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Climate science needs to take risk assessment much more seriously

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Abstract

For decision makers, climate change is a problem in risk assessment and risk management. It is, therefore, surprising that the needs and lessons of risk assessment have not featured more centrally in the consideration of priorities for physical climate science research, or in the Working Group I contributions to the major Assessment Reports of the Intergovernmental Panel on Climate Change. This article considers the reasons, which include a widespread view that the job of physical climate science is to provide predictions and projections - with a focus on likelihood rather than risk - and that risk assessment is a job for others. This view, it is argued, is incorrect. There is an urgent need for physical climate science to take the needs of risk assessment much more seriously. The challenge of meeting this need has important implications for priorities in climate research, climate modelling and climate assessments.

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1. Introduction

Climate science has achieved a great deal. It has demonstrated unequivocally that human activities have been the major driver of climate change since the mid twentieth century (IPCC, 2013), and there has been considerable – if insufficient – progress toward global actions to address the problems arising. But following the Paris Agreement, what are the priorities for climate research? Which concerns should guide the further development of global climate models? And what are the consequences for climate assessments, especially those of the Intergovernmental Panel on Climate Change (IPCC)?

From the perspective of societal needs - that is, the needs of decision makers in governments, businesses or civil society - climate change is a problem in ***risk assessment***[1] and ***risk management***. Therefore a central question is: what information can science provide to meet these needs? In this article I want to focus particularly on the contribution of physical climate science, and the community of scientists represented by IPCC Working Group I (WGI). It is notable that the requirements to inform risk assessment have had little prominence in the WGI contributions to the major IPCC Assessment Reports, such as the most recent 5th report (IPCC, 2013). By contrast, these requirements were highlighted prominently in the Summary for Policy Makers of the WGII contribution (IPCC, 2014). This article explores the reasons why physical climate science has not paid more attention to risk assessment and argues that this situation should be remedied urgently. It also discusses some of the implications for priorities in climate research and modelling, and for IPCC climate assessments.

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[1] Assessment of opportunities is also important and can be considered within a similar framework, but is not a focus of this article.

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2. Principles of risk assessment

In simple terms a risk is “something bad that might happen” (King et al, 2015). Risk *assessment* requires information about: 1) what events are possible; 2) how likely they are; and 3) what the impacts or consequences could be. A common measure of the risk associated with a specific event is *risk = likelihood x impact*, which highlights the importance of considering likelihood and impact together. Risk assessment cannot be done properly by focussing on only one of these factors, or by considering them only sequentially: for risk, the interaction between them matters.

A landmark climate change risk assessment was published in 2015 by King et al. The introduction to this report summarises key principles of risk assessment as follows:

1. Identify risks in relation to objectives (e.g. “protect human prosperity and security”)
2. Identify the biggest risks
3. Consider the full range of probabilities
4. Use the best available information
5. Take a holistic view (i.e. consider all relevant factors)
6. Be explicit about value judgements

Risk assessment is invariably a multi-disciplinary task: the necessary information can only be obtained by drawing together the expertise from more than one community. For example, physical climate science can provide information about future climate, whilst biological, economic and social science are required to assess the full range of impacts and consequences. However, there is no single “best” measure of impact: as is highlighted by principles 1 and 6, impact is ultimately a consequence of choices about objectives and values.

A key consequence of principles 2 and 3 is ***the importance of paying specific attention to high impact events, even if their likelihood is considered low.*** Insuring homes against fire risk is a standard example: most people buy such insurance not because they consider it likely that their house will burn down, but rather because their potential loss is very great.

Concerning principles 3 and 4, quantitative information - where it is available - is always desirable. However, another important insight from the literature on risk assessment is that qualitative information can still be very valuable. In particular, there are many situations in which only qualitative assessments of likelihood are possible (e.g. Weaver et al, 2013; Weaver et al, 2017; Shepherd et al, 2018). In such situations it is common to use qualitative tools, such as discrete *scenarios*. A scenario describes a plausible sequence of future events but is not associated with a specific probability. However, the impacts arising from different scenarios can be explored in detail. If scenarios are designed well, they are very useful to inform decision making.

3. Why hasn't physical climate science paid more attention to risk assessment?

Why didn't the IPCC produce a risk assessment like that of King et al (2015) at a much earlier date? A key reason is the "siloing" of expertise between the three Working Groups, which has inhibited the necessary integration of knowledge from different disciplines (i.e. taking a "holistic view"). This siloing has been exacerbated by a scoping process for the major assessment cycles that remains too "bottom-up", starting with the scientists rather than

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with the needs of decision makers. One peculiarity of this process is that scoping of the headline Synthesis Report occurs only long *after* the scoping of the individual working group reports. To meet the needs of decision makers more effectively it should be the other way round. It is important to acknowledge that the recent cross-cutting reports (e.g. IPCC, 2012; IPCC, 2018) are evidence of significant progress in the IPCC addressing the needs for risk assessment more effectively, but the cycle of major assessment reports is continuing in the Sixth Assessment without substantial changes to the process.

One consequence of the siloing of climate science is that WGI scientists have tended to assume that risk assessment is not their business because it requires information about impacts that is possessed by WGII. However, this is incorrect. Impacts and risks can – indeed must – be assessed, and where possible quantified, using a wide range of metrics. WGI is the appropriate community to assess risks in terms of climate variables (e.g. temperatures, carbon budgets, extreme weather etc), especially variables that are relevant to a wide range of decisions in connection with adaptation or mitigation.

An additional - related - reason that WGI has paid little attention to risk assessment is the widespread view that the primary job of the WGI community is to provide *predictions* and *projections* (i.e. predictions conditioned on socio-economic scenarios) rather than risk assessments.[2] The WGI community has focussed large resources on attempts to "quantify the uncertainty in climate predictions/projections" (e.g. Hawkins and Sutton, 2009), i.e. on *quantifying likelihoods,* with little attention to impacts. This focus reflects the strong influence of meteorology on the development of climate science. Predictions in

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[2] See, for example, the WCRP Strategic Framework 2005-15: Coordinated Observation and Prediction of the Earth System.

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meteorology involve using models to propagate forward information about the current state of the atmosphere (i.e. initial conditions) to generate quantitative estimates of its state and uncertainty at a future time, often expressed in terms of quantified likelihoods. Confidence that these likelihoods are meaningful relies either on (1) repeating the prediction process sufficiently often that skill and reliability can be demonstrated robustly, or (2) arguments and evidence that the relevant uncertainties can all be quantified, at least in principle. Unfortunately, neither of these conditions holds for statements about future climate change, at least for lead times beyond a decade or so. Anthropogenic climate change is a unique experiment and there is a significant body of research demonstrating that there are *no adequate methods* to quantify all the epistemic uncertainties associated with the climate response to anthropogenic greenhouse gas forcing (e.g. those related to processes missing from all climate models), even at a global scale; for regional and smaller scales the problem is much worse.

The impossibility of quantifying precisely the likelihood that future climate change will have a particular magnitude (or other specific features) does not, of course, mean we have no information about it. Scientific arguments and evidence can often provide bounds or – in IPCC terminology - a "*likely* range" for key parameters such as global mean temperature. And, of course, if we can acquire new evidence that enables narrowing such bounds, this is progress. However, we should not imagine that it will ever be possible to provide detailed and meaningful probability distributions (pdfs) for future climate change analogous to those that - at least in principle - are possible for short range weather forecasts.

A final reason that may have contributed to the WGI community neglecting the needs of risk assessment is concern about accusations of scaremongering (e.g. Sutton, 2018). Risk assessment does involve drawing attention to potential “bad” outcomes even when they are very uncertain. Such an approach does not come naturally to many scientists who - for good reasons - are cautious by nature. The politicised debates around climate change have exacerbated this situation.

4. Some consequences

The consequence of physical climate science paying little attention to the needs of risk assessment has been that important issues have been neglected. Two examples can illustrate this point.

One consequence has been to afford insufficient attention to the low-likelihood high impact events which - as already discussed - are a central concern in risk assessment. King et al (2015) point out that decision makers facing risks are typically most concerned with two questions: 1) what is likely? 2) how bad could it be/what must we avoid? The latter question is fundamental to the development of robust strategies for both adaption (e.g. “resilience”) and mitigation. However, WGI has focussed overwhelmingly on question 1 (e.g. assessing the *likely* range for key parameters). But physical climate science has much knowledge and expertise to bring to question 2. It is essential that climate science identifies what is *possible* in the climate system, not merely what is likely (e.g. Weaver et al, 2013; Schellnhuber, 2018). Possibilities - which come with the potential for surprises - are a major concern for risk assessment. Furthermore, there are no fundamental obstacles to including assessments of the relevant risks within WGI reports (Sutton, 2018).

WGI has given some attention to the potential for “abrupt” climate change. However, abrupt changes are only a subset of low-likelihood high impact scenarios and not necessarily the most important subset (Sutton, 2018). High climate sensitivity is an example of a very

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high impact possibility that is not associated with any abrupt change in the Earth system. Furthermore, even when WG1 has considered low-likelihood high impact scenarios it has tended to focus too narrowly on likelihood and given insufficient attention to impacts. Here is an example from the AR5 SPM (IPCC, 2013): "It is very unlikely that the AMOC will undergo an abrupt transition or collapse in the 21st century for the scenarios considered." No information whatsoever about the impacts of an AMOC collapse is communicated, despite the importance of impact information for decision-making. WGII is not the appropriate community to provide information about the magnitude of regional climate change or sea level rise that could result from a collapse of the AMOC, were it to occur; this responsibility sits squarely with the WGI, but WGI - either as a research community or in the production of IPCC reports - has not considered it a priority. This neglect must be remedied.

A second example is that physical climate science has until recently afforded surprisingly little attention to what is a key issue for many decision makers, namely ***quantifying current risks*** – more specifically, *what is the current likelihood of high impact events?* Such events are by definition rare, i.e. they are associated with low likelihood. But whether this likelihood is 1 in 20, 1 in 200 or 1 in 200,000 is of great importance for those concerned with contingency planning and building resilience. In this case the quantification of likelihoods *is* very important, and is more tractable than for statements about future climate change. In a changing (non-stationary) climate, the appropriate likelihoods cannot be reliably estimated from historical data alone. A model of how climate change is affecting likelihoods (and risk) is required. For simple events (e.g. daily extremes of temperature) statistical models may suffice, but for more complex events (e.g. multivariate or correlated hazards) large ensembles of simulations with general circulation models are needed (Stott et al, 2015; Mizuta et al, 2017). The recent-climate component of the Japanese d4PDF programme

(Mizuta et al, 2017) is a pioneering example of the type of work required, although it does not directly address the attribution of changing risk to specific drivers. There is an urgent need for much more research on this problem.

5. The role of scenarios

As discussed in section 2, risk assessment situations in which likelihoods cannot be quantified with precision are by no means unusual. Strategic planning in government and business routinely makes use of scenarios as tools to inform thinking about future possibilities, and how to manage them. Thus, scenarios are the obvious tool to describe future climate in ways that are relevant to decision makers. The impacts and consequences of climate scenarios can be explored in considerable quantitative detail, using metrics that range from meteorological (e.g. rainfall rate) to those that are most decision-relevant (e.g. flood level, numbers of people affected, economic loss etc). This characterisation of impacts must, of course, include the uncertainty in these impacts.

Climate scenarios - in the sense used here - differ from climate projections. Climate projections, as used by the WGI community, purport to be a conditional prediction in which the product is some form of continuous likelihood distribution for a particular socio-economic scenario. Climate scenarios are a discrete set of physically-consistent and self-consistent *storylines* about the future, under a specified set of assumptions. Indeed, Shepherd et al (2018) use the term “storylines” to describe climate scenarios of this type. They define a storyline as “a physically self-consistent unfolding of past events or of plausible future events”, and have recently developed the concept in detail, explaining how it can be used to synthesise scientific evidence in decision-relevant terms.

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Many national climate scenarios have been developed (e.g. http://www.climatescenarios.nl/, http://scenarios.globalchange.gov) but interestingly discrete global or regional climate scenarios have not been widely used, arguably because the WGI climate science community has not promoted them. By contrast, socio-economic scenarios have long been used by IPCC (e.g. O'Neill et al, 2014). However, for the purposes of risk assessment there is little difference between our knowledge/ignorance of (say) future population growth and our knowledge/ignorance of (say) the future rate of global warming, so it would be helpful for decision makers if the same tools – scenarios – were used to communicate this knowledge. Such an approach would be in line with King et al (2015)'s fifth principle of risk assessment: take a holistic approach. Decision-relevant climate scenarios could usefully be developed to sample all the major dimensions of epistemic uncertainty (e.g. rapid economic growth, high greenhouse gas emissions *and* high climate sensitivity).

As has already been emphasised, high impact scenarios are of special importance for risk assessment. Sutton (2018) proposed the development of "Physically Plausible High Impact Scenarios" (PPHIS) as a specific tool for the WGI community to assess and communicate the relevant scientific evidence.

6. Conclusions and further implications

For decision makers, climate change is a problem in risk assessment and risk management. It is, therefore, surprising that the needs and lessons of risk assessment have not featured more prominently in the consideration of priorities for physical climate science[3], or in the

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[3] Even the latest WCRP Strategic Plan 2019-2028 (https://www.wcrp-climate.org/wcrp-sp) hardly mentions risk and includes no specific consideration of risk assessment needs.

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WGI contributions to the major IPCC Assessment Reports. In this article I have argued that this state of affairs is a result of the siloing of climate science between different disciplines (for example, between the three IPCC working groups), but it has been exacerbated by a widespread view that the job of the WGI community is to provide predictions and projections (with a focus on likelihood rather than risk) and that risk assessment is a job for others. This view, I have argued, is incorrect. Risk assessment requires the consideration of impacts as well as likelihood. Furthermore, impacts must be assessed and quantified using a wide range of variables, and the WGI community is the appropriate group to assess impacts and risks in terms of decision-relevant physical climate variables. Future WGI reports should address this requirement.

There is also a need to recognise explicitly that, whilst some quantitative bounds can be assessed and potentially narrowed, it will never be possible to quantify with precision the likelihood that future climate change will take a particular form (e.g. magnitude). Consequently, an important task for the WGI community is to ***develop discrete sets of climate scenarios, which individually are not associated with a specific probability but which collectively are designed to span the relevant uncertainty in the climate response to anthropogenic forcing*** (not merely the "*likely range*" for specific socio-economic scenarios). The "storyline" method of Shepherd et al (2018) offers a powerful approach. This work should include systematic attention to identifying and developing potential high impact scenarios, even if their likelihood is considered low (Sutton, 2018). Impacts, including the uncertainty in impacts, should be assessed for each climate scenario.

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King et al (2015) emphasise that risks must always be assessed in relation to objectives. In the case of climate change, the relevant objectives relate to: (i) mitigation, and (ii) adaptation. For mitigation, specific priorities for WGI include:

1. Develop a discrete set of ***global climate scenarios***. These should include scenarios for, e.g., high climate sensitivity or high TCRE due to changes in the natural carbon sink. The design of such scenarios should be based on understanding of the relevant Earth System processes.
2. For each global climate scenario quantify the conditional impacts:
    a. On the remaining carbon budget to reach specific warming targets (e.g. IPCC, 2018).
    b. On a range of decision-relevant physical climate variables (e.g. global sea level rise; major changes in regional climates such as the monsoons; the likelihood of triggering irreversible melting of Sheets; etc.)

For adaptation, specific priorities include:

1. Quantify ***current risks***, in particular the current likelihood of a wide range of decision-relevant high impact physical events (notably extreme weather), including multi-hazard and correlated risks. In this area there is an urgent need for research to address the attribution of changing risks to specific drivers.
2. To assess future risks:
    a. Develop ***regional climate scenarios*** (a discrete set for each chosen region). On regional scales, changes in atmospheric circulation are potentially as important as changes in global mean temperature, so regional scenarios must be designed accordingly. These should include specific high impact scenarios,

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e.g. associated with a shutdown in the AMOC or an abrupt shift in monsoon circulations.

b. For each regional climate scenario, quantify the conditional impacts and risks. As for current risk, this assessment should include a wide range of decision-relevant high impact physical events, including multi-hazard and correlated risks.

These priorities also have consequences for climate modelling. For example, the importance of modelling strategies to quantify current risks was already highlighted in section 4. This is one area where new MIPs should be considered (e.g. a “RISK-MIP”, possibly based on the d4PDF experimental design). In this case large ensembles which sample internal variability (e.g. Kay et al, 2015), at the highest resolutions possible (to capture high impact weather), are a key requirement. A second area is the development of appropriate global and regional climate scenarios. Here, large ensembles are also required – in this case particularly to define adequately the climate response to anthropogenic forcing – but high resolution may be a lower priority. The 10-member ScenarioMIP experiments are a step in the right direction but it should be recognised that they rely on an unprovable assumption that the current generation of models adequately spans the real uncertainty in the climate response to anthropogenic forcing, and furthermore these experiments involve no focused attempt to consider properly the full range of low likelihood high impact scenarios. The need to assess the *impacts* of specific climate scenarios, including low-likelihood scenarios, is a third area. An “AMOC-MIP”, for example, could be used to assess the potential impacts of a significant shutdown in the AMOC.

The physical climate science, WGI, community cannot of course complete the task of climate change risk assessment by itself. Collaboration with other communities - notably WGs II and III - and directly with decision-makers, is essential. In the context of the IPCC Assessment Cycle, global and regional climate scenarios developed by WGI could be taken up by WGs II and III, and be used by national governments, to assess the full range of impacts and risks, and the implications for risk management. They would also be very helpful for the production of an integrated Synthesis Report. More cross-cutting IPCC reports, and changes to the scoping process for the major assessment reports could also make very valuable contributions. Essential to all this, however, is for physical climate science to take its critical role in risk assessment much more seriously than hitherto.

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For further reading

Hawkins and Sutton, 2009: The potential to narrow uncertainty in regional climate predictions, *Bull. Am. Meteorol. Soc.* **90**, 1095–1107.

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D., Mastrandrea, K.J. Mach, G.K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 582 pp.

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2014: Summary for policymakers, in: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R., and White, L. L., Cambridge University Press, Cambridge, UK and New York, NY, USA, 1–32, 2014.

IPCC, 2018: Global Warming of 1.5^{o}C, Summary for policymakers, in press, (http://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf)

Kay, J., et al., 2015: The Community Earth System Model (CESM) large ensemble project: a community resource for studying climate change in the presence of internal climate variability. *Bull. Am. Meteorol. Soc.* **96**, 1333–1349.

Accepted for publication in *Bulletin of the American Meteorological Society.* DOI 10.1175/BAMS-D-18-0280.1.

King, D., Schrag, D., Dadi, Z., Qui, Y., and Ghosh, A, 2015: Climate change: a risk assessement, Cambridge University Centre for Science and Policy, Cambridge, U.K.

Mizuta, R., A. Murata, M. Ishii, H. Shiogama, K. Hibino, N. Mori, O. Arakawa, Y. Imada, K. Yoshida, T. Aoyagi, H. Kawase, M. Mori, Y. Okada, T. Shimura, T. Nagatomo, M. Ikeda, H. Endo, M. Nosaka, M. Arai, C. Takahashi, K. Tanaka, T. Takemi, Y. Tachikawa, K. Temur, Y. Kamae, M. Watanabe, H. Sasaki, A. Kitoh, I. Takayabu, E. Nakakita, and M. Kimoto, 2017: Over 5000 years of ensemble future climate simulations by 60 km global and 20 km regional atmospheric models. *Bull. Amer. Meteor. Soc.* July 2017, 1383-1398

O'Neill, B.C., Kriegler, E., Riahi, K. et al. 2014: A new scenario framework for climate change research: the concept of shared socioeconomic pathways, *Climatic Change*, 122: 387. https://doi.org/10.1007/s10584-013-0905-2

Schellnhuber, H. J. (2018). *Foreword*. In Spratt, D. & Dunlop I., *What Lies Beneath: The understatement of existential climate risk.* Breakthrough National Centre for Climate Restoration, Melbourne, 2

Shepherd, T.G., Boyd, E., Calel, R.A., Chapmane, S.C., Dessai, S., Dima-West, I.M., Fowler, H.J., James, R., Maraun, D., Martius, O., Senior, C.A., Sobel, A.H., Stainforth, D.A., Tett, S.F.B., Trenberth, K., van den Hurk, B., Watkins, N.W., Wilby, R.L., Zenghelis, D.A., 2018: Storylines: An alternative approach to representing uncertainty in physical aspects of climate change, *Climatic Change*, 151 (3-4). pp. 555-571. ISSN 0165-0009 doi: https://doi.org/10.1007/s10584-018-2317-9

Stott, P.A., Christidis, N., Otto, F.E.L., Sun, Y., Vanderlinden, J.-P., van Oldenborgh, G.J., Vautard, R., von Storch, H., Walton, P., Yiou, P., and Zwiers, F.W., 2016: Attribution of extreme weather and climate-related events, WIRES Climate Change, 7:23-41, doi: 10.1002/wcc.380

Sutton, R.T., 2018: ESD Ideas: a simple proposal to improve the contribution of IPCC WGI to the assessment and communication of climate change risks, *Earth Syst. Dynam.*, 9, 1155–1158, https://doi.org/10.5194/esd-9-1155-2018

Weaver, C. P., Moss, R. H., Ebi, K. L., Gleick, P. H., Stern, P. C., Tebaldi, C., Wilson, R. S., and Arvai, J. L.: Reframing climate change assessments around risk: recommendations for the US National Climate Assessment, *Environ. Res. Lett.*, 12, 08021, 2017.

Weaver, C.P., Lempert, R.J., Brown, C., Hall, J.A., Revell, D., and D. Sarewitz, 2013: Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks, *WIREs Clim Change* 2013, 4:39–60. doi: 10.1002/wcc.202

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