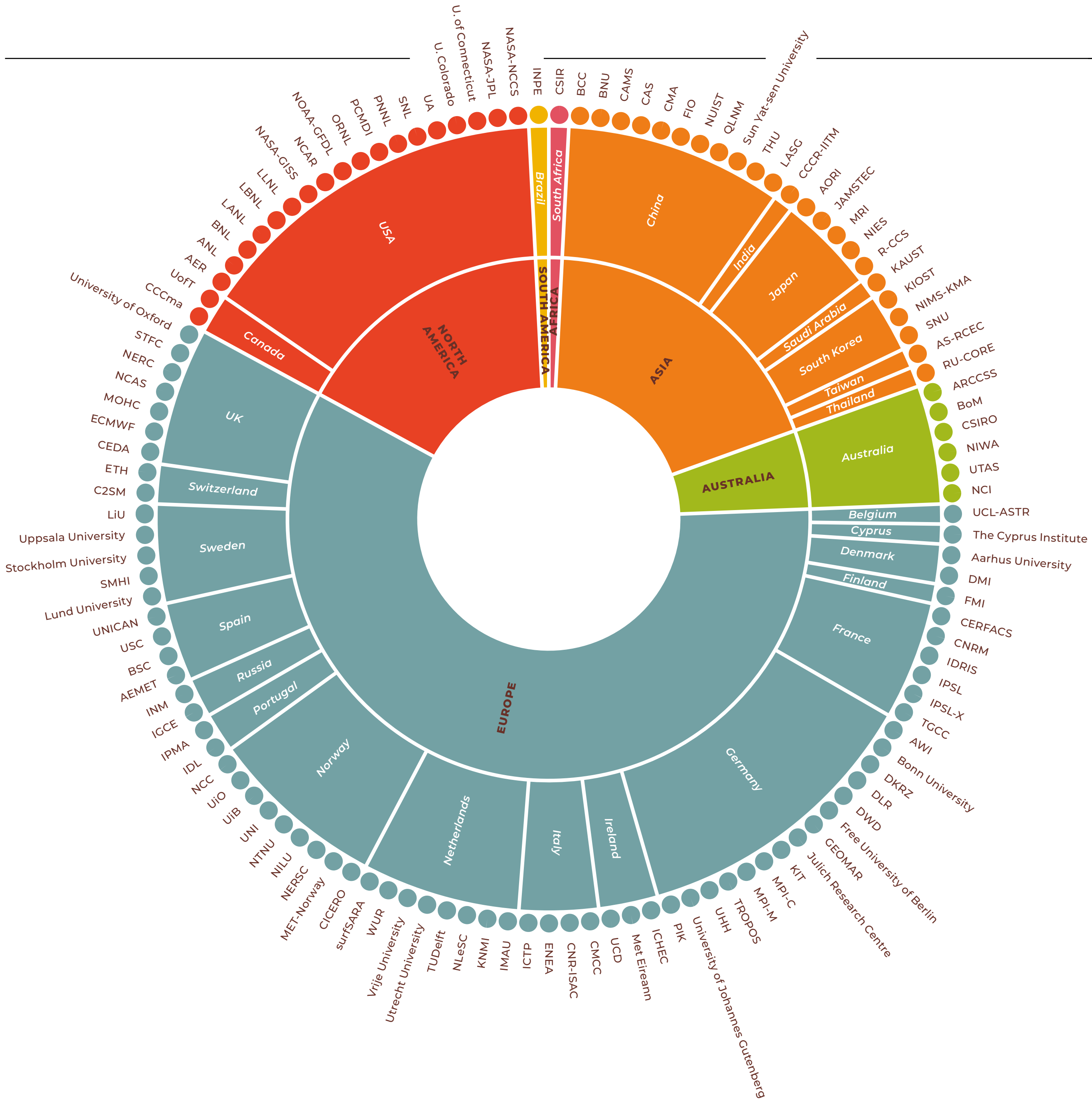


Figure 6. Earth System Grid Federation (ESGF) data nodes and modelling centers contributing to AR6 WGI simulations (data source).

only option is pretty much to substitute another model for the real world to simulate 'external' data for validation (which is an actual part of some model evaluation protocols). Furthermore, what it means for data to fit a model 'well' is rarely well-defined, although in weighting different models within an ensemble, the weighting procedure selected depends on explicit fitness criteria.

There should be different approaches to evaluating models, but having a unifying framework would be useful. Although there are efforts to have a generic open-source framework for evaluating climate models such as ESMValTool, neither methodologies nor terminology on model evaluation are standardised. In various chapters of the AR6 WGI report, the authors speak of model skill, model performance, fitness for purpose, plausibility, Type 1 and Type 2 errors, biases, and so on. Some terms, more common in modelling in other fields, such as 'model validation' or 'hindcasting'—where some historical data is taken away from the model so it can try to predict it—rarely appear in the AR6 WGI report, and various synonyms are used instead.

A key problem with using historical data to assess models are uncertainties in data, especially at regional scales. "The evaluation of model performance at historical variability and long-term changes provides further relevant information (Flato et al., 2014). Trend evaluation may provide very useful insight, but has limitations in particular at the regional scale, mainly due to multi-decadal internal climate variability (Section 10.3.3.8), observational uncertainty (in both driving reanalysis and local trends; Section 10.2), and the fact that often not all regional forcings are known, and that past trends may be driven by forcings other than those driving future trends (Sections 10.4.1 and 10.6.3)" (AR6 WGI 2021).

It is far easier to improve models that make predictions that can be tested often, e.g. weather models. The scarce opportunities for climate models to be confronted with external data presents further challenges. In particular, when they do occur and appear not to go well (e.g. 'hiatus'[5]), trust in climate modelling gets damaged. **Trust in climate models is also not independent of trust in other models;** comparisons (fair or not) between complex climate models and complex economic models are often made. The inability of mainstream economic and financial modelling to predict the 2008 economic crisis was damaging to the trust people placed in models. Government decisions informed by epidemiological modelling during the Covid-19 pandemic reinforced perceptions of a lack of independence between politics and modelling.

Evaluation of models is also uneven across regions, often following the same geographical patterns as data availability and reliability of predictions. For example, there are relatively few studies examining model performance over Southwest Asia.[6] Sometimes it is Catch-22: to assess if a model is fit-for-purpose demands a more detailed model that is harder to parameterise in data-poor regions.

Within a given geographical region, model performance may also depend on the aspect of the climate being modelled. For example, in Africa some features of current climate are captured by some of the climate models while others (such as rainfall over Uganda) are not (Kisembe et al. 2019). Some regions (e.g. Central Africa) might lack historical observations, not only leading to poor quality predictions, but also making it difficult to assess if the model is fit-for-purpose as such evaluations sometimes must rely on more detailed models (that require higher resolution data and longer time series data to be properly conditioned). "Fitness-for-purpose can also be assessed by comparing the simulated response of a model with simulations of higher resolution models that better represent relevant processes (Baumberger et al., 2017)" (AR6 WGI 2021).

LANGUAGE TO DESCRIBE UNCERTAINTY IN AR6 WGI

Efforts have been made to improve the consistency of uncertainty language, but there is more work to be done when it comes to model uncertainty

The IPCC has held workshops, issued guidance, and held discussions on how to reduce linguistic uncertainty and judgment uncertainties (see Box 1.1, Figure 1 in AR6 WGI). The aim was to have a standardised language to describe uncertainty, so that at least the report is internally consistent when it comes to expressions of confidence and likelihood, terms known to have very subjective meanings. In 'Confident, likely, or both? The implementation of the uncertainty language framework in IPCC special reports,' Janzwood reports on the results of interviews with many of the scientists involved in the IPCC. Despite available guidance, these terms remain stubbornly hard to apply consistently across various contexts in the special reports, and subjectivity remains hard to subdue (Janzwood 2020). For example, they find that "high confidence" can mean either subjective belief about a level of agreement among experts, perception by the author of the state of existing literature, interpretations of agreement between models, relativist perceptions on the abundance and quality of evidence/data, and so forth. Lower gradings could easily fail to differentiate between shortcomings in data, knowledge, model agreement, consensus among experts, etc. (Janzwood 2020).

5 Trust is easy to lose, and hard to regain. Making bad predictions can damage perception. Negative confrontation with data tends to receive more attention and stick in the public imagination: "One of the topics widely discussed even outside of the climate science community was the apparent 'failure' of the CMIP5 models to reproduce the warming hiatus seen in observations of the global mean warming rates from 1998 to 2013. Because of the high attention this topic received, there were even potential implications on the public perception of the trustworthiness of climate models and climate projections in general. It has been shown that the hiatus was likely predominantly a result of internal climate variability with the phase of the IPO playing an important role" (Bock et al. 2020).

6 "There is limited evidence about the performance of GCMs and RCMs in representing the current climate of southwest Asia due to very few studies evaluating models over this region, but literature is now emerging particularly on CMIP5/CMIP6 and CORDEX simulations" (AR6 WGI 2021).

The term 'virtually certain' is used in the AR6 WGI relatively infrequently but sometimes crucially: "It is virtually certain that global surface temperature rise and associated changes can be limited through rapid and substantial reductions in global GHG emissions."

The term 'virtually certain' is used in the AR6 WGI relatively infrequently but sometimes crucially: "It is *virtually certain* that global surface temperature rise and associated changes can be limited through rapid and substantial reductions in global GHG emissions."

There is a category above 'virtually certain' that is called 'fact' in the report. Table TS.1 names two facts: the world has warmed and we caused it (AR6 WGI 2021). The report is *virtually certain* that extreme warming events will increase in frequency as the climate continues to warm.[7] It is *virtually certain* that the Northern Hemisphere will see less snow. It is *virtually certain* about ocean acidification and changes in stratification. However, the likelihood and the direction of changes is often insufficient for decision-makers who want to know the magnitude, location and time period (and the relevant uncertainties).

While there was investment in harmonising the process by which authors report on uncertainty in general, there is less consistency about the language used to describe uncertainty related to modelling. While generic tools are being developed to test models, appraisals of models' predictive skills and comparisons between relative reliability of models are not transparent.

It is difficult to find uniformly described information in the AR6 WGI report (or elsewhere) about what uncertainties are important in what models and why, which uncertainties the modellers were able to account for and which ones they could not, how the models were validated, tested or evaluated, what appears to be the main concerns in terms of sensitivity of the results, and so forth. How were these uncertainties elicited in the first place? Was there an assessment of consensus among the experts? Greater transparency about uncertainties in modelling and their fitness for purpose in various relevant decision-making contexts is required.

VISUALISATIONS OF UNCERTAINTIES

Here's our verdict on two visualisations from the SPM

There are two general categories of uncertainty visualization:

- Intrinsic representation techniques integrate uncertainty by varying the appearance of the variable being visualised (e.g. shape, texture, brightness, opacity, hue)
- Extrinsic representation techniques involve addition of geometry to describe uncertainty (e.g. arrows, error bars, charts, glyphs)

AR6 WGI uses both techniques, sometimes in the same figure, for example AR6 WGI Figure SPM.3 (partly reproduced below as Figure 7). Ideally uncertainty visualisations are evaluated through testing, using robust methodology that does not only rely on self-reporting. In this chapter we make do with close interpretative readings, guided by principles such as the principle of appropriate knowledge and the semantic principle (see Chapter 5, 'Hacks, Insights, and Resources').

7 "Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, medium confidence. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90– 100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, very likely. This is consistent with AR5. In this Report, unless stated otherwise, square brackets [x to y] are used to provide the assessed very likely range, or 90% interval" (AR6 WGI 2021).

VISUALISING PRECIPITATION TRENDS

Figure 7 shows part of Figure SPM.3, which visualises observed change in precipitation worldwide and the confidence with which it can be attributed to human-caused climate change. We also present a slightly modified version (Figure 8) to aid in the discussion.

Several sources of uncertainty related to attribution are aggregated into one measure called "Confidence in human contribution." Confidence in attributions has three levels (high, medium, low), and four options (high, medium, low due to limited agreement, low due to limited data). For this Toolkit, we have not been able to run objective tests on comprehension of these visualisations, but we invite readers to consider several questions to evaluate them informally. For example: Do they communicate effectively to core users? Do they provide accessible pathways for audiences who are not core users, but are nonetheless interested? Do they capture the attention of people who really should be core users, whether they know it or not? How easy is it to find the relevant information? Are these figures aesthetically expressive? Will the conventions chosen reinforce, rather than undermine, what the figures need to communicate? Are there potential unintended associations, such as grey diagonal stripes representing rain, or the 'blank' interior of Africa invoking neocolonial imaginaries (see **the semantic principle** in Chapter 3, 'Hacks and Insights')?

For many audiences, the most striking message of Figure 7 will be that **so many parts of South America and Africa are characterised by "limited data and/or literature"** on observed change (with North America, Australasia and the South Pacific also patchy, containing several regions characterised by "low agreement in the type of change"). Part of the explanatory text reads:

The IPCC AR6 WGI inhabited regions are displayed as hexagons [grouped in an anthropocentric way to reflect where people live, described elsewhere in the report] with identical size in their approximate geographical location (see legend for regional acronyms). All assessments are made for each region as a whole and for the 1950s to the present. Assessments made on different time scales or more local spatial scales might differ from what is shown in the figure.

The last bit involved some controversy during the SPM approval process. A number of delegates, especially from Global South countries, objected to their regions being characterised as having insufficient evidence.

ANGOLA noted that for AR5, there was information on precipitation in Africa, generally indicating precipitation had decreased, but Figure SPM.3 contradicts AR5 in claiming insufficient evidence. The authors said the regions were aggregated at the subcontinental level to be large enough to generate a good evidence base from the modeling, to then be matched to evidence from the literature, and that much regional evidence is assessed in the underlying chapter but is insufficient to be aggregated to the scale of Figure SPM.3. (Bansard and Akanle Eni-ibukun, n.d.)

Trends detectable in one location do not necessarily translate into detectable trends on a larger scale, even if all local trends within a larger area show significant trends. This can happen if trends in adjacent areas are in conflict, when they should agree. Disagreement with geographically adjacent trends can be a sign that regional predictions are of poor quality and not fit for purpose. The delegates'

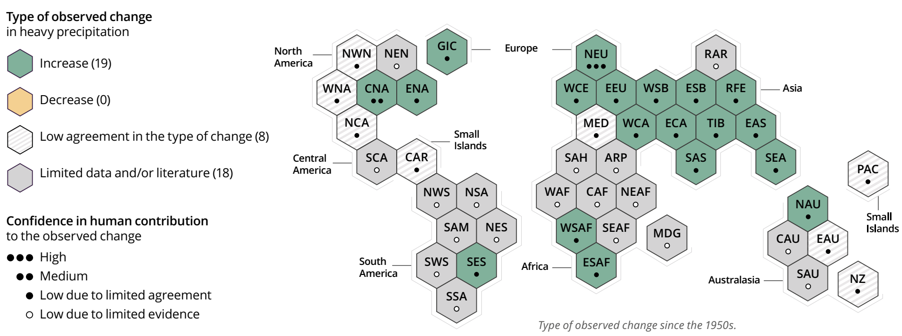


Figure 7. Part of IPCC WGI AR6 SPM.3, recreated.

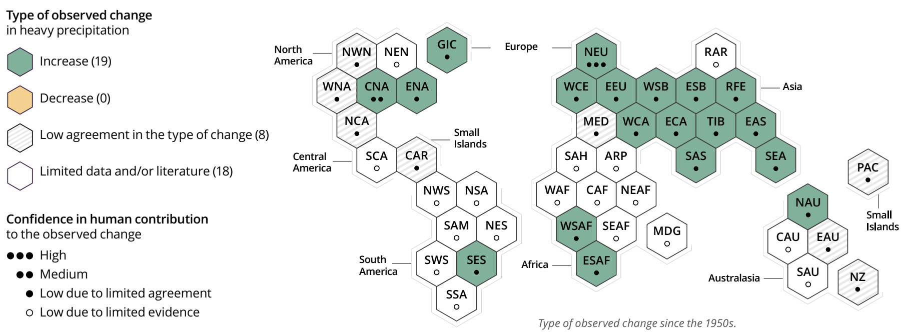


Figure 8. Suggestions for improving uncertainty visualisations for Figure SPM.3 (IPCC WGI et al. 2021)

discussion illustrates how **even experts are challenged by the fact that you may appear to know something at a smaller geographical scale only to see that knowledge questioned at a more aggregated level.** Usually it is the other way around — we can estimate global trends, e.g. temperature, more reliably than local ones. More generally, confusion over uncertainty at different spatial scales is a persistent problem for communicating climate risk:

> *There is no one-size-fits-all method for representing robustness or uncertainty in future climate projections from a multi-model ensemble. One of the main challenges is the dependence of the significance on the spatial scale of interest: while a significant trend may not be detected at every location, a fraction of locations showing significant trends can be sufficient to indicate a significant change over a region, particularly for extremes (e.g., it is likely that annual maximum 1-day precipitation has intensified over the land regions globally even though there are only about 10% of weather stations showing significant trends; Figure 11.13). The approach adopted in WGI works at a grid-box level and, therefore, is not informative for assessing climate change signals over larger spatial scales. For instance, an assessment of the amount of warming required for a robust climate change signal to emerge can strongly depend on the considered spatial scale. A robust change in the precipitation extremes averaged over a region or a number of grid-boxes emerge at a lower level of warming than at the grid-box level because of larger variability at the smaller scale (Cross-Chapter Box Atlas.1, Figure 2).*
> *(AR6 WGI 2021)*

The delegates eventually agreed amendments "to distinguish between low confidence [in human contribution] due to limited agreement and that due to limited evidence, as well as between low agreement in the type of change and limited data and/or literature"(Bansard and Akanle Eni-ibukun, n.d.). Presumably when there is low confidence in the type of change, there cannot be sufficient confidence in human contribution. The fact that there are no grey hexagons with black dots seems to confirm this. Of course, some redundancy is not necessarily a bad thing in data visualisation; however, these amendments do bear the hallmarks of the context of deliberation, politicking and compromise in which they arose. Is there any alternative? Perhaps a structured collaboration between scientists and graphic designers to refine visualisation problems, explore creative solutions, test graphics with audiences, and present options for review and approval.

The amendments also demonstrate the challenge of choosing the right level of detail in communicating uncertainty. Considering Angola's concerns (and setting aside the attribution aspect), the delegates' decision to differentiate "insufficient evidence" into "low agreement" and "limited data and/or literature" arguably only makes things worse.

Given the reasonable assumption that users will expect information about where heavy rain or snow may be increasing or decreasing, and given the fact the figure makes *some* differentiations between different forms of insufficient evidence, perhaps even more detail is necessary about why the figure does not provide trend information for some regions. Without more information, there is a risk of playing into a long history of colonial Western cartography, in which Africa has been shown as blank (Bassil 2011; Jarosz 1992). For example, the summary could have mentioned that in some places the time-series data are shorter and hence noisier, obscuring trends (if that was the case). What this map does say is that we can already detect human-caused impacts of climate change on precipitation in two regions (Northern Europe (NEU) and Central North America (CNA)) with at least medium confidence. It would be unlikely for climate change to manifest uniformly across space and time, so there are likely natural reasons for these discrepancies also.

Another aspect of Figure 7 that is worthy of consideration is the use of colour to represent both the *assessed quantity* (increase or decrease in observed precipitation) and *reliability* of assessment.

> ***The colours** in each panel represent the four outcomes of the assessment on observed changes. **White and light grey striped** hexagons are used where there is **low agreement** in the type of change for the region as a whole, and **grey hexagons** are used when there is **limited data and/or literature** that prevents an assessment of the region as a whole. Other colours indicate at least medium confidence in the observed change.*
> *(AR6 WGI 2021)*

Glyphs in terms of stripes represent model disagreement, but it might have been better to use blank space to denote limited evidence, especially because the colour grey being used to denote limited evidence has other semantic connotations in this context (grey skies filled with rain and snow). The use of stripes to represent disagreement in predictions is more or less consistent throughout the report as well as online (interactive-atlas.ipcc.ch/). Grey is not used as a signifier of limited evidence in the Atlas: a more consistent graphical language that bridges both static and interactive illustrations should be explored. Leaving the grey hexagons blank, as we illustrate in Figure 8, would also be more internally consistent with blank circles representing limited evidence in attribution studies, as Figure's explanatory text describes:

> *The confidence level for the human influence on these observed changes is based on assessing trend detection and attribution and event attribution literature, and it is indicated by the number of dots: three dots for high confidence, two dots for medium confidence and one dot for low confidence (filled: limited agreement; empty: limited evidence)*
> *(AR6 WGI 2021)*

Overall, the graphic looks clean and appealing, but it is open to debate whether the information on uncertainty is being represented well, so that people can read and understand the information off the chart correctly and efficiently.

CLIMATIC IMPACT DRIVERS (CIDS) IN SPM

Climatic impact drivers (CID) refers to many different physical climate system conditions such as heatwaves and cold spells, snowstorms and avalanches, cyclones and dust storms, floods and droughts, and other means, events, extremes, that can affect ecosystems and societies. Figure SPM.9 presents a synthesis of AR6 WGI reference regions where CIDs are projected to change. High and medium confidence are differentiated with dark and light shades within a stacked bar chart, where the bars sit against a background of an even lighter 'envelope' that represents the number of regions where the analysis is relevant.

There are several sensible design choices made here. Lighter shades have been chosen to represent less confidence, and the lighter ink is more distant from the axis. See *Visualising Uncertainty: An Introduction* (Levontin et al. 2020) for more on hue, saturation and colour value, as well as modifications such as blurring and pixelation, to convey uncertainty. The phrases "number of land & coastal regions" and "number of open ocean regions" both appear twice, relatively prominently, to help preclude the misinterpretation that the chart is something to do with the magnitude of projected changes, rather than the number of areas in which changes are projected. The relatively prominent separation of the Open Ocean is also appropriate; however, on the other hand (as discussed below) it is perhaps still not prominent *enough*, perhaps inviting illegitimate comparisons across the two columns. Furthermore, the 'Assessed Future Changes' legend is formatted in a way that opens it to misinterpretation: does it refer to the whole chart, or only column B?

A summary of discussion on this figure (SPM.9) at the intergovernmental negotiations offers further insights into the politics of visualisations. Representations are never 'objective' or 'neutral' but reflect subtly cultural, political and social values — a fact that is rarely acknowledged, but that might be explored by close textual analysis of deliberations, or notes based thereon.

> *The US suggested specifying that all regions are "projected to" experience changes in at least five CIDs, instead of "will," and specifying this is the case "at 2°C warming." LUXEMBOURG requested adjusting the visualization so that the upper end of scales on the number of regions aligns with the maximum number of land and ocean regions considered. CANADA called for specifying the number of regions for which each CID is applicable, noting that for instance, only some regions have snow glaciers. The REPUBLIC OF KOREA and the US requested clarifying whether changes relate to increases in frequency, intensity, or duration, noting this is not evident for all CIDs. The NETHERLANDS, SPAIN, and MEXICO called for presenting information in a more region-specific manner to increase policy relevance. Other comments related to: reinstating a map showing the regions that are considered in the figure; including meteorological droughts; and referring to coastal and "open ocean" CIDs, instead of "oceanic." The US asked what type of assessment was conducted for agricultural and ecological droughts, noting some indices are highly dependent on temperature. The authors noted they did not use any metric based on temperature, primarily relying on soil moisture. The figure was approved, with revisions including the addition of an "envelope" representing the maximum number of regions for which a CID is relevant.*
> *(Bansard and Akanle Eni-ibukun, n.d.)*

Poor visualisations is one of the costs of the institutional arrangement for agreeing on visualisation that precludes a possibility of testing the proposed amendments to graphics with audiences. One risk is that multiple amendments will be considered separately and approved as good ideas, but interact in adverse ways. A potential benefit of the deliberative process is the generation of relatively ample explanatory notes, although there may also be a tendency to over-rely on them throughout AR6 WGI. With any iterative de-

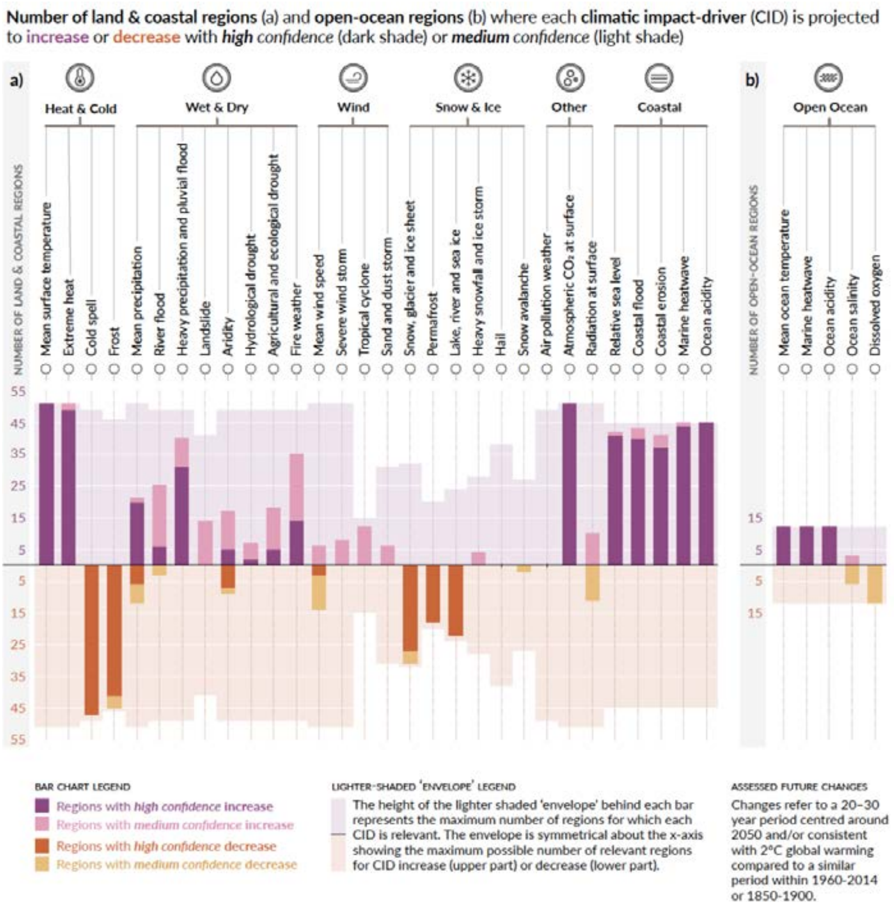


Figure 9. Partial reproduction of SPM. 9 (IPCC WGI et al. 2021)

sign process, there is always the risk that the final stage of amendments prior to a release will introduce entirely new problems. This can partly be addressed by insisting on further review where amendments are other than very minor; in the context of visualisation, however, even an apparently very minor amendment can sometimes have a large impact on how the visualisation works.

In the case of the SPM.9, the added 'envelope' (the pale, symmetrically ragged background to the bars) is a relatively poor visualisation element which is open to being misinterpreted or ignored. For example, the number of regions for which a CID was found to be significant might easily be confused with the magnitude of an impact, despite the text telling us otherwise. It is also misleading in the way that extreme events over oceans appear 'less likely' (the smaller envelope on the right). However this is only due to the fact that there are much fewer regions. Increases in hazards, such as heat waves and acidity, are in fact expected to occur over 100% of the area (ocean), yet they look less likely than heat waves on land that are also projected to occur over 100% of the area (landmass), only because the area (landmass) was subdivided into more parts, making the envelopes larger and the heights of the bars in the figure higher. Further, it is left unclear what the baseline is (is it starting in 1890 or 1960?).

Other approaches could be explored and tested. There could be an argument for transposing the chart sideways. On the downside, the distinction between increase and decrease would be less marked on such a rotated version, and would require careful and prominent labelling. On the other hand, the labels of each CID might be more easily read. There also might be a slightly easier on-ramp for the audience, likely to start at the top of the list with some relatively obvious CIDs (mean surface temperature, extreme heat, cold spell). On the actual visualisation, the eye is drawn to spend more time at the centre of the diagram.

Why is the figure whose main point is the geographical extent of specific changes not plotted on a map, perhaps with fewer CIDs represented or more aggregation? Another option to explore would be a set of mini-maps (perhaps one for 'Heat & Cold,' one for 'Wet & Dry,' and so on). In Figure 9, the wide range of different CIDs considered and the ambitious compression of information has led to the ambiguities noted by the delegates from the Republic of Korea and the USA ('increase' or 'decrease' in what sense?), which could perhaps be resolved by differentiating into separate mini-maps.

Overall, the figure is once more clean and elegant, with several sensible choices, but there may be room for further experimentation and improvement.

Poor visualisations is one of the costs of the institutional arrangement for agreeing on visualisation that precludes a possibility of testing the proposed amendments to graphics with audiences.

THE AR6 WGI INTERACTIVE ATLAS

"In a society accustomed to overconfident forecasters who mistake the confidence they express in a forecast for its veracity, expressions of uncertainty are not seen as a winning strategy by either side." (Silver 2013)

The interactive Atlas represents a major step forward in communicating climate risk by the IPCC. In particular, there is much more consistency to representing uncertainty in maps. Further, researchers tested proposed visualisations with the audiences. It is always recommended to do so. The research found:

> *[...] wide-ranging interpretations and varied understandings of climate information amongst respondents due to the choice of visuals. In addition, Taylor et al. (2015) found that preferences for a particular visualization approach do not always align with approaches that achieve greatest accuracy in interpretation. Choosing appropriate visuals for a particular purpose and audience can be informed by testing and evaluation with target groups.*
> *(AR6 WGI 2021)*

Who is the Atlas for? The intended audience includes everyone, including policymakers, but not necessarily in all situations:

> *Communication aimed at informing the general public about assessed scientific findings on climate change have a different purpose and format than if intended to inform a specific target audience to support adaptation or mitigation policies (Whetton et al., 2016). The growing societal engagement with climate change means IPCC reports are increasingly used directly by businesses, the financial sector, health practitioners, civil society, the media, and educators at all levels. The IPCC reports could effectively be considered a tiered set of products with information relevant to a range of audiences.*
>
> *The Interactive Atlas does provide access to a collection of observational and modelling datasets, presented in a form that supports the distillation of information on observed and projected climate trends at the regional scale. Access to the repository of underlying datasets enables further processing for particular purposes. As noted above, it is not the intention nor the ambition of this IPCC assessment and the Interactive Atlas component to provide a climate service for supporting targeted policies. For this an increasing number of dedicated climate change assessment programs have been carried out, aiming at mapping climate change information relevant for adaptation and mitigation decision support.*
> *(AR6 WGI 2021)*

Representing uncertainty as clearly and eloquently as the Atlas endeavours is not without risks. Communicating about uncertainty and reliability is seen by many scientists as the basis of maintaining trust in science within a larger society (cf. e.g. O'Neill, 2012; Stocker et al., 2013; Van Der Bles et al., 2020; Padilla et al. 2021). During the COP26 Universities Network's Climate Risk Summit, we asked participating scientists whether they believed that uncertainty should be communicated even when uncertainty is small — 100% replied 'yes'.

Nevertheless, uncertainty in climate science has been derided, politicised, and weaponised across the political spectrum (Silver 2013). Uncertainty has served both to sow doubt about the urgency of addressing climate emergency and to heighten a sense of emergency. The obstacles to reasonable climate action often are not clarity and credibility, but rather economics and politics, and so it is often certitude that is demanded by decision-makers, environmental activists, and concerned citizens. And it is certitude that is sometimes provided (often with good cause) by the scientists.

Hopefully the Atlas will serve to increase popular understanding of both models' usefulness and their limitations. Nevertheless, it is clearly only a first step, and one which poses many questions. Which users have appropriate knowledge to correctly interpret the displays? Can the Atlas come with more resources aimed at developing the knowledge and graphicacy needed to interpret it? What VR, AR and other immersive storytelling implementations may spin off from the Atlas? Does the Atlas presage more interactive decision support tools which are more explicitly designed to integrate modelling and stakeholder deliberation, and what dangers might this pose for unaccountable "black boxes" in participatory decision-making processes? The Interactive Atlas is interactive, but is it playful? Does it encourage learning, creativity, collaboration, exploration and the sharing of knowledge? How do the Atlas's maps compare to the many other alluring interactive maps available online (such as Google Maps)? The IPCC's texts and visuals have been created with the tacit assumption that others will translate them into many different appropriate contexts; does the Atlas supply appropriate resources for interactive designers?

SEVEN RECOMMENDATIONS FOR THE IPCC AND THE MODELLING COMMUNITY

Recommended areas for action and further research

1) Communicate key assumptions around model uncertainty: "Global model includes all relevant regional forcings and realistically simulates all relevant regional scale processes and feedbacks and their dependence on large-scale climate. Parameterisations are valid in future climate" (IPCC WGI et al. 2021). For example, all future projections depend on the assumptions that existing knowledge of the processes that shape the climate system is accurate and applicable in the future. Under what conditions would this assumption be invalid? Can the processes change, e.g. if the climate crosses a tipping point? Can our knowledge about them change so as to lead to entirely different forecasts? Only qualitative answers to these questions are often possible, and measuring consensus (see below) becomes especially important for communication.

2) Explore how to better foster interdisciplinarity. When developing visualisation formats, or other means of communicating model uncertainty, favour interdisciplinary teams across the sciences, social sciences, arts and humanities, as well as non-academic participants, especially core end users. The case to do so is even stronger in respect of interactive formats such as the Atlas and any successors, and might include for example social scientists and arts and humanities with expertise in AI and automation and critical data studies, as well as more obvious fields such as the environmental humanities.

3) Encourage scientists to adopt a common vocabulary for discussing models' predictive skill, methods to assess whether a model is fit for purpose, and procedure for weighing or rejecting models. Conduct workshops dedicated to finding common approaches to communicating the results of these evaluations.

4) Improve representation in the modelling community. There is a need for a wider discourse on model validation, the subjectivities it involves — this is one reason to include in the research (e.g. workshops mentioned above) a greater diversity of participants. Similarly, collect and report data on representation (especially race and gender) among the climate modelling teams, and take strong measures to improve representation. Modelling is a quantitative way to create narratives about our futures, and narratives empower us to intervene in these futures via shared cultural imaginaries. African futures, for example, should not be forecast by teams that exclude Africans.

5) Develop more best practice for communicating the reliability of forecasts. Find ways to disengage if necessary. One of the hardest things for a modeller to say is, "I don't think my model is good enough for the question you are asking." Where there is high uncertainty but no feasible opportunity to communicate it to the relevant decision-maker given the available time and resources, there is the danger that modelling can no longer serve transparency or robust decision-making. Visualisations, such as Figure 11, can help scientists communicate how a model's skill varies across temporal and spatial scales — it is generally easier to predict changes for large areas in the near future, than on a finer scale and far into the future.

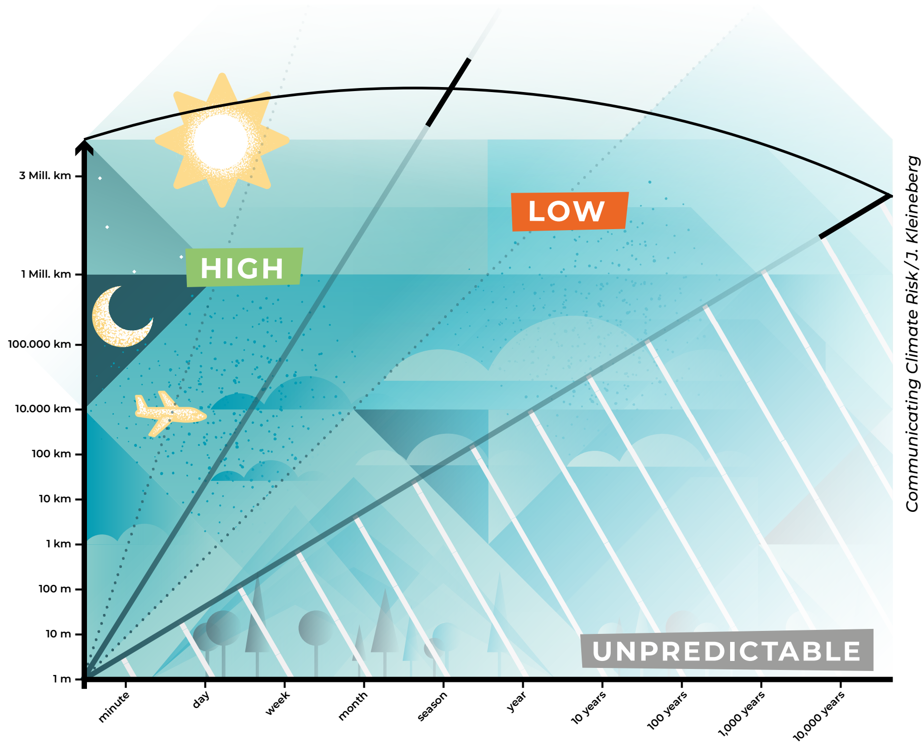
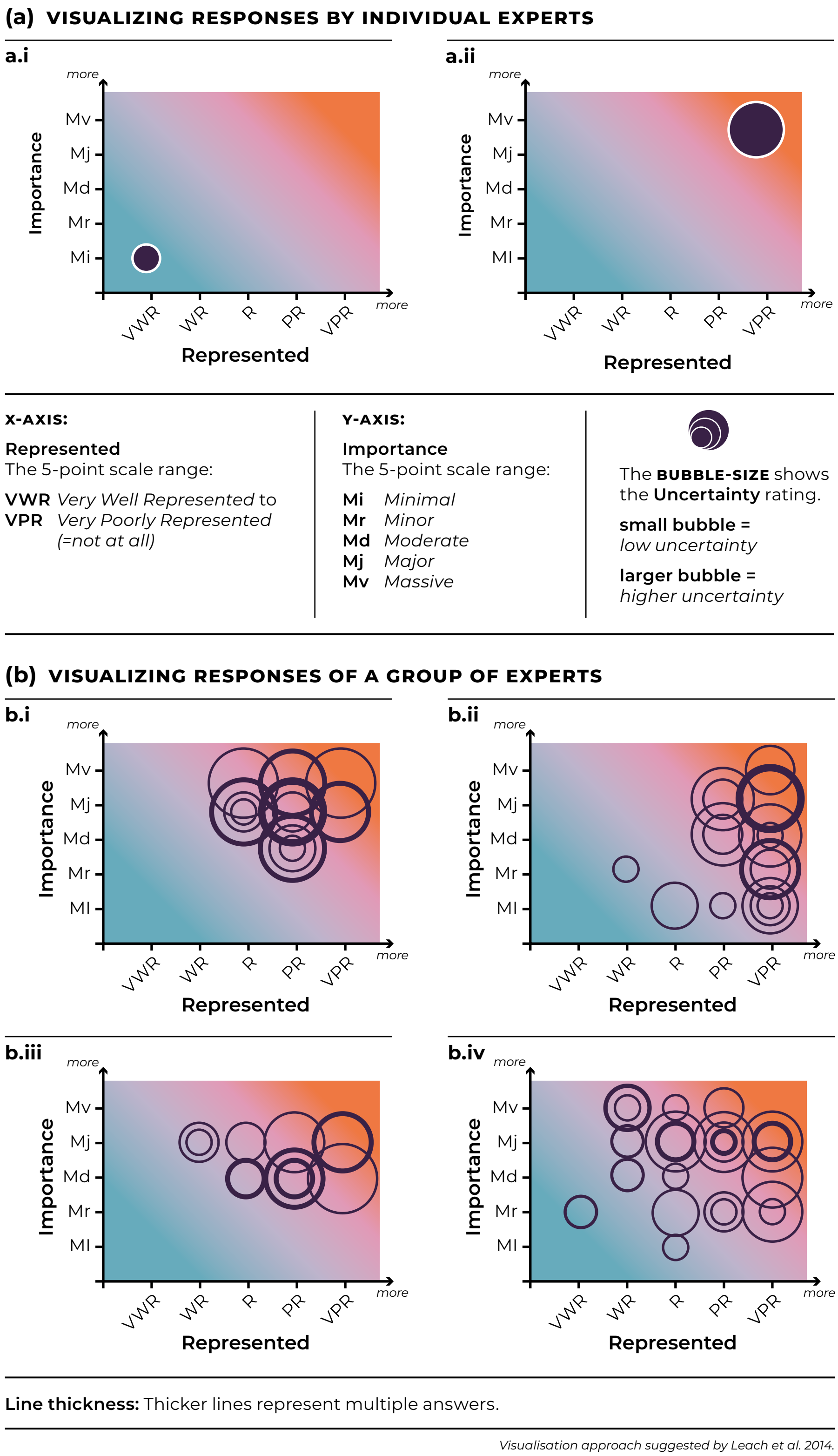


Figure 10. Illustrating how model prediction skill depends on spatial and temporal scales.

First, conduct expert elications and/or literature review to scope a list of relevant uncertainties, and group them in pertinent ways (e.g. data and processes). Use a formal process to investigate perceptions of uncertainties identified in the scoping stage among the scientists collaborating on a specific modelling project.

Figure 11. Prioritising uncertainties based on a formal expert elicitation process that also accesses consensus [(Leach et al. 2014)].



6) Address a mismatch between the expectations of decision-makers and perceived ability of models to make predictions meaningful to policy on regional scales:

> *While the ability of global models to simulate large-scale indicators of climate change has improved since AR5 (Chapter 3), the simulation of regional climate and climate change poses an additional challenge. Users demand regional climate projections for decision making and have high expectations regarding accuracy and resolution (Rössler et al., 2019a), but some scientists consider such projections still a matter of basic research (Hewitson et al., 2014a).*

Policymakers often want forecasts on specific temporal and spatial scales. Currently, models are rarely fit for purpose to make such predictions. Even models that appear reliable when it comes to predicting averages might not be so when it comes to predicting rare events that live in the hard to estimate tails of probability distributions. It is not only harder to make predictions about the tails, having less data to estimate rare events means also having less data to evaluate the quality of predictions. The IPCC AR6 are open about such difficulties but not necessarily transparent because of the language used to communicate this:

> *In particular extreme events are often caused by specific, in some cases persistent, circulation patterns (Sections 11.3–11.7). It is therefore important for climate models to reasonably represent not only continental, but also regional climate and its variability for such extremes. As explained in Section 3.3.3, standard resolution GCMs can suffer biases in the location, occurrence frequency or intensity of large-scale phenomena, such that statements about a specific regional climate and its change can be highly uncertain (Hall, 2014).*

7) Measure and visualise consensus (or its lack) on uncertainties. First, conduct expert elications and/or literature review to scope a list of relevant uncertainties, and group them in pertinent ways (e.g. data and processes). Use a formal process to investigate perceptions of uncertainties identified in the scoping stage among the scientists collaborating on a specific modelling project.

A visualisation approach suggested below (Leach et al. 2014) can be a useful tool to prioritise uncertainties that need to be communicated. It is also a useful exercise for helping researchers reflect on their current research in new and fruitful ways, and perhaps shape future priorities.

Three aspects of each source of uncertainty should be investigated (Figure 11a):

- **Importance:** believed potential to affect modelling results (e.g. how sensitive are model results to small changes in the source of uncertainty). Shown on y-axis.
- **Level of uncertainty:** ranging from "low" where a variable is believed to be well understood to "high" where there is little information about the variable or it is known to be highly uncertain. Shown on x-axis.
- **Representation:** to what extent analysis already accounts for this source of uncertainty. Shown by bubble size.

The background of Figure 11 intends to provide an additional visual cue as to which uncertainties should be prioritised but the standard 'traffic light' red-green spectrum has been replaced to make the figure colourblind-friendly (Katsnelson 2021). Sources of uncertainty that end up in the upper-right "red" corner (Figure 11 aii) are high priority: they are those that respondents believed to be important, are associated with high levels of (epistemological) uncertainty, and are not yet to be properly accounted for in modelling or risk assessment. Those in the bottom-left "green" corner (Figure 11 ai) can probably be left out of wider conversations with stakeholders, as they are believed not to impact results, and are well understood and accounted for.

There is often an assumption that scientists share views on uncertainty. But formal elicitations can reveal surprising differences. Figure 11b demonstrates how results might look based on actual surveys we conducted (Leach et al. 2014). Each ring is a response from a scientist. Since the answers are on discrete 5-point scales some answers will overlap and this is represented by ring thickness. Scientists might agree on everything: the importance of a particular source of uncertainty, on how uncertain they are about it, and on how well it is already accounted for or 'represented' in the model (Figure 11 b.i). Or elications might show a total lack of consensus (Figure 11 b.iv).

Once perceptions of uncertainty are clarified and priorities are identified, we can plan how to communicate them. Caveat: Scientists can be wrong at predicting how important a source of uncertainty is.

AUTHOR CONTRIBUTIONS:

Conceptualization: *JLW, MJB, PL and MW;* ***Research:*** *JLW, PL, MJB and MW;* ***Writing:*** *JLW, MJB and PL.*

REFERENCES

Abramowitz, Gab, Nadja Herger, Ethan Gutmann, Dorit Hammerling, Reto Knutti, Martin Leduc, Ruth Lorenz, Robert Pincus, and Gavin A. Schmidt. 2019. 'ESD Reviews: Model Dependence in Multi-Model Climate Ensembles: Weighting, Sub-Selection and out-of-Sample Testing'. Earth System Dynamics 10 (1): 91–105. https://doi.org/10.5194/esd-10-91-2019.

Bansard, Jennifer, and Tomilola Akanle Eni-ibukun. n.d. 'Summary of the 54th Session of the Intergovernmental Panel on Climate Change and the 14th Session of Working Group I: 26 July - 6 August 2021'. Earth Negotiations Bulletin. https://enb.iisd.org/climate/IPCC/IPCC-54-WGI-14/summary.

Bassil, Noah R. 2011. 'The Roots of Afropessimism: The British Invention of the "Dark Continent"'. Critical Arts 25 (3): 377–96. https://doi.org/10.1080/02560046.2011.615141.

Bles, Anne Marthe van der, Sander van der Linden, Alexandra L. J. Freeman, James Mitchell, Ana B. Galvao, Lisa Zaval, and David J. Spiegelhalter. 2019. 'Communicating Uncertainty about Facts, Numbers and Science'. Royal Society Open Science 6 (5): 181870. https://doi.org/10.1098/rsos.181870.

Bock, L., A. Lauer, M. Schlund, M. Barreiro, N. Bellouin, C. Jones, G. A. Meehl, V. Predoi, M. J. Roberts, and V. Eyring. 2020. 'Quantifying Progress Across Different CMIP Phases With the ESMValTool'. Journal of Geophysical Research: Atmospheres 125 (21). https://doi.org/10.1029/2019JD032321.

Budescu, David V, Han-Hui Por, and Stephen B Broomell. 2012. 'Effective Communication of Uncertainty in the IPCC Reports'. Climatic Change 113 (2): 181–200.

Dieckmann, Nathan F, Robin Gregory, Ellen Peters, and Robert Hartman. 2017. 'Seeing What You Want to See: How Imprecise Uncertainty Ranges Enhance Motivated Reasoning'. Risk Analysis 37 (3): 471–86.

INED. 2019. 'Projections by Continent'. Ined - Institut National d'études Démographiques. 2019. https://www.ined.fr/en/everything_about_population/data/world-projections/projections-by-continent/.

IPCC WGI, P. Zhai, A. Pirani, S. L. Connors, and WGI. 2021. 'IPCC, 2021: Summary for Policymakers'. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Iturbide, Maialen, Fernández, Jesús, Gutiérrez, José Manuel, Bedia, Joaquín, Cimadevilla, Ezequiel, Díez-Sierra, Javier, Manzanas, Rodrigo, et al. 2021. Repository Supporting the Implementation of FAIR Principles in the IPCC-WGI Atlas (version v2.0-final). Zenodo. https://doi.org/10.5281/ZENODO.3691645.

Janzwood, Scott. 2020. 'Confident, Likely, or Both? The Implementation of the Uncertainty Language Framework in IPCC Special Reports'. Climatic Change 162 (3): 1655–75. https://doi.org/10.1007/s10584-020-02746-x.

Jarosz, Lucy. 1992. 'Constructing the Dark Continent: Metaphor as Geographic Representation of Africa'. Geografiska Annaler: Series B, Human Geography 74 (2): 105–15. https://doi.org/10.1080/04353684.1992.11879634.

Katsnelson, Alla. 2021. 'Colour Me Better: Fixing Figures for Colour Blindness'. Nature 598 (7879): 224–25. https://doi.org/10.1038/d41586-021-02696-z.

Kisembe, Jesse, Alice Favre, Alessandro Dosio, Christopher Lennard, Geoffrey Sabiiti, and Alex Nimusiima. 2019. 'Evaluation of Rainfall Simulations over Uganda in CORDEX Regional Climate Models'. Theoretical and Applied Climatology 137 (1–2): 1117–34. https://doi.org/10.1007/s00704-018-2643-x.

Leach, Adrian W., Polina Levontin, Johnson Holt, Laurence T. Kell, and John D. Mumford. 2014. 'Identification and Prioritization of Uncertainties for Management of Eastern Atlantic Bluefin Tuna (Thunnus Thynnus)'. Marine Policy 48 (September): 84–92. https://doi.org/10.1016/j.marpol.2014.03.010.

Masson-Delmotte, V., P. Zhai, A. Pirani, and S. L. Connors. 2021. 'Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change'. Cambridge University Press.

Meehl, Gerald A., Catherine A. Senior, Veronika Eyring, Gregory Flato, Jean-Francois Lamarque, Ronald J. Stouffer, Karl E. Taylor, and Manuel Schlund. 2020. 'Context for Interpreting Equilibrium Climate Sensitivity and Transient Climate Response from the CMIP6 Earth System Models'. Science Advances 6 (26): eaba1981. https://doi.org/10.1126/sciadv.aba1981.

Padilla, Lace, Sarah Dryhurst, Helia Hosseinpour, and Andrew Kruczkiewicz. 2021. 'Multiple Hazard Uncertainty Visualization Challenges and Paths Forward'. Frontiers in Psychology 12: 1993. https://doi.org/10.3389/fpsyg.2021.579207.

Schmidt, Gavin. 2021. 'RealClimate: #NotAllModels'. 9 August 2021. https://www.realclimate.org/index.php/archives/2021/08/notallmodels/.

Silver, Nate. 2013. The Signal and the Noise: The Art and Science of Prediction. Penguin Economics. London: Penguin Books.

Chapter 5 HACKS, INSIGHTS, *AND* RESOURCES

INTRODUCTION

As climate risk communication grows more important in society, what tools and insights will be of use to communicators?

This final chapter is something of a grab-bag. It contains tips for using visuals in climate risk communication, tips for communicating with policymakers, some provocations collected from the COP26 Universities Network Climate Risk Summit workshop on climate risk communication (October 2021), some useful definitions about uncertainty and risk, and the beginnings of a growing directory of climate risk communication resources, also available here as a living document (bit.ly/ClimateCommsTools).

The authors of this Toolkit are hopeful that future iterations will be possible to expand this practice-oriented content, and we welcome feedback, recommendations, and offers of collaboration and co-production. In the years to come climate risk communication will be an increasingly important theme, and there is every chance that the field will diversify, mutate, and undergo fragmentation while also being shaped by projects of inventory, synthesis, simplification and curation.

What is the future of climate risk communication? Whatever it is, it's coming at us fast. There are already a wealth of available resources out there about communicating with policy and the general public, a small handful of which are signposted below. Many of these resources conceptualise climate risk communication in a fairly generic and high level way; creating such resources, exploring innovations, testing them empirically and refining them, and introducing them into new contexts will remain important work going forward. However, our experience of assembling this Toolkit has also suggested the need for more tools and resources doing the following seven things.

(a) Innovate on scope, including much more targeted and niche approaches aimed at a smaller number of users and applicable to a smaller number situations, but in more specific and concrete ways;

(b) Innovate on participation, including tools which embed the insights of international and historical global perspectives, and a real orientation to substantive equity and just transition;

(c) Innovate on standards and scores, including tools which seek to address the shortcomings and risks of league tables and other excellence frameworks, standards and certification, and gamification;

(d) Innovate on customisation, modularity, and recombinancy, exploring for example how more tailored tools (as in (a) above) can be created at scale, using robust procedural generation methods;

(e) Innovate on framing, exploring for example ways to spread climate change and climate action throughout culture and society, rather than letting it be boxed off as a specific topic or theme;

(f) Innovate on reflexivity, including tools which help users to reflect on the tools' own limitations, understand where those tools may need to be adapted, or where users might go to find a more appropriate tool (or where the material circumstances are not adequate to achieve the desired purposes, no matter what communications and/or decision support tool is used);

(g) Innovate on findability. It's already a crowded landscape, and it's likely to get more crowded. This may mean meta-resources (curated directories etc.), and other ways of getting resources to those who need them when they need them.

Subsections

i

THE PRINCIPLE OF EXPRESSIVENESS	» A data visualisation should encode all the relevant information, and no irrelevant information. » Avoid unnecessary decoration and 'chart junk.' » **HOWEVER:** there can be exceptions; for instance, a truly novel or clever presentation may be more eye-catching and memorable for some users.
THE PRINCIPLE OF APPROPRIATE KNOWLEDGE	» Make sure your user knows the conventions for extracting the relevant information. » E.g. you can: provide a clear key and explanatory notes; use conventions that are well-established; provide training. » **HOWEVER:** if a user is interpreting a visualisation 'wrongly' there may be a deeper reason. So be prepared to listen and adjust your own expectations about what is and is not relevant.
THE SEMANTIC PRINCIPLE	» Choose conventions that will support correct interpretation, even in the absence of appropriate knowledge. » This can be thought of as making 'natural' or 'common sense' choices, aligned with common schemas such as 'bigger means more' or 'red or orange means conflict / danger / heat.' » **HOWEVER:** visual elements come with baggage you can't wish away, and which will be different for different users.
COLLABORATE ACROSS DISCIPLINE	» For example, visualisation teams can bring together climate experts, end users, graphic designers, science communication practitioners, as well as researchers across the social sciences and arts and humanities (especially the digital humanities and the environmental humanities), and wider stakeholder communities. » **HOWEVER:** reaching consensus across diverse roles is not a substitute for robust testing.
TEST YOUR VISUALISATION	» Ideally you should test comprehension and decision quality with the actual end users, in the actual use setting, using an objective methodology. » Self-reporting is not reliable. A graphic designer's satisfied client is not the same as a user making good choices. » **HOWEVER:** some testing is always better than none, even if it is informal.

5 TIPS FOR USING PHOTO RESOURCES
TO COMMUNICATE ABOUT CLIMATE CHANGE

MAKE IT SPECIFIC

- Show real people's everyday lives. Avoid stock photography or scenes that look very staged.
- Show human subjects. But be cautious when representing causes of climate change: it may be better to try to show the causes on larger scales, rather than 'blaming' individual consumers, for example.
- Show specific, serious impacts at a local scale, and use captions and text to tell your audience what they're seeing.

EVERYBODY LOVES A CRYSTAL BALL

- People want to see 'how we will live in the future.' Photos are not the most obvious way to do this ...
- ... however, showing low carbon behavior and other climate 'solutions' can at least prefigure the future. They can also produce more positive emotional responses, and they are usually less polarising.
- Also take care not to imply that you are illustrating the future, if that's not what you're doing.

KNOW YOUR AUDIENCE (EVEN BETTER, LISTEN TO THEM)

- As with any form of communication, it helps to know your audience or — even better! — to engage in dialogue with them.
- Remember to listen openly, and be prepared to adjust your own perceptions.
- Remember, what you see is not necessarily what they see.

EXPERIMENT

- Don't rely exclusively on familiar climate images such as melting ice caps or smoke stacks.
- Climate change affects everything. Make fresh connections and tell new stories.
- Sometimes imaginative artistic and curatorial choices can make a usually cliched subjects feel fresh and new.

CONSIDER THE CONTEXT

- How do your images relate to your text? To each other? What emergent story do they tell?
- What other associations might your images have that you didn't intend? Deciding those associations aren't relevant doesn't mean they won't impact your audience. You can't wish them away, but you can be aware of them.
- Working with arts and humanities researchers (e.g. environmental humanities) may help to understand the context.

10 TIPS FOR DIALOGUE *WITH* POLICYMAKERS

THESE TEN TIPS FOCUS ON THE UK CONTEXT, BUT THEY ARE APPLICABLE IN MANY PLACES ...

1. **Listen actively to create real dialogue.** The temptation to go into "lecture mode" is real. It can help to prepare structured interactive formats in advance. The presence of a trained and experienced facilitator can make a big difference. Keep in mind your policymaker(s) may have many kinds of expertise of their own. Later, when you follow up (e.g. a letter of thanks), show that you are listening to policymakers' expertise, agendas, priorities, and needs.
2. **Prepare key insights in advance.** Make your advice memorable; "make your advice concise" (Tyler 2013). Do communicate complexity and uncertainty around your key insights, don't obscure those insights. Come prepared, but be cautious of becoming too attached to any pre-prepared insights (or to specific ways of expressing them). A real commitment to dialogue implies adaptability.
3. **Give options and talk about the pros and cons of each.** You want to strike a balance between "I think you should do x" and "I'm here with the facts, what happens next is your problem." When you present options in a balanced way, policymakers can integrate their own insider expertise on policy trends, political acceptability, policy levers, and their own understandings of uncertainty. Be supportive and attentive, and ready to clarify, reframe, or update your options if necessary. "Policy making is iterative; the art of the possible" (Tyler 2013).
4. **Expect policymakers' time to be limited.** Do your homework about who you are speaking to, so you can make the most of whatever time you have together. A pragmatic science-policy co-production process may consist of several short sessions with different groups of policymakers (De Meyer et al. 2021).
5. **Try to meet policymakers where they are.** Remember that in many policy areas, "[s]tarting policies from scratch is very rarely an option" (Tyler 2013). Deep and rapid changes are necessary, but options always need to take into account what is already there. Connect your information with the structures, risks and opportunities that policymakers already intuitively understand. This may involve their specific area of responsibility, and/or broader concerns such as jobs or national security. Climate risk affects all aspects of society, so you should be able to find ways to connect with policymakers where they are already.
6. **If the mood is against you, try saying it another way.** At any given moment and policy context, there will be assumptions which are very hard for you to shift. When assumptions cannot go unchallenged, then of course you should have the courage to do so. But also be aware that you may be seen as unreasonable, even when the evidence is firmly on your side. Your other option is to remove the jarring elements of your message, and find some other way of expressing the same thing.
7. **Bring all your expertise, and bring your networks too.** Be prepared to speak beyond the specific research you are engaging in. Also look out for emergent opportunities to facilitate connections. You may not be speaking to exactly the right policymaker, or you may not be exactly the right expert for this policymaker to be speaking to.
8. **Celebrate positive and plural action.** Climate change is polarising, but climate change is also urgent. Mitigation and resilience should not be unduly delayed by efforts to get everyone on the same page. If you are at an impasse with policymakers, try to support them to take some positive action in the short term (even when based on reasons you disagree with) and keep dialogue open in the longer term. Mutually exclusive frameworks can still give rise to policies that are mutually complementary.
9. **Be ambitious in shifting the bigger narratives around climate risk.** Consider how you might engage with less obvious departments and agencies. Explore both direct and indirect engagement with policymakers, e.g. through the media, grassroots organizations, community groups, think tanks, pressure groups, consultants, professional services networks, industry and third sector, social media and broader cultural production.
10. **Rapport changes the rules.** Where possible, seek to build longer-term relationships, especially at the more local level. "Policy makers are people" (Tyler 2013).

RECOMMENDED FURTHER READING:

De Meyer, Kris, Freya Roberts and Lucy Hubble-Rose, '*Risk for Elephants:* Three insights from the sciences of brain and mind to understand and improve risk communication' and 'Golden nuggets: communicating with policymakers' (Climate Action Unit, 2021).

Sutherland, William J., David Spiegelhalter, and Mark Burgman. 2013. 'Policy: Twenty Tips for Interpreting Scientific Claims'. Nature 503 (7476): 335–37. doi.org/10.1038/503335a.

Tyler, Chris. 2013. 'Top 20 Things Scientists Need to Know about Policy-Making'. The Guardian, 2013. https://www.theguardian.com/science/2013/dec/02/scientists-policy-governments-science.

SOME OF THE MOST RECENT CHATTER ABOUT CLIMATE RISK COMMUNICATION

COP26 Universities Network Climate Risk Summit took place over three days from the 29th September to the 1st October 2021. The last day was dedicated to an interactive workshop with just under a hundred participants (scientists, policymakers, consultants, engineers, lawyers, etc.) exploring the theme of communicating climate risks. Here are a few questions and insights shared on the day; this Toolkit is, in part, our response.

RESPONSES FROM A QUESTIONNAIRE

The question we asked was: *"Please give a specific example of a challenge you have faced around climate risk communication and decision-making. (For example, a challenge in communicating information, or a challenge in finding and interpreting the information you need. It could be a past challenge, or an ongoing challenge. Try to be as specific as possible)."*

See Climate Risk Communication engagement form.

Contributions may be incorporated into any future iteration of this Toolkit.

Some of the challenges that respondents mentioned:

- Desire for "sound bites" not contextual understanding
- Trust in the wrong even openly (science-)fictional sources of information
- Political bias
- Perceived lack of agency in response to risk
- Perceived irrelevance to lived experience
- Uncertainty over what values one holds
- Difficulty in grasping complex non-linear systemic risks
- Scientists assuming that everyone thinks like them
- Peer-review system denying scientists an opportunity to encounter diverse audiences
- Jargon and responsibility the scientists feel necessary to communicate details and caveats instead of a simplified narrative
- Tendency to emotionally reject information that entails large changes
- Tendency for people to interpret new information in support of prior beliefs regardless of its content
- Inaccessible styles of communication (long complex sentences)
- Uncertainty of what someone's baseline knowledge is
- Making unambiguous and intuitive visualisation that preserve the detail and uncertainty of science
- Communicating uncertainty effectively, ensuring that it is correctly understood
- Communicating modelling uncertainty while not miscommunicating a sense of urgency and credibility of results
- Finding up to date and relevant local information in the developing world
- Making information about the distant future feel pertinent
- Making information about risks in distant places feel pertinent
- Constructing 'what if?' future scenarios based on current knowledge across different timelines
- Connecting climate risks to actions in indirectly impacted domains, such as cardiology

HIGHLIGHTS FROM THE ZOOM CHAT

Here are a selection of thought-provoking comments from the climate risk communication workshop Zoom chat. They have been anonymised, and in one or two cases slightly tweaked for spelling and readability.

"We need to work together to bring together academia and practitioners in risk communication. Culture is a factor in assessing whether messages are relevant and effective in communication with different groups of stakeholders, notably the younger generation."

"We need to move towards a dialogue model — the people 'on the ground' have crucial knowledge and approaches to bring to the discussion, and should not purely be viewed as 'recipients' of 'beneficiaries' of climate information."

"Do we sufficiently understand the value of uncertainty in terms of informing robust decisions?"

"There are so many human difficulties in perception of risk, especially for low-frequency high-impact events."

"'Understanding the meaning behind the numbers' is very important for many disciplines, including my own (finance)."

"Society needs to engage so as to hold decision-makers to account for the impact of their decisions."

"Does 'risk communication' become more effective when it includes 'response communication' or 'solutions communication'?"

"The challenge with risk and uncertainty is that different people and different decisions (even for the same person) may have different risk appetites, and as a result can cope with different levels of uncertainty."

"I like engaging with end-users, but it really does take work to understand their needs, and their jargon, and your own, and bridge it."

"Actively engaging with the end-user is critical for understanding their perspectives, their pain points and their motivations. It has been essential to adapting the messages and the tools to their needs."

"On communicating with business leaders: generally they get the urgency of climate change, but persuading them that it's their responsibility, or that it's in their interests to act ambitiously (especially when the economic system doesn't incentivise them to lead change) is the most challenging thing."

"I think that's a really interesting point about identifying user needs but also working with users to transform how they understand their own needs…"

"A huge one is the assumption of the need for economic growth / GDP / cost-benefit analysis as key measures of success, therefore 'greenness' needing to sit alongside growth in the form of 'sustainable' 'green' 'inclusive' etc., rather than moving away from economic growth as a priority altogether."

"GDP is fundamentally flawed when talking about sustainability, but that is a topic most incumbent policymakers in many countries don't want to engage with."

"Degrowth also means deconsumption, which means fewer jobs."

"Of course, 'degrowth' is also one of those terms that can mean many things, e.g. some prefer to talk about 'post-growth' or 'growth agnostic' approaches, or just talk about 'decoupling,' or Beyond GDP metrics."

"I really like Lord Deben's argument that we should reclaim the word 'growth' as people's associations with it are positive (children grow, plants grow, we grow professionally etc.), but redefine what we're trying to grow."

"I definitely would NOT call this the capitalocene. The, 'rentalocene' yes. Remember the extra money is not made based on the capital good as such; the capital good is used as a facade to extract rents. So rentalism is a better term than capitalism. In a 'true capitalist' system there wouldn't even be the possibility to pollute, because the competitors wouldn't allow it."

"I think honesty on the part of scientists is important. When I attend small circle seminars scientists are more honest and humble about what they really know and what they conjecture about. Honesty can help one carry their message further. Scientists pretending they know things they don't know is not only dishonest, it also hurts the credibility of scientists."

WHEN WORDS MEAN DIFFERENT THINGS IN DIFFERENT CONTEXTS

We asked: "Anyone want to share a word that has different uses in different contexts?" Participants flagged up terms such as *adaptation; life cycle analysis* (meaning different things in biochemistry and engineering domains) *one-in-a-hundred-year flood; positive trends* (does it mean increasing or good?); *just transition; materiality* (material financial risks to the business, or material risks to people and planet (or both), or tangibility and physicality); *flexibility* (the same arrangements may be seen as flexible or inflexible from the perspective of employer or employee); and *ethics* (in business this often connotes a compliance and liability orientation, rather than a concern with what is right and wrong, which happens (if at all) in connection with terms like CSR and ESG). Of course there are many more. Can you think of some?

DEFINITIONS OF RISK, UNCERTAINTY, *AND* RELATED TERMS FROM THE IPCC

AR6 WGI strongly reinforces the need for rapid and deep reduction in CO2 and other GHG emissions (achieving at least net zero) alongside other forms of climate action. There is no room for reasonable doubt about this. Nonetheless, uncertainty and risk remain crucial concepts to mediate between climate science and appropriate climate action. For its recent AR6 WGI report, **the IPCC has outlined definitions of uncertainty and risk.** We have deliberately not aligned the Toolkit to these IPCC definitions. This is because we want to showcase a range of different understandings of these concepts, and how they may impact communication. A more flexible approach is therefore appropriate for this Toolkit. However, it is also useful to present the IPCC definitions here, since these are referred to in several places in the Toolkit, and form relevant background throughout.

On the subject of **risk** specifically, AR6 WGI states that it has

> *adopted a unified framework of climate risk, supported by an increased focus in WGI on low-likelihood, high-impact events. Systematic risk framing is intended to aid the formulation of effective responses to the challenges posed by current and future climatic changes and to better inform risk assessment and decision-making. AR6 also makes use of the 'storylines' approach, which contributes to building a robust and comprehensive picture of climate information, allows a more flexible consideration and communication of risk, and can explicitly address low-likelihood, high-impact events.*
> *(AR WGI, Ch 1, p. 6)*

The following definitions are from AR6 WGI 'Annex VII: Glossary' (2021).[1]

Risk: The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of *climate change,* risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, *livelihoods,* health and *well-being,* economic, social and cultural assets and investments, infrastructure, services (including *ecosystem services*), *ecosystems* and species.

In the context of climate change impacts, risks result from dynamic interactions between climate-related *hazards* with the *exposure* and *vulnerability* of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and *likelihood* of occurrence, and each may change over time and space due to socio-economic changes and human decision-making (see also *risk management, adaptation* and *mitigation*).

In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the *Sustainable Development Goals* (SDGs) (see also *risk trade-off*). Risks can arise for example from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions. See also *Hazard* and *Impacts* (*consequences, outcomes*).

Uncertainty: A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, incomplete understanding of critical processes, or uncertain projections of *human behaviour.* Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts) (Burgman 2016). See also *Confidence* and *Likelihood.*

Note that the definitions of *risk* and *uncertainty* do not cross-reference each other. Further definitions directly related to **risk and uncertainty** from the IPCC AR6 WGI Glossary include:

Deep uncertainty: A situation of deep uncertainty exists when experts or stakeholders do not know or cannot agree on: (1) appropriate conceptual models that describe relationships among key driving forces in a system; (2) the probability distributions used to represent uncertainty about key variables and parameters; and/or (3) how to weigh and value desirable alternative outcomes (Lempert, Popper, and Bankes 2003).

1 Italics and other cross-citational information has been preserved as in the original, and two minor amendments ("trickle backs") listed at the top of the Annex have been implemented in the text. As with all citations to the AR6 WGI at the time of writing, these definitions remain subject to final IPCC edits.

Sampling uncertainty: Uncertainty arising from incomplete or uneven availability of measurements in either space or time or both.

Risk assessment: The qualitative and/or quantitative estimation of risks. See also *Risk management* and *Risk perception.*

Risk framework: A common framework for describing and assessing risk across all three working groups is adopted to promote clear and consistent communication of risks and to better inform risk assessment and decision making related to climate change.

Risk management: Plans, actions, strategies or policies to reduce the *likelihood* and/or magnitude of adverse potential consequences, based on assessed or perceived *risks.* See also *Risk assessment, Risk perception,* and *Risk transfer.*

Risk perception: The subjective judgment that people make about the characteristics and severity of a *risk.* See also *Risk assessment, Risk management,* and *Risk transfer.*

Risk trade-off: The change in the portfolio of risks that occurs when a countervailing *risk* is generated (knowingly or inadvertently) by an intervention to reduce the target risk (Graham and Wiener 1995).

Other definitions relevant to understanding the IPCC's approach to risk and uncertainty include:

Agreement: In this report, the degree of agreement within the scientific body of knowledge on a particular finding is assessed based on multiple lines of *evidence* (e.g., mechanistic understanding, theory, data, models, expert judgement) and expressed qualitatively (Mastrandrea et al. 2011). See also *Confidence, Likelihood, Uncertainty,* and *Evidence.*

Confidence: The robustness of a finding based on the type, amount, quality and consistency of *evidence* (e.g., mechanistic understanding, theory, data, models, expert judgment) and on the degree of *agreement* across multiple lines of evidence. In this report, confidence is expressed qualitatively (Mastrandrea et al. 2011).

Hazard: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Impacts: The consequences of realised risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather / climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial.

Low-likelihood, high impact events: Outcomes/events whose probability of occurrence is low or not well known (as in the context of deep uncertainty) but whose potential impacts on society and ecosystems could be high. To better inform risk assessment and decision-making, such low-likelihood outcomes are considered if they are associated with very large consequences and may therefore constitute material risks, even though those consequences do not necessarily represent the most likely outcome.

As the COVID-19 pandemic has made obvious, people's ways of making decisions under uncertainty vary greatly across individuals. For example, cultural and political beliefs shape what different individuals perceive as reasonable. Cognitive biases which are fairly uniform across cultures may manifest in different ways according to the circumstances of the individual. Differences can be present even in closely knit groups of scientists, who are likely to perceive some scientific uncertainties in divergent ways, or even have different mental pictures of what different uncertainties are and what their relative importance is. This is especially true in connection to tipping points or other 'deep uncertainties'.

Knowledge about climate risks comes from many sources: observations, experiments, theory, and models (embodied, conceptual, statistical, simulations, etc.). Each source of knowledge contains many different forms of uncertainty, and there is no universal system for classifying them. Here we offer a few fairly broad and commonly recognised categories of uncertainty. Some categories may overlap.

RECOMMENDED FURTHER READING:

Levontin, Polina et al. 2020. Visualising Uncertainty: An Introduction. AU4DM. au4dmnetworks.co.uk/resources/

French, Simon (ed), 2019. Decision Support Tools for Complex Decisions Under Uncertainty. AU4DM. au4dmnetworks.co.uk/resources/

- **Stochastic uncertainties:** Physical randomness of the physical, ecological, social, economic, or technical processes.
- **Epistemological uncertainties:** Limitations to our ability to describe/represent the world linguistically, mathematically, or statistically.
- **Observational uncertainties:** Limitations to our ability to record what is going on. Observational uncertainties might include limitations such as:
  - Accuracy — the difference between observation and reality;
  - Precision — the quality of the estimate or measurement;
  - Completeness — the extent to which information is comprehensive;
  - Consistency — the extent to which information elements agree (conflicts in data);
  - Lineage — the pathway through which information has been passed;
  - Currency and temporality more generally — the time span from occurrence to collection of data;
  - Credibility — the reliability of the information source;
  - Subjectivity — the extent to which the observer influences the observation;
  - Interrelatedness — the dependence on other information;
  - Spatial coverage.
- **Semantic uncertainties or ambiguities:** Terminology is often ill-defined and has conflicting meanings in different (scientific) contexts. Words can be ambiguous and lead to different interpretations of information. Interpretations can be influenced by how the communication is framed, the setting in which it takes place, perceptions about the communicator's intentions, as well as many other factors. Sometimes a word can have a very similar meaning but a different nuance or emotional charge across different communities, which can also lead to uncertainty.
- **Ethical uncertainties:** What makes a good decision? What is 'right' and for whom? What should be valued? What are acceptable risks, thresholds, and trade-offs? Who should have the right to decide and how?
- **Subjective (expert) judgements:** Experts are constantly making calls, from a decision that some uncertainty should be quantified, to setting parameter values, to processing data, selecting appropriate equations, deciding if the model is sufficiently plausible, and how different models should be weighted, to advising on trade-offs, constraints, and climate goals.
- **Computational uncertainty:** Increasingly, computers are integral to gaining insights into climate risk. The complexity of models and their code, run times and other computational demands, the nature of statistical algorithms (e.g. machine learning, if used) introduce their own uncertainties. Is the code error-free? Have models converged? Are they exploring the whole parameter space, have they been over-fitted to data, do they have predictive power or skill, and how should we assess whether the models are fit for purpose?
- **Deep uncertainty:** Decisions are made under deep uncertainty when key stakeholders cannot agree on appropriate models, probability distributions, and/or values.

TOOLS *AND* RESOURCES

Here are a small handful of resources related to communicating climate and environment information, including communicating climate science for decision-makers and stakeholders, climate and environmental storytelling, and facilitating participatory processes. This list has been crowdsourced, starting in October 2021, and will be maintained at least for the next year as the living document (located here) component of the Toolkit. Please feel free to recommend your own resources in the online document, and be as descriptive as possible about why you are recommending them.

NAME / LINK	TYPE OF RESOURCE	COMMENTS	KEYWORDS
COP26 Universities Network + Climate Action Unit Communicating Climate Risk workshop 'Goody Bag'	Toolkit and presentation slides	A variety of tips and insights, mostly from Climate Action Unit, primarily aimed at scientists engaging with policymakers. Includes insights for understanding and engaging end users, writing hacks	comms; end users; writing; data visualisation; decision support
IPCC WGI Interactive Atlas	Interactive atlas	"A novel tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning the Working Group I contribution to the Sixth Assessment Report, including regional synthesis for Climatic Impact-Drivers (CIDs)."	maps; interactive maps; IPCC; uncertainty;
#TalkingClimateChange Handbook	Guide	"We are deeply influenced by the conversations we have with our peers. Talking about climate change with our family and friends is a crucial part of making change. Explore our guidance for how to have climate conversations that will leave you feeling inspired and connected."	public; popular discourse; conversations; guides; deliberation; participation
#TalkingClimateChange workshop package	Workshop resources	"These resources provide practical evidence-based guidance on how you can help friends, family, colleagues, neighbours and members of your community feel more confident about talking about climate change in their daily lives. The idea is to spread the word and upskill our communities to have better climate conversations—conversations that leave them feeling inspired and connected."	public; popular discourse; conversations; guides; education; workshops, training
FlowingData	Blog	"I'm Nathan Yau. I run FlowingData. [...] I have a PhD in statistics from UCLA, with a focus on visualization for presenting data to everyone. I want as many people as possible to understand data, and I think visualization — from statistical charts to infographics to data art — is the best way to get there."	data visualisation; data art; aesthetics
Kate Raworth, *Doughnut Economics* www.kateraworth.com/doughnut/	Book	Raworth's book seeks to imagine the economics of the future, and is also notable for its discussion of the role of charts and diagrams in the history of economics and its social and political impact	data visualisation; economics; degrowth; growth agnosticism; Beyond GDP; metrics
CambridgeZero www.zero.cam.ac.uk/	Organisation	The university's hub for all things related to climate crisis and transition to a zero-carbon world, connecting up many different research centres and groups, and with a strong strand of climate communication	net zero; research; climate science
IPCC Photo Library www.ipcc.ch/sr15/mulitimedia/photo-library/	Website	A small collection of photographs together with guidance on how to use visuals to communicate about climate change	documentary; visuals; photographs; aesthetics
10 Tips on Visualising Climate Risk	Tool	Ten tips for using visuals to communicate (both data visualisation and photography) from AU4DM	design principles; visuals; photographs; aesthetics

NAME / LINK	TYPE OF RESOURCE	COMMENTS	KEYWORDS
Communicating Climate Risk Toolkit—a survey	Survey	Help the COP26 Universities Network and AU4DM to develop tools focused on communicating complex and uncertain information.	survey
weADAPT www.weadapt.org/	Platform	"weADAPT is a collaborative platform on climate change adaptation issues. It allows practitioners, researchers and policy-makers to access credible, high-quality information and connect with one another."	infographics; research; comms
National Trust Climate Hazard Maps	Dashboard	An ArcGIS based platform to explore climate hazards in the UK	maps; interactive maps; hazards; GIS
MCC Carbon Clock www.mcc-berlin.net/en/research/co2-budget.html	Communication	Live countdown of 'remaining carbon budget.'	case studies; visuals; speculative design
Visualising Uncertainty: A short introduction	Toolkit	This primer, published by the Analysis under Uncertainty for Decision-Making network (AU4DM), summarises the current state of the art of uncertainty visualisation research. It brings together a wealth of relevant studies, concepts, and practical tools and recommendations.	design principles; data visualisation; deep uncertainty
WeDoData	Company	Specialises in all kinds of data visualisation, great examples (in French).	data visualisation; dashboards; narratives; infographics
Worldwide Climate Policy	Dashboard	'How could the burden of GHG emissions reductions be shared among countries? We address this arguably basic question by purely statistical methods that do not rely on any normative judgment about the criteria according to which it should be answered.' Although, assuming that statistical methods are not 'normative' is, in our opinion, incorrect, there are valuable insights in this visualisation. See also *Climate Equity Reference Calculator.*	data visualisation; dashboards; mitigation policies
RealClimate.Org	Scientists' Blog	"We're often asked to provide a one stop link for resources that people can use to get up to speed on the issue of climate change, and so here is a selection. Unlike our other postings, we'll amend this as we discover or are pointed to new resources. Different people have different needs and so we will group resources according to the level people start at."	climate science communication; visualisation; modelling
Carbon Brief	Website	"Carbon Brief is a UK-based website covering the latest developments in climate science, climate policy and energy policy. We specialise in clear, data-driven articles and graphics to help improve the understanding of climate change, both in terms of the science and the policy response. We publish a wide range of content, including science explainers, interviews, analysis and factchecks, as well as daily and weekly email summaries of newspaper and online coverage."	graphics; climate science communication; factchecks
Climate Equity Reference Project	Website and Dashboard	"The Climate Equity Reference Calculator is a general online equity reference tool and database that systematically applies a generalized and transparent equity reference framework with the goal of quantitatively examining the problem of national fair shares in a global effort to rapidly reduce greenhouse gas emissions. It can be applied using a range of possible assumptions, and whatever values are chosen, they are applied to all countries, in a dynamic fashion that reflects the changing global economy."	data visualisation; dashboards; mitigation policies; equity
Chapman, Daniel A., Adam Corner, Robin Webster, and Ezra M. Markowitz. 2016	Article	'Climate Visuals: A Mixed Methods Investigation of Public Perceptions of Climate Images in Three Countries'. *Global Environmental Change* 41 (November): 172–82. https://doi.org/10.1016/j.gloenvcha.2016.10.003.	climate imagery; visual communication, imagery public engagement; mixed-methods

Temperature quilt. 2021.
With friendly permission from Fran Sharp.

THE STORY BEHIND THE COVER

The cover, and some other aspects of design in this Toolkit, have been inspired by this unfinished tapestry Temperature Quilt (pictured above) by Fran Sharp. Quilters are helping to visualise and communicate climate risks to the public through their work.

Fran Sharp told us that she aims to finish the quilt before COP26. The quilt represents the temperature record from Boston, USA, from January to December of 2019. Each day is represented by a rectangle made up of two triangles that depict the day's
high and low temperatures, starting with Jan. 1 is on the upper left (that's why there are "white spaces" at the bottom—those dates don't exist).

Fran Sharp is a quilter and designer from Maynard, MA, United States.

We learned about Fran Sharp's work from an article by Rebecca Onion (2020) in Slate.com, which put this work into the context of not just communication but resistance: "These projects also play with the idea of 'steganography'—the concealment of secret information in plain sight. The Tempestry Project's Emily McNeil told the Philadelphia Inquirer in 2019 that the group formed after hearing about scientists and archivists who were preserving climate-related research data before the Trump inauguration in early 2017. "We were just sort of joking one night about how we should return to more concrete forms of data storage, like tapestries, because you can't just get rid of them on the Internet," McNeil said. The history and mythology of fiber and textile art is full of steganography, real, fictional, and apocryphal—the Belgian resistance during World War II, recruiting women whose windows were located over train yards to knit patterns of the trains' arrivals and departures; Madame Defarge of Dickens' A Tale of Two Cities, knitting a list of people to be guillotined; enslaved women sewing codes into quilts that helped people navigate the Underground Railroad." Onion remarks, "Climate change is a classic open secret: a thing that we all know is happening, but that our officials (by and large) choose to ignore when they are making the decisions that matter. The temperature blanket is a very 2020 way to call attention to the reality of this data. There it is, warming your legs."

Onion, Rebecca. 'The Quilters and Knitters Who Are Mapping Climate Change'. Slate, 8 February 2020. slate.com/technology/2020/02/quilts-knitting-cross-stitch-climate-change.html.

ACKNOWLEDGEMENTS

This work has received funding and support from the
COP26 Universities Network.

COP26 UNIVERSITIES NETWORK

The **COP26 Universities Network** (COP26 UN) is a group of over 80 UK-based universities and research centres working together to raise ambition for tangible outcomes from the UN COP26 Climate Change Conference, November 2021. The Network is improving access to academic expertise for governments, NGOs, and other actors, creating lasting partnerships and legacies that reach beyond this single event to deliver a zero-carbon, resilient world.

For further details about the network, visit www.gla.ac.uk/research/cop26/

FUTURE COLLABORATIONS

- **Jo Lindsay Walton**
  https://www.jolindsaywalton.com/
  j.c.walton@sussex.ac.uk
- **Polina Levontin**
  polina.levontin02@imperial.ac.uk
- **Jana Kleineberg,**
  Kleineberg Illustration & Design
  http://www.kleineberg.co.uk/
  jkl@kleineberg.co.uk
- **Or contact us here**
  http://au4dmnetworks.co.uk/

AU4DM Network

KLEINEBERG ILLUSTRATION & DESIGN

The **Communicating Climate Risk Toolkit** seeks to narrow the gap between climate science and climate action, by providing insights, recommendations, and practical tools to support dialogue between scientists, decision-makers, and many diverse communities. The Toolkit also endeavours to identify open problems and pose questions for further study and debate. Topics covered include varying conceptions of uncertainty and risk, best practice in visualising uncertainty data, case studies on tipping points and model uncertainty. Based on close collaboration across decision science, climate risk modelling, statistics, the environmental humanities, and science communication, the Toolkit seeks to drive a step change in achieving holistic, joined-up, and participatory climate action, equal to the scale of the task of the decade ahead.

AU4DM
Network

CURRENTLY AVAILABLE TITLES