

# *Climate science needs to take risk assessment much more seriously*

Article

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# Climate science needs to take risk assessment much more seriously



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1 **Abstract**

2

3 For decision makers, climate change is a problem in risk assessment and risk management.

4 It is, therefore, surprising that the needs and lessons of risk assessment have not featured

5 more centrally in the consideration of priorities for physical climate science research, or in

6 the Working Group I contributions to the major Assessment Reports of the

7 Intergovernmental Panel on Climate Change. This article considers the reasons, which

8 include a widespread view that the job of physical climate science is to provide predictions

9 and projections - with a focus on likelihood rather than risk - and that risk assessment is a

10 job for others. This view, it is argued, is incorrect. There is an urgent need for physical

11 climate science to take the needs of risk assessment much more seriously. The challenge of

12 meeting this need has important implications for priorities in climate research, climate

13 modelling and climate assessments.

14

15

16        **1. Introduction**

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

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

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<sup>1</sup> Assessment of opportunities is also important and can be considered within a similar framework, but is not a focus of this article.

37        **2. Principles of risk assessment**

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

45

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

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

54

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

60 principles 1 and 6, impact is ultimately a consequence of choices about objectives and  
61 values.

62

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

67

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

77

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

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

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

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

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

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<sup>2</sup> See, for example, the WCRP Strategic Framework 2005-15: Coordinated Observation and Prediction of the Earth System.



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

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

126 A final reason that may have contributed to the WGI community neglecting the needs of risk  
127 assessment is concern about accusations of scaremongering (e.g. Sutton, 2018). Risk

128 assessment does involve drawing attention to potential “bad” outcomes even when they  
129 are very uncertain. Such an approach does not come naturally to many scientists who - for  
130 good reasons - are cautious by nature. The politicised debates around climate change have  
131 exacerbated this situation.

#### 132 **4. Some consequences**

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

136 One consequence has been to afford insufficient attention to the low-likelihood high impact  
137 events which - as already discussed - are a central concern in risk assessment. King et al  
138 (2015) point out that decision makers facing risks are typically most concerned with two  
139 questions: 1) what is likely? 2) how bad could it be/what must we avoid? The latter question  
140 is fundamental to the development of robust strategies for both adaption (e.g. “resilience”)  
141 and mitigation. However, WGI has focussed overwhelmingly on question 1 (e.g. assessing  
142 the *likely* range for key parameters). But physical climate science has much knowledge and  
143 expertise to bring to question 2. It is essential that climate science identifies what is *possible*  
144 in the climate system, not merely what is likely (e.g. Weaver et al, 2013; Schellnhuber,  
145 2018). Possibilities - which come with the potential for surprises - are a major concern for  
146 risk assessment. Furthermore, there are no fundamental obstacles to including assessments  
147 of the relevant risks within WGI reports (Sutton, 2018).

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

151 high impact possibility that is not associated with any abrupt change in the Earth system.

152 Furthermore, even when WG1 has considered low-likelihood high impact scenarios it has

153 tended to focus too narrowly on likelihood and given insufficient attention to impacts. Here

154 is an example from the AR5 SPM (IPCC, 2013): “It is very unlikely that the AMOC will

155 undergo an abrupt transition or collapse in the 21st century for the scenarios considered.”

156 No information whatsoever about the impacts of an AMOC collapse is communicated,

157 despite the importance of impact information for decision-making. WGII is not the

158 appropriate community to provide information about the magnitude of regional climate

159 change or sea level rise that could result from a collapse of the AMOC, were it to occur; this

160 responsibility sits squarely with the WGI, but WGI - either as a research community or in the

161 production of IPCC reports - has not considered it a priority. This neglect must be remedied.

162 A second example is that physical climate science has until recently afforded surprisingly

163 little attention to what is a key issue for many decision makers, namely **quantifying current**

164 **risks** – more specifically, *what is the current likelihood of high impact events?* Such events

165 are by definition rare, i.e. they are associated with low likelihood. But whether this

166 likelihood is 1 in 20, 1 in 200 or 1 in 200,000 is of great importance for those concerned with

167 contingency planning and building resilience. In this case the quantification of likelihoods *is*

168 very important, and is more tractable than for statements about future climate change. In a

169 changing (non-stationary) climate, the appropriate likelihoods cannot be reliably estimated

170 from historical data alone. A model of how climate change is affecting likelihoods (and risk)

171 is required. For simple events (e.g. daily extremes of temperature) statistical models may

172 suffice, but for more complex events (e.g. multivariate or correlated hazards) large

173 ensembles of simulations with general circulation models are needed (Stott et al, 2015;

174 Mizuta et al, 2017). The recent-climate component of the Japanese d4PDF programme

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

## 178 **5. The role of scenarios**

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

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

197 Many national climate scenarios have been developed (e.g.  
198 <http://www.climatescenarios.nl/>, <http://scenarios.globalchange.gov>) but interestingly  
199 discrete global or regional climate scenarios have not been widely used, arguably because  
200 the WGI climate science community has not promoted them. By contrast, socio-economic  
201 scenarios have long been used by IPCC (e.g. O’Neill et al, 2014). However, for the purposes  
202 of risk assessment there is little difference between our knowledge/ignorance of (say)  
203 future population growth and our knowledge/ignorance of (say) the future rate of global  
204 warming, so it would be helpful for decision makers if the same tools – scenarios – were  
205 used to communicate this knowledge. Such an approach would be in line with King et al  
206 (2015)’s fifth principle of risk assessment: take a holistic approach. Decision-relevant  
207 climate scenarios could usefully be developed to sample all the major dimensions of  
208 epistemic uncertainty (e.g. rapid economic growth, high greenhouse gas emissions *and* high  
209 climate sensitivity).

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

## 214 **6. Conclusions and further implications**

215 For decision makers, climate change is a problem in risk assessment and risk management.  
216 It is, therefore, surprising that the needs and lessons of risk assessment have not featured  
217 more prominently in the consideration of priorities for physical climate science<sup>3</sup>, or in the

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<sup>3</sup> 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.

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

228 There is also a need to recognise explicitly that, whilst some quantitative bounds can be  
229 assessed and potentially narrowed, it will never be possible to quantify with precision the  
230 likelihood that future climate change will take a particular form (e.g. magnitude).

231 Consequently, an important task for the WGI community is to **develop discrete sets of**  
232 **climate scenarios, which individually are not associated with a specific probability but**  
233 **which collectively are designed to span the relevant uncertainty in the climate response to**  
234 **anthropogenic forcing** (not merely the “likely range” for specific socio-economic scenarios).

235 The “storyline” method of Shepherd et al (2018) offers a powerful approach. This work  
236 should include systematic attention to identifying and developing potential high impact  
237 scenarios, even if their likelihood is considered low (Sutton, 2018). Impacts, including the  
238 uncertainty in impacts, should be assessed for each climate scenario.

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

242 1. Develop a discrete set of **global climate scenarios**. These should include scenarios  
243 for, e.g., high climate sensitivity or high TCRE due to changes in the natural carbon  
244 sink. The design of such scenarios should be based on understanding of the relevant  
245 Earth System processes.

246 2. For each global climate scenario quantify the conditional impacts:

247 a. On the remaining carbon budget to reach specific warming targets (e.g. IPCC,  
248 2018).

249 b. On a range of decision-relevant physical climate variables (e.g. global sea  
250 level rise; major changes in regional climates such as the monsoons; the  
251 likelihood of triggering irreversible melting of Sheets; etc.)

252 For adaptation, specific priorities include:

253 1. Quantify **current risks**, in particular the current likelihood of a wide range of  
254 decision-relevant high impact physical events (notably extreme weather), including  
255 multi-hazard and correlated risks. In this area there is an urgent need for research to  
256 address the attribution of changing risks to specific drivers.

257 2. To assess future risks:

258 a. Develop **regional climate scenarios** (a discrete set for each chosen region).

259 On regional scales, changes in atmospheric circulation are potentially as  
260 important as changes in global mean temperature, so regional scenarios must  
261 be designed accordingly. These should include specific high impact scenarios,

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

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

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



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

294

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297 Shepherd and Ed Hawkins for many informative discussions, and the three BAMS reviewers  
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#### 299 **For further reading**

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