

Statistical Language Backs Conservatism in Climate-Change Assessments

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The scientific evidence for anthropogenic climate change is empirically settled, but communicating it to nonscientific audiences remains challenging. To be explicit about the state of knowledge on climate science, the Intergovernmental Panel on Climate Change (IPCC) has adopted a vocabulary that ranks climate findings through certainty-calibrated qualifiers of confidence and likelihood. In this article, we quantified the occurrence of knowns and unknowns about “The Physical Science Basis” of the IPCC’s Fifth Assessment Report by counting the frequency of calibrated qualifiers. We found that the tone of the IPCC’s probabilistic language is remarkably conservative (mean confidence is medium, and mean likelihood is 66%–100% or 0–33%), and emanates from the IPCC recommendations themselves, complexity of climate research, and exposure to politically motivated debates. Leveraging communication of uncertainty with overwhelming scientific consensus about anthropogenic climate change should be one element of a wider reform, whereby the creation of an IPCC outreach working group could enhance the transmission of climate science to the panel’s audiences.

Keywords: climate change, communication, Intergovernmental Panel on Climate Change, terminology, uncertainty

Communicating scientific and statistical uncertainty to nonacademic audiences, including policymakers, is one of the most important challenges of modern science. This is particularly true for climate science where the risks posed by anthropogenic climate disruption have become a strategic topic among rivalling political ideologies (McCright and Dunlap 2011), and represent considerable losses in actual and future economic production (Burke et al. 2015), as well as an unprecedented threat to human health (McMichael 2013), and to biodiversity (Strona and Bradshaw 2018) and the multiple ecosystem services it provides to human societies (Scheffers et al. 2016). Despite the climate-change community leading the development of a quantitative language for uncertainty (Morgan and Mellon 2011), communication experts question whether the conveyance of uncertainty to the public might in fact promote political inaction for dealing with the environmental and social impacts of a changing climate (Lewandowsky et al. 2015a). In this *Forum* article, we analyze the major linguistic effort made by the Intergovernmental Panel on Climate Change (IPCC) to communicate the (un)certainly of climate science to its target audiences, and we quantify the occurrence of knowns and unknowns present in IPCC reports by counting the frequency of statements reported to a given range of uncertainty. We then explain why transparency about scientific uncertainty renders the IPCC’s reporting conservative,

and finally we identify challenges and propose future directions that could bolster the IPCC’s communication strategy and the public transmission of climate science as a whole. Our scope is to provide a constructive overview of the IPCC’s probabilistic language explicitly free of statistical analyses.

Intergovernmental Panel on Climate Change

Effective communication has been a major area of elaboration and concern for scientists in the IPCC, who are consistently challenged with adhering to scientific rigour while delivering clear and unambiguous messaging (Lynn 2018). Established in 1988 by the United Nations’ World Meteorological Organization and Environmental Program, and with a current membership of 195 countries, the principal duty of this Panel rests on the review of the climate-related primary and secondary literature by three working groups (known as WGI, II, and III), and on the evolving development of methodologies by the “Task Force on National Greenhouse Gas Inventories” for calculating greenhouse-gas emissions and removals. The IPCC’s overarching goal through their working groups is to assess the physical sciences of climate change (WGI), its potential socioeconomic consequences in terms of impacts, adaptation and vulnerability (WGII), and the associated mitigation options (WGIII). Their outputs are published in a series of periodical reports. To date there have been five Assessment Reports, published in 1990, 1995, 2001, 2007 and 2014 (Jones 2013).

Box 1. Intergovernmental Panel on Climate Change's (IPCC) target audiences quoted literally from its communication strategy (IPCC 2016a).

“The primary target audiences of the communications efforts of the IPCC are governments and policymakers at all levels, the UNFCCC (United Nations Framework Convention on Climate Change), and the UN-wide system intergovernmental processes more broadly.

Broader audiences, such as IPCC observer organizations, the scientific community, the education sector, non-governmental organizations, the business sector and the wider public also have an interest in the work and assessments of the IPCC. While these are not the primary audiences of the IPCC communications efforts, the IPCC should look for ways to ensure that information is available and accessible for these audiences.

Third parties can play an additional valuable role taking elements of IPCC assessments to create accessible products aimed at specific audiences. The IPCC takes note of such derivative products, and may engage with relevant organizations that produce them. However, such products must not be considered joint productions or in any way products of the IPCC.

Engaging and building relationships with the media is an important way in which the IPCC can communicate the information contained in its reports, as well as its processes and procedures.

IPCC audiences are truly global in extent and are therefore very diverse. In its communications and outreach activities, the IPCC will take the specific context of different countries into account, which may require tailor-made outreach activities. For instance, communications needs of developing countries may be different to those of developed countries.”

The (latest) Fifth Assessment Report is a compendium of four publications: an overall synthesis report and one report from every working group (the full content is listed by sections in supplemental table S1). The synthesis report subsumes the working-group outcomes in a technical summary preceded by a summary for policymakers (IPCC 2014d). The reports of the working groups each consist of their own summary for policymakers and technical summary, in-depth chapters, and supplements (IPCC 2013a, WGI 2014a; IPCC 2013b, WGII; IPCC 2014c, WGIII)—all fully available from the IPCC's website (www.ipcc.ch). The elaboration of the technical summaries and in-depth chapters is done by “contributing authors” who provide the raw materials (text, data, graphs, tables), “lead authors” who integrate and synthesize the input of contributing authors and deal with comments from a selected group of “expert reviewers,” and “coordinating lead authors” who oversee completeness, coherence and style consistency (InterAcademy Council 2010). At least two “review editors” observe the whole assessment process for each in-depth chapter (InterAcademy Council 2010). Synthesis reports and summaries for policymakers follow a similar review process with additional participation of government representatives (Lynn 2018, see below).

Probabilistic language tailored to expected audiences

The IPCC reports are meant to inform a primary target audience of national governments, policymaking stakeholders, and intergovernmental actors across the United Nations (box 1), and represent the cornerstone of the United Nations Framework Convention on Climate Change as in the 2015 Paris Agreement. This role is essential because, in the current Information Age, it is striking that the primary literature of climate-change research has minimal coverage in policy (Bornmann et al. 2016). The IPCC fills the gap by

acting as the principal mediator between the scientific community and governments in a global context, and so fuels the political response to anthropogenic climate disruption, with IPCC reports being policy relevant but not policy prescriptive (InterAcademy Council 2010).

Nonetheless, the IPCC acknowledges that many other sectors (business, educators, the media, observer organizations, the scientific community, and the public in general; box 1) are interested in its work and published reports, and might require context- and country-specific outreach (IPCC 2016a). Despite intending to engage such a global, broad and diverse audience, the style of IPCC reports unfortunately remains technical (Schellnhuber 2008), therefore compromising the conveyance of scientific uncertainties to a broad audience (Lewandowsky et al. 2015a), and overall making their readability challenging for nonscientific audiences (Barkemeyer et al. 2016, but see Mach et al. 2017). Because IPCC reports are increasingly voluminous (Jones 2013), when the Sixth Assessment Report (and three additional reports that focus on “global warming,” “land,” and “ocean and cryosphere”) sees the public light by 2022 (Lynn 2018), communication challenges are bound to grow in sync with the number of bytes of climate information.

To hone the communication and understanding of climate-science uncertainty to their expected audiences, the IPCC has adopted what it refers to as a “calibrated language” to rank scientific uncertainty. This strategy firmly aligns with the IPCC's communication strategy of “... providing clear and balanced information on climate change, including scientific uncertainties, without compromising accuracy” (IPCC 2016a). The expression “calibrated language” implies a common vocabulary and scale of judgment of the degree of certainty in findings (e.g., magnitude, pattern, prediction, projection, rate, trend) across IPCC working groups. Guidelines around how to construct calibrations by the

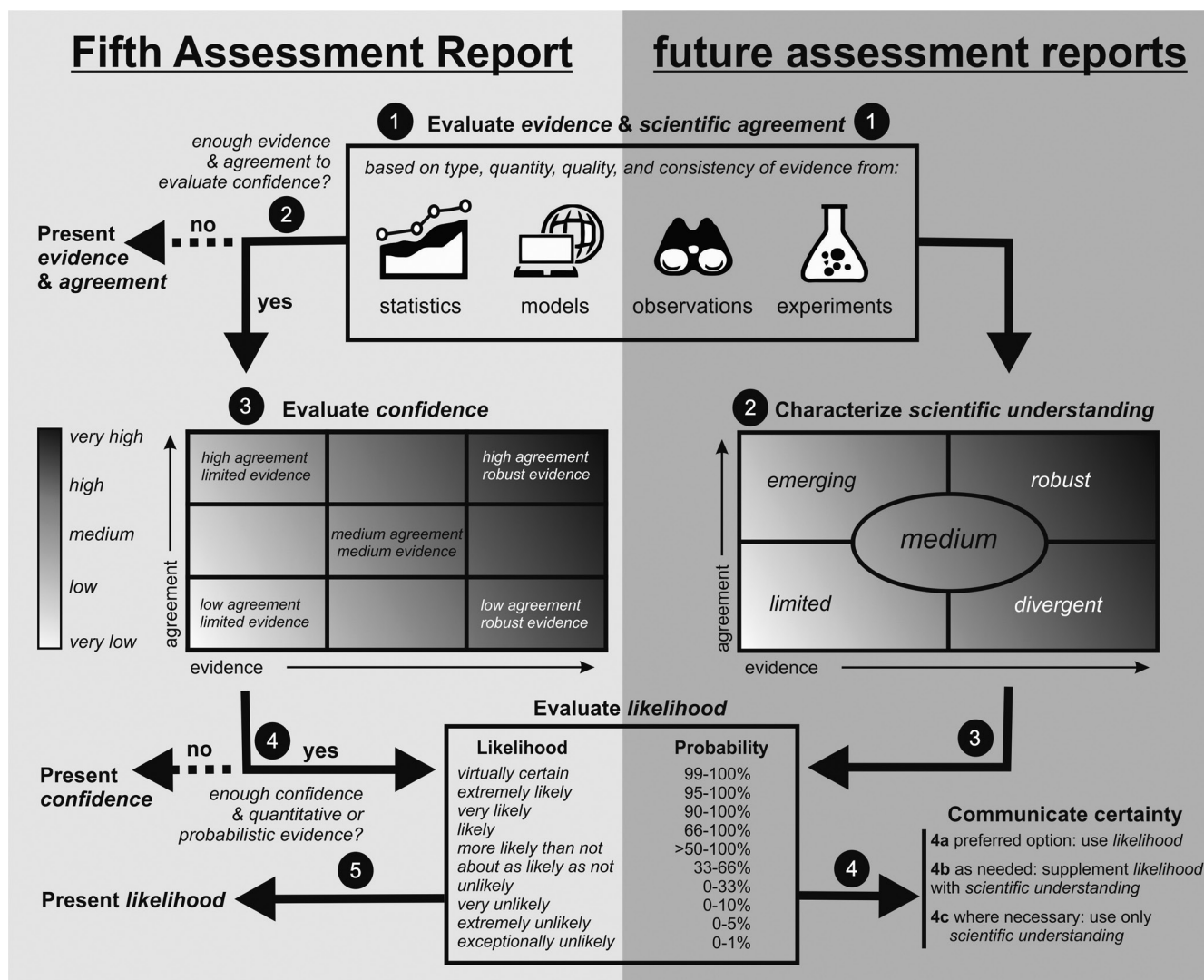


Figure 1. Procedures for assigning confidence and likelihood qualifiers to the scientific evidence for anthropogenic climate change in the Intergovernmental Panel on Climate Change’s (IPCC) Fifth Assessment Report, and as proposed by the Core Writing Team for future assessments—modified from Mach and colleagues (2017). Numbered circles represent steps in the assessment process.

IPCC’s “lead authors” have evolved through the Third (Moss 2011), Fourth (IPCC 2007) and Fifth (Mastrandrea et al. 2011a, Mastrandrea et al. 2011b) Assessment Reports, and currently consist of two sets of calibrated qualifiers: *confidence* and *likelihood*. *Confidence* is a qualitative composite of the strength of evidence (type, quality, amount, consistency) and the scientific agreement (proportion of different lines of evidence that support the same conclusion) available for a given finding (Mastrandrea et al. 2011a). By contrast, *likelihood* “... is used to express a probabilistic estimate of the occurrence of a single event or of an outcome” (Mastrandrea et al. 2011a). Figure 1 displays the five categories of *confidence* (from *very low* to *very high*) and ten categories of *likelihood* (from *exceptionally unlikely* to *virtually certain*) in the Fifth Assessment Report. IPCC Core Writing Team members have outlined a proposal to revise those qualifiers

for future assessments (Mach et al. 2017), where *confidence* would turn to *scientific understanding* (five “unranked” categories according to evidence and agreement: *limited*, *emerging*, *medium*, *divergent*, *robust*), while *likelihood* categories would remain unchanged (figure 1).

Through the assessment process, IPCC’s calibrations imply that the scale of scientific evidence (based on published climate data and research) maps to a scale of assessment (based on the collective judgement of IPCC lead authors); therefore, calibrated qualifiers do not capture the view of individual contributing authors or expert reviewers (Morgan 2014, see below). This calibrated language undoubtedly reaffirms the sophisticated discourse of IPCC reports, but it might ironically jeopardize the clarity with which they might resonate with nonscientific audiences. Indeed, several studies have reported caveats in the communicative efficacy of the IPCC’s

Table 1. Two sets of core conclusions by the Intergovernmental Panel on Climate Change (IPCC) and the US National Research Council (NRC).

IPCC statements	Mean rank ^a
Observed changes in the climate system: Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.	<i>Confidence</i> = 3.8 (SE = 0.3, <i>n</i> = 4) <i>Likelihood</i> = 4.0 (SE = 1.0, <i>n</i> = 3)
Drivers of climate change: Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO ₂ since 1750.	<i>Confidence</i> (<i>n</i> = 0) <i>Likelihood</i> (<i>n</i> = 0)
Understanding the climate system and its recent changes: Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.	<i>Confidence</i> = 5 (<i>n</i> = 1) <i>Likelihood</i> = 5 (<i>n</i> = 1)
Future global and regional climate change: Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.	<i>Confidence</i> = 4 (<i>n</i> = 1) <i>Likelihood</i> = 3.0 (SE = 0.5, <i>n</i> = 5)
NRC endorsements	
i, Earth is warming. ii, Most of the warming over the last several decades can be attributed to human activities. iii, Natural climate variability cannot explain or offset the long-term warming trend. iv, Global warming is closely associated with a broad spectrum of other changes. v, Human-induced climate change and its impacts will continue for many decades. vi, The ultimate magnitude of climate change and the severity of its impacts depend strongly on the actions that human societies take to respond to these risks.	
Note: The first set of conclusions shows (left column) literal overarching statements about “The Physical Science Basis” of climate change in the IPCC’s Fifth Assessment Report as stated in the “Headline Statements” (WGI Technical Support Unit 2014), and (right column) the number of climate outcomes (<i>n</i>) that are attributed to a given <i>confidence</i> and <i>likelihood</i> through those statements. The second set shows the endorsements by the NRC (2010) based on the IPCC’s outcomes of <i>high</i> and <i>very high confidence</i> after Cooke (2015). ^a <i>Confidence</i> ranks: <i>very low</i> , 1; <i>low</i> , 2; <i>medium</i> , 3; <i>high</i> , 4; <i>very high</i> , 5. <i>Likelihood</i> ranks: <i>about as likely as not</i> , 1; <i>more likely than not</i> , 2; <i>likely</i> or <i>unlikely</i> , 3; <i>very likely</i> or <i>very unlikely</i> , 4; <i>extremely likely</i> or <i>extremely unlikely</i> , 5; <i>virtually certain</i> or <i>exceptionally unlikely</i> , 6. See figure 1 and footnote of figure 2.	

calibrations, which can be summarized as follows: (a) the media often uses the IPCC’s calibrated qualifiers without reference to their intended meanings (Collins and Nerlich 2016), (b) interpretation can be affected by the linguistic background of the audience (Harris et al. 2013, Budescu et al. 2014), and (c) general-public language is unfit to gauge the joint uncertainty of related climate findings (Cooke 2015). An unexplored issue is that the IPCC’s calibrations delimit a continuous scale of how much we know and do not know about climate change—a headline that receives considerable media coverage and public attention (e.g., Abraham 2013, Frost 2014, Barnard 2017). We evaluate this issue in the next section by quantifying the frequency of calibrated qualifiers in the IPCC’s Fifth Assessment Report.

Tone of the physical science of climate change

From the Fifth Assessment Report, we counted the number of *confidence* and *likelihood* qualifiers in the WGI component as a case study (supplemental table S1). This working group sifts through the literature of the physical science basis of how the climate system functions and changes (IPCC 2013a), and has supported the overwhelming scientific consensus (Oreskes 2004, Benestad et al. 2016, Cook et al. 2016) that human activities have altered the Earth’s climate on a historical timescale, and will continue to do so

as long as fossil fuels prevail as our main sources of energy (table 1).

Confidence and *likelihood* qualifiers can be easily tracked in the Fifth Assessment Report because they are italicized. We counted qualifiers separately in the “Technical Summary” (Stocker et al. 2013), the “Summary for Policy Makers” (IPCC 2013b), and the in-depth chapters 2 to 14 each prefaced by a self-contained “Executive Summary” (IPCC 2013a)—but excluded chapter 1 because it is an introduction to concepts, definitions, climate-change indicators (and how they compare to the Fourth Assessment Report), scenarios, and the state of the art of climate science as used in the remaining chapters. We distinguished summaries from in-depth chapters in our analysis because the former flag the main outcomes of the latter, so both are distinct in terms of content and relevance (and potential audiences), and might be dominated by contrasting degrees of certainty. This is particularly the case for the “Summary for Policymakers” because representatives of all IPCC-signatory governments carefully read line by line, make amendments, and finally approve the text in agreement with the Panel during a plenary session (Lynn 2018). For *likelihoods*, we pooled statements of identical probability; for instance, *very likely* and *very unlikely* indicate the same magnitude of uncertainty for a positive and negative statement, respectively (figures 1 and 2). To avoid the

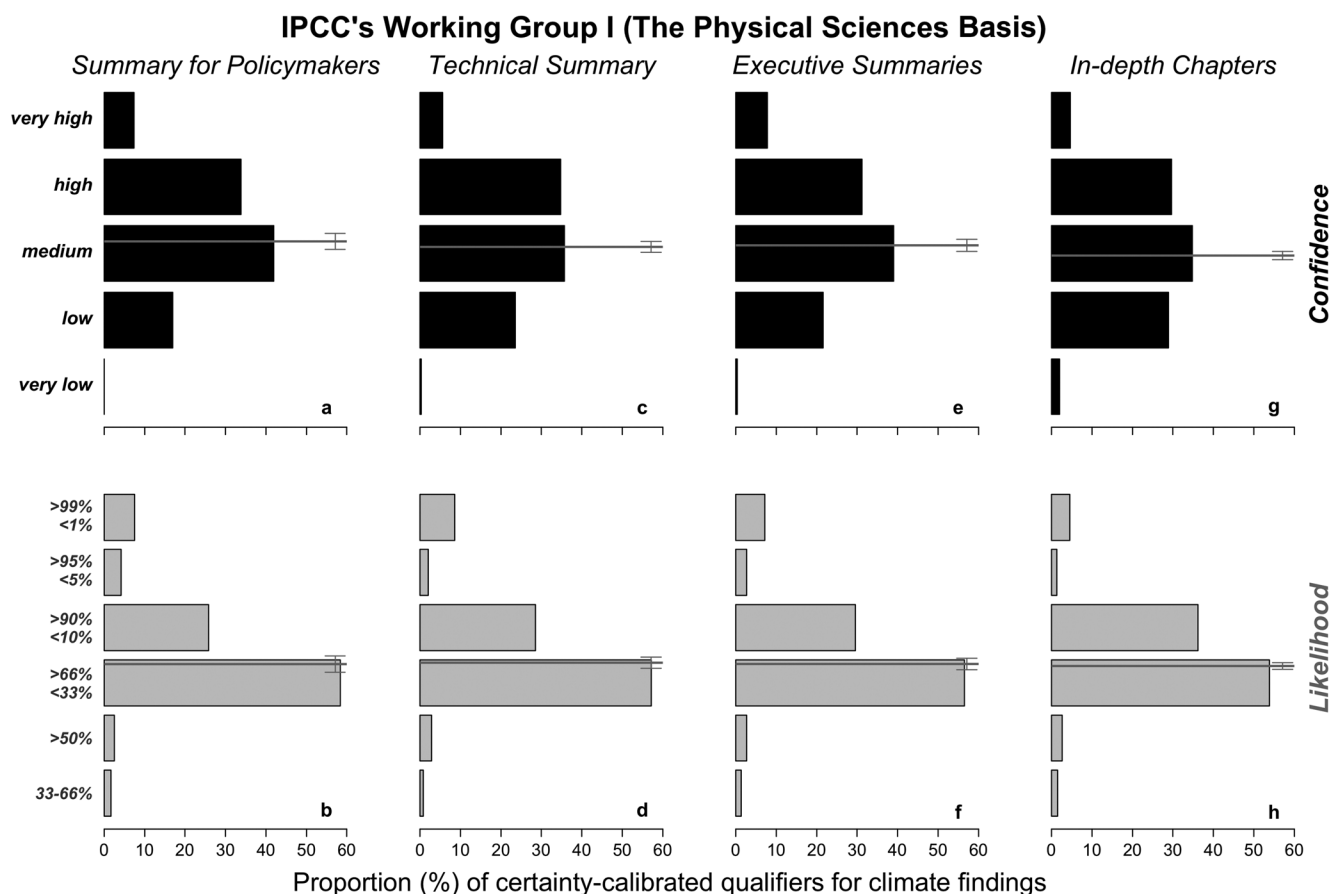


Figure 2. Proportion of confidence (top row) and likelihood (bottom row) qualifiers in the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (Working Group I: "The Physical Science Basis"). Counts cover the "Summary for Policymakers" (a, b), the "Technical Summary" (c, d), and the "Executive Summaries" (e, f) and main text (g, h) of the in-depth chapters. Histograms show decreasing uncertainty from lower to upper categories. Horizontal lines in grey are mean ranked uncertainties; the error bars represent two standard errors (sample sizes reported in supplemental table S2). Confidence ranks: very low, 1; low, 2; medium, 3; high, 4; very high, 5. Likelihood ranks: about as likely as not, 1 (33–66%); more likely than not, 2 (>50%); likely (>33%) or unlikely (<66%), 3; very likely (>90%) or very unlikely (<10%), 4; extremely likely (>95%) or extremely unlikely (<5%), 5; virtually certain (>99%) or exceptionally unlikely (<1%), 6.

large displays (which we use hereafter to define boxes, figures and tables) in the in-depth chapter 14 on future regional climate change biasing our counts (they accounted for 28% of total calibrations counted in all chapters; supplemental table S2), we show the frequency of qualifiers in the main text of the in-depth chapters in figure 2, and in displays in supplemental figure S1. We provide full methodological details in the supplemental material.

We counted 3191 calibrated qualifiers (1979 and 1212 confidences and likelihoods, respectively) in the IPCC WGI's "The Physical Science Basis"—sample sizes shown in supplemental table S2. Throughout, we found that the proportions of the different qualifiers assigned to climate findings follow a nearly symmetric distribution (figure 2). In the "Summary for Policymakers", 59% of the confidence qualifiers ($n = 136$) are low to medium (figure 2a), and 58% of the likelihood qualifiers ($n = 120$) are likely (66%–100% probability) or unlikely (0%–33% probability; figure 2b). In figure 2, horizontal grey

lines are the means of qualifiers from lowest (1) to highest (5, confidence, or 6, likelihood) strength of evidence, indicating a mean (ranked) confidence of 3.3 (standard error [SE] = 0.1 and likelihood of 3.5 (SE = 0.2; table S2). The "Technical Summary" (figure 2c and d; $n = 567$ calibrated qualifiers), and the executive summaries (figure 2e and f; $n = 492$) and main text of the in-depth chapters (figure 2g and h; $n = 1136$) match the trend of the "Technical Summary" for both metrics, with mean confidences and likelihoods all from 3.1 to 3.5 (table S2), and medians fixed at 3 in all cases (table S2).

In all of those components, the proportion of the top/bottom categories of certainty (very high/very low, virtually certain/exceptionally unlikely) never exceeded 8%. Therefore, when the IPCC's WGI synthesizes information about the physical phenomena, rates, and trends of climate change from in-depth chapters to their different summaries (and, potentially, audiences), the average certainty of the climate science assessed remains medium—probabilistically

Box 2. Literal recommendations in the Intergovernmental Panel on Climate Change's guidance note for lead authors of the Fifth Assessment Report (Mastrandrea et al. 2011a) that enhance the frequency of weak-certainty statements.

"Because risk is a function of probability and consequence, information on the tails of the distribution of the outcomes can be specifically important. Low-probability outcomes can have significant impacts, particularly when characterized by large magnitude, long persistence, broad prevalence, and/or irreversibility. Author teams are therefore encouraged to provide information on the tails of distributions of key variables, reporting quantitative estimates when possible and supplying qualitative assessments and evaluations when appropriate.

For findings (effects) that are conditional on other findings (causes), consider independently evaluating the degrees of certainty in both causes and effects, with the understanding that the degree of certainty in the causes may be low.

The [*likelihood*] categories can be considered to have "fuzzy boundaries." A statement that an outcome is "likely" means that the probability of an outcome can range from $\geq 66\%$ (fuzzy boundaries implied) to 100% probability... When there is sufficient information, it is preferable to specify the full probability distribution or a probability range (e.g., 90%–95%) without using the [*likelihood*] terms.

Consider that, in some cases, it may be appropriate to describe findings for which evidence and understanding are overwhelming as statements of fact without using uncertainty qualifiers."

within 0%–33% (*unlikely*) and 66%–100% (*likely*) ranges. As shown in supplemental figure S1, these overall trends and conclusions persist when we counted *likelihood* qualifiers in the displays of the in-depth chapters, except that *high* confidence predominated in those displays due to climate findings documented in only three in-depth chapters, namely chapters 2 ("Observations: Atmosphere and Surface"), 10 ("Observations: Cryosphere") and 14 ("Climate Phenomena and their Relevance for Future Regional Climate Change").

Uncertainty driving conservativeness

Overall, the predominance of qualifiers of low to intermediate certainty reported above reveals that the tone of the probabilistic language of the IPCC's report on the physical science of climate is remarkably conservative, and contrasts with the overwhelming scientific consensus about anthropogenic climate change (Oreskes 2004, Benestad et al. 2016, Cook et al. 2016) that the IPCC is endorsing (table 1). We argue below that such conservatism results from the combined effect of three factors, namely the IPCC's guidelines themselves, research complexity, and politically motivated challenges.

IPCC's guidelines. The IPCC recommends that the calibrated assessment of climate findings should be explicit about all sources and ranges of uncertainty, and often focuses on reference probabilities of low magnitude. Box 2 shows four of such recommendations in the original guidance notes for the Fifth Assessment Report's lead authors (Mastrandrea et al. 2011a), which we describe below.

To the IPCC, reporting the tails of the distribution of low-probability adverse outcomes is sensible because those tails can have major implications in climate-change science, impact, adaptation, or mitigation (box 2). The most obvious case is where different ranges of the magnitude of a climate-change metric receive specific calibrations (Mastrandrea et al. 2011b), e.g., "... observed climate change, climate models and feedback analysis, as well as paleoclimate evidence

indicate that ECS [equilibrium climate sensitivity] is positive, *likely* in the range 1.5°C to 4.5°C with *high confidence*, *extremely unlikely* less than 1°C (*high confidence*) and *very unlikely* greater than 6°C (*medium confidence*)" (Stocker et al. 2013).

This is somewhat akin to where the IPCC assesses the magnitude of a spatial or temporal metric such that certainty will normally decrease as estimates cover relatively poorly studied regions and longer periods (into the past or the future), often due to data deficiency and coverage, and alternative modelling approaches. For example, "... *confidence* in precipitation change averaged over global land areas is *low* prior to 1951 and *medium* afterwards because of insufficient data" and "... *low confidence* in basin-scale projections of changes in intensity and frequency of tropical cyclones ... reflects the small number of studies exploring near-term tropical cyclone activity, the differences across published projections ... and the large role for natural variability" (Stocker et al. 2013).

Likelihood categories in the IPCC's reports have "fuzzy" boundaries (box 2), and so can assign low to intermediate calibrations to findings that are highly probable (the opposite can also occur). This renders IPCC calibrations naturally conservative, e.g., the statement "... it is *likely* that human influence has affected the global water cycle since 1960" (Stocker et al. 2013) implies that anthropogenic forcing might be anywhere from 66% to 100% probable. The narrative of fuzzy boundaries is one that the nonscientific readers of IPCC reports might misunderstand because it is nonstandard terminology (Cooke 2015)—instead, common reasoning is more bound to gauge the certainty of a *likely* event by the lower value (66%). Think of boarding an airplane that has a 66 to 100% chance of crashing; in this case, would the upper bound even matter to most people?

Importantly, the IPCC prompts its working groups not to rank the certainty of statements of fact in the IPCC calibration guidelines (box 2), and highlights this guideline with

the same sentence in the introductory section of the WGI's "Summary for Policymakers" (IPCC 2013b, p. 4) and the "Technical Summary" (Stocker et al. 2013, p. 35): "... where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers." These *facts* are sometimes (twice in the "Technical Summary", ten times in the in-depth chapters) denoted by the term "certain" subject to no qualifier or italicization, e.g., "... it is certain that global mean [land] surface temperature has increased since the late 19th century" (IPCC 2013b).

Climate complexity. Consensus in the scientific community regarding whether humans are altering the climate (Cook et al. 2016) is not proportional to, and should not be confused with, consensus in IPCC reports as expressed through calibrated qualifiers. The latter is applied to the multiple processes operating in the climate system, in which anthropogenic forcing is one of many other mechanisms at work. Along those lines, IPCC reports assess many different data and publications on complex, dynamic, and interacting systems (atmosphere, climate, ecosystems, oceans, human societies). Those systems are imperfectly understood with respect to their individual and interacting forcings, and keep shifting as climate-change progresses and novel feedbacks emerge, as much as the technology and methods to measure climate change are imperfect, evolving and improving. Uncertainty is thus an explicit property (not a weakness) of climate-change research and of IPCC reports and, for that matter, inherent to any field of research. In that respect, the review scope of the IPCC implies assessing single phenomena under multiple, plausible explanations that can further slant the number of calibrations towards uncertainty. We illustrate this aspect with three examples in the remainder of this subsection.

The IPCC must account for the fact that in the analysis of climate data, the uncertainty of observed effects will be commonly overshadowed by the uncertainty of their potential causes. One thing is what we see and measure, another is which mechanism might trigger it. There is often one effect and several alternative or complementary explanations, and this unbalance can act as a multiplier of weak- versus strong-certainty qualifiers. For instance, the "Summary for Policymakers" states as a fact that "... total radiative forcing is positive, and has led to an uptake of energy by the climate system [since the Industrial Revolution]," but the *confidence* of the contribution of different atmospheric drivers to that forcing varies through *low* (aerosol-mediated cloud adjustment), *medium* (albedo driven by land use, carbon monoxide, nonmethane volatile organic compounds, NO_x, solar irradiance), *high* (CH₄, halocarbons) and *very high* (CO₂, N₂O; IPCC 2013b). This statement deals with one effect, while four drivers score *high confidence* and six get *low to medium confidence*, and the range of those uncertainties is even stronger in expert elicitation (Morgan et al. 2006).

In addition, when the IPCC assesses climate change into the future (or the past), it applies mathematical frameworks and assumptions of varying complexity. This approach

likewise results in projections of varying uncertainty, all of which are presented in IPCC reports. The IPCC's prose reads rather wordy when those projections are enumerated—for example, relative to the period 1850–1900 "... global temperatures averaged in the period 2081–2100 are projected to *likely* exceed 1.5°C ... for RCP4.5 [RCP stands for Representative Concentration Pathway, or scenarios explaining concentration and trajectories of aerosols and greenhouse and chemically active gases], RCP6.0 and RCP8.5 (*high confidence*) and ... 2°C ... for RCP6.0 and RCP8.5 (*high confidence*). Temperature change above 2°C ... under RCP2.6 is *unlikely* (*medium confidence*). Warming above 4°C by 2081–2100 is *unlikely* in all RCPs (*high confidence*) except for RCP8.5, where it is *about as likely as not* (*medium confidence*)" (chapter 12 in Stocker et al. 2013, IPCC 2013a). In the former statement, *confidence* varies from *medium* to *high*, but *likelihood* only gets up to 66%–100%, denoting the imperfect performance of those projections.

Finally, we scientists can choose the interval of certainty of our measurements in our publications, and the IPCC authors are not different. Thus, when the Panel documents a given range of climate change, the "*likely* range" is the most common option. When assessed under different assumptions, models and scenarios, *likely* ranges are cited many times, therefore magnifying the occurrence of climate findings at *likelihoods* of 66 to 100%. This magnification renders conservative many estimates of the most critical metrics of climate change reported in the in-depth chapters, namely cloud and aerosol forcing (chapters 7 and 8), equilibrium climate sensitivity (chapter 10), future global surface air temperatures, greenhouse-gas emissions, anthropogenic forcing and transient climate response (chapters 11 and 12), and global sea level rise and its causes (chapter 13; IPCC 2013a). In addition, *likely* ranges pass on from the in-depth chapters to the executive, policymaking-related and technical summaries—for example, "based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st Century" (IPCC 2013b).

Seepage. Organizations often labelled as climate-change "contrarians," "deniers" or "sceptics" (see review of terms by Howarth and Sharman 2015) actively cherry-pick IPCC's calibrated statements as evidence to support their claims that the science backing anthropogenic climate change is flawed or biased towards alarmism or uncertain knowledge (table S3). Therefore, calibrations have been in the spotlight of polemics such as "Glaciergate," where the IPCC (Fourth Assessment Report) allocated a 90%–100% *likelihood* (*very likely*) to a prediction of complete meltdown of Himalayan glaciers by 2035, instead of three centuries into the future as intended (Cogley et al. 2010). Once in the public sphere, calibrations can consequently undermine IPCC-driven engagement of policymaking stakeholders, particularly if findings of weak uncertainty predominate. The logical fallacy is that "... scientific uncertainty about climate science implies uncertainty

about whether something should be done in response to it" (Lewandowsky et al. 2015b). And such a fallacy becomes a flawed probabilistic device exploited by "merchants of doubt," who exploit uncertainty to discourage public endorsement of policies against a range of societal problems, from smoking to global warming, usually with a clandestine financial ulterior motive (Oreskes and Conway 2010).

The reality is that contrarian views against anthropogenic climate disruption can lobby the scientific community, and the IPCC in particular, to be conservative and so reinforce contrarian views in a vicious, self-reinforcing circle—a phenomenon called *seepage* (Lewandowsky et al. 2015b). Why? Essentially, the IPCC must carefully gauge the costs and entailing loss of credibility of making a mistake given the heated and politicized debate about climate change, so the Panel has a tacit motivation for using a cautious language. Medimorec and Pennycook (2015) examined how the IPCC selects words and constructs sentences in its reports relative to the Nongovernmental International Panel on Climate Change (NIPCC), a group of "scientists" who define themselves as "... not predisposed to believe climate change is caused by human greenhouse gas emissions and ... able to offer an independent *second opinion* of the evidence reviewed—or not reviewed—by the IPCC on the issue of global warming" (*climatechangereconsidered.org*). In actual fact, the NIPCC is staged by the Heartland Institute, a conservative American "think tank" with a long history of attacks on climate science (e.g., they once compared climate scientists to the Unabomber; Hickman 2012). Medimorec and Pennycook (2015) found that the IPCC's language is far more cautious and less emotional than the NIPCC's, and the predominance of low to intermediate qualifiers found in our study aligns with the former observation.

Seepage seems perhaps the major motivation for the IPCC's WGI to "err on the side of least drama" and so underestimate climate-change impacts (Brysse et al. 2013), and to overemphasize the avoidance of false-positive (supporting an untrue outcome) against false-negative (rejecting a true outcome) probabilistic statements (Anderegg et al. 2014). Even the coverage of new climate findings in the primary literature by the most-read US newspapers indicates that anthropogenic climate change can outpace the projections of the IPCC itself (Freudenburg and Muselli 2010). This is extraordinary because the US prestige press tends to balance their attention to arguments for humans *versus* natural variability as the main drivers of climate change, thereby creating the biased impression that both perspectives have equal backing in the scientific community (Boykoff and Boykoff 2004).

Challenges and future directions

Uncertainty is double edged. Climate-change contrarians see uncertainty in IPCC reports as proof of weakness in climate science (supplemental table S3), ignoring the fact that uncertainty is inherent to scientific research. Most climate researchers, certainly those in the IPCC, see it instead as proof of scientific rigour. Regardless, uncertainty should

be visualized as a sound measure of the risks imposed by climate change and inspire action rather than indifference (Lewandowsky et al. 2015a). We conclude this paper by highlighting potential improvements in the IPCC's calibrations and outreach.

Calibrations. We contend that a major communication caveat in IPCC assessments is that the Panel is not explicit about how a hierarchy of thousands of calibrated statements propagates their (often low to intermediate) uncertainties into the highly certain, core outcomes collectively supporting the fact that humans are (and, if not reducing emissions of greenhouse gases, will continue being) the main drivers of ongoing (and future) climate change. In addition, it has been noted that in the IPCC's Assessment Reports "... many less-important conclusions have attached likelihoods, whereas some crucial ones do not," yet they are the most relevant ones to policymaking (Reilly et al. 2001). But current calibrations play no role in how and how much the latter causatively lead to the former. Thus, the WGI's "Summary for Policymakers" (IPCC 2013b) and "Headline Statements" (table 1; WGI Technical Support Unit 2014) use section-heading boxes (bolded text in color-shaded frames) followed by a few synthesizing statements. However, only 10 of the 19 ("Summary for Policymakers") and none of the four ("Headline Statements"; table 1) boxes include calibrations, and the probabilistic link between headings and associated statements is open to (mis)interpretation.

In situations where climate-change contrarians misleadingly use IPCC reports as a house of cards (supplemental table S3), whereby the removal of one or few cards demolishes the whole or most of the house, both a graphical depiction and an explicit quantification of how core outcomes depend probabilistically on ancillary ones could help defang such attacks on the science of climate change. In the context of our study and for simplicity, we identify "core outcomes" (table 1; see Cooke 2015) with the IPCC's "Headline Statements" by WGI (WGI Technical Support Unit 2014, Stocker and Plattner 2016), along with the endorsements made by the US National Research Council (NRC 2010), while "ancillary outcomes" are scientific findings leading to those core outcomes. However, if the IPCC was to address the probabilistic links between the two explicitly, each of the IPCC's working groups should identify which are the core outcomes relative to the specific areas of climate science they revise (supplemental table S1) and the audiences they target (box 1).

Along those lines, the Fifth Assessment Report is typeset in italics to highlight *confidence* and *likelihood* exclusively for findings subject to uncertainty, not for "climate facts" (box 2), despite the latter being ostensibly scrutinized by the same review process as any other climate outcome. A useful analogy is that it is difficult to imagine that an employer would evaluate a set of job applicants' *curriculum vitae* by only taking the lowest-scoring subjects into consideration; instead, the employer would also rank their best subjects. Similarly, the omission of certainty qualifiers for factual

outcomes seems inadvisable because they should represent gold standards of climate-change science, and therefore deserve a unique and highest category of certainty that no reader should be able to misinterpret easily. This seems a simple yet powerful way by which the IPCC can provide a more balanced probabilistic treatment of outcomes of extreme certainty or uncertainty.

In general, most calibrated qualifiers currently used by the IPCC (Mastrandrea et al. 2011a: *exceptionally, extremely, high, low, major, medium, minor, very, virtually*), and the newly proposed ones (Mach et al. 2017: *divergent, emerging, limited, robust*) are unquantifiable, the amount of scientific evidence and agreement within and between *confidence* categories is unknown, and both aspects entertain subjective interpretation by readers of IPCC reports. We concur with others that a dual language coupling the numbers with the terms quantifying uncertainty thresholds (Budescu et al. 2014) would be an essential minimum for the IPCC's audiences (box 1) to interpret correctly what the IPCC is actually saying.

A different matter is whether the IPCC's calibration protocol might be underestimating the metrics of climate change, with experts noting that "... if current scientific consensus is in error, it is likely because global climate disruption may be even worse than commonly expected to date" (Freudenburg and Muselli 2013). For instance, by the end of the 21st Century, global warming rates have been claimed to be 15% higher and 30% less uncertain than the estimates given by the IPCC's WGI in the Fifth Assessment Report (Brown and Caldeira 2017). Likewise, lower bounds of the *likely* ranges of sea-level rise have been argued to be over 10 cm higher than the IPCC estimates (Horton et al. 2014). Furthermore, Reilly and colleagues (2001) stressed that the method of attaining expert judgements is inconsistent through the IPCC working groups, and not detailed (e.g., to be replicable) in the IPCC calibration guidelines, and that the IPCC's emphasis on calibrating consensus might misrepresent the state of knowledge about climate change. This caveat has led many authors to advocate a move from informal (the current approach) to formal expert elicitation in IPCC assessments (e.g., Oppenheimer et al. 2007, Zickfeld et al. 2010, Morgan and Mellon 2011), whereby divergent expert views play a formal role in calibrations, and *likelihoods* could capture the uncertainty of not only model inputs (current approach), but also model structure (Reilly et al. 2001, Morgan 2014). It is of course unknown whether expert elicitation would change the overall frequency of qualifiers in IPCC reports that we have summarized in our study.

Outreach. The upswing in populist governments worldwide (Oliver and Rahn 2016) further threatens the public understanding of the IPCC's message and recommendations, so clarity of language is particularly important to counter public lack of awareness of anthropogenic climate change and the perception of its risks (Lee et al. 2015). Nevertheless, while climate-change awareness is largely determined by educational attainment (Lee et al. 2015), risk perception can

respond to collective beliefs more than to science literacy or comprehension of scientific information (Kahan et al. 2012). Thus, the improvement of the IPCC's probabilistic vocabulary should not be treated as a panacea, but as one element of an unprecedented, global communication strategy encompassing the sociological and psychological dimensions of the potential audiences of IPCC reports (box 1). A clear wording of uncertainty will always rely on a clear strategy of communication of words to transmit its genuine meaning. As an apolitical, scientific, multidisciplinary, and authoritative body, the IPCC is the institutional beacon to endorse such a strategy where scientific practice, policy making, and public engagement meet.

The IPCC has greatly expanded, and foresees to expand further, its communication capabilities, acknowledging that (i) "... effective outreach requires engagement with stakeholders ... to understand what they are looking for in an IPCC report," and (ii) "... involve communications specialists from a range of disciplines in the writing process [of IPCC reports]" (IPCC 2016b). In that direction, the IPCC has just issued a handbook for IPCC authors to communicate uncertainty and promote public awareness of climate change (Corner et al. 2018). However, we argue that instead of resorting to external, commissioned specialists and knowledge brokers to generate communication tools for the IPCC working groups, the IPCC's credibility and societal impact could be enhanced by launching a new IPCC working group entirely focused on climate-change outreach and based on the outputs of the three existing working groups. This outreach working group would ideally include communication experts from different fields, comprising educators, linguists, pedagogues, psychologists, and climate scientists (recruited from academia and nonacademic sectors), and follow the same assessment process as that of the remaining working groups (with "contributing authors," "expert reviewers," and "review editors"; see above). The group would elaborate a novel component in the IPCC's assessments (i.e., a self-contained booklet, and one section in the overall synthesis report) accounting for the heterogeneous, public perceptions of climate change (Weber, 2010, 2016), thus reaching beyond policymakers to other critical sectors like agriculture (e.g., farmers) or education (e.g., school teachers).

To accomplish this complex task, it seems strategically important that each of the IPCC member countries should define a network of relevant organizations linked across different scales (local, regional, national) that maximize the flow of usable information (Kalafatis et al. 2015). Those networks might encounter both a common set of experiences that can be escalated at the regional and national level (Buizer et al. 2016) and documented in IPCC reports, but also context-specific situations needing innovative approaches (Clar and Steurer 2018) beyond the direct scope of the IPCC. Representatives of those networks (at least at the regional level) could participate as "contributing authors" in the assessment process of the IPCC's outreach working group (in exactly the same way commissioned scientists contribute

to the assessment by the current three working groups) and subsequently, play the role of actors when outreach recommendations were to be implemented nationally. In such a scheme, the IPCC would adopt a leading role in managing the boundaries between knowledge (science) and action (policymakers and stakeholders), which could enhance the credibility of climate information and the legitimacy of emerging policies and applications (Cash et al. 2003).

Across the board, the scientific community (including the IPCC) would do well to appreciate that once the cause of an environmental problem has been unambiguously identified (e.g., that humans are changing the Earth's climate), doing more research, producing more papers or assembling larger reports, solely to reduce the amounts of uncertainty or to strengthen the message, is potentially ineffective in the public domain because uncertainty (Sarewitz 2004, Oreskes 2015), and much of the scientific jargon (Weber and Schell-Word 2001, Kueffer and Larson 2014), have different meanings and implications in the sciences relative to society and politics. Those realms speak different languages. Knowledge that scientists might identify as “useful” for policymakers could in fact be labelled by policymakers as not “usable” for taking actions (Lemos et al. 2012). After all, the resolution of environmental problems is always in the political court no matter how widespread and consolidated scientific consensus might be. In the scientific court, one of the most urgent actions we scientists can currently take to address the climate crisis is to communicate unequivocally to nonscientists the state of knowledge. We should frame and underline what the data tell us that we know for certain about climate change, and be transparent about those areas that remain uncertain and by how much.

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Supplemental material

Supplemental data are available at *BIOSCI* online.

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