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The Treatment of Uncertainties in the Fourth IPCC Assessment Report

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Abstract: The IPCC has developed an approach to the treatment of uncertainties for the Fourth Assessment Report which is an evolution of the approach established for the Third Assessment Report. Several features of this evolution are discussed briefly here and this paper serves as an introduction to the "IPCC Uncertainty Guidance Note" for lead authors which is included as an appendix. Particular attention is given to use of the terms "likelihood" and "confidence" as alternative ways of expressing uncertainty. This distinction emerged in the Third Assessment Report and was the subject of some debate before finalising the Guidance Note, however, it is now recognized that each term provides a complementary aspect of describing uncertainties.

Key words: uncertainties; report; IPCC AR4

Introduction

People have always had a keen interest in knowing what will happen in the future. In the modern world, it is widely recognized that information about the future has environmental, economic and social value. A key role played by science is to explore the extent to which understanding of deterministic processes can provide an objective basis for predicting the future. However, all but the most trivial of predictions come with some degree of uncertainty.

Studies of climate change have paid careful attention to identifying and quantifying uncertainties from the outset, perhaps more so than in any other area of science. There are many reasons for this. The physical climate system is highly complex, has aspects that are inherently chaotic, and involves non-linear feedbacks operating on a wide variety of time scales. Our empirical knowledge of how these operate ranges from being good on decadal time scales, moderate over time scales of 100−1000 years, to being quite limited at 10000 years and longer. Similar complexities and observational limits apply to our understanding of the effects of climate change on ecological or human systems. Furthermore, any projection of climate change has to take some account of how human behaviour and decision making will respond to both the perception and the reality of climate change as it occurs. Uncertainties associated with this human dimension are not easily quantified and generally require a different approach to those applied to natural biological and physical processes.

Assessments of climate change science by the IPCC have always recognized the importance of communicating uncertainties. From the outset it was recognized that policymakers required not just an expression of numeric ranges for values of interest, such as global mean temperature change, but also information on how confident scientists were of the basis for such quantitative statements. The first IPCC assessment [1] began with an Executive Summary that explicitly grouped the scientific understanding of the time under headings of: what was certain, what could be calculated with confidence, what was predicted, and what was based on the judgment of the authors. These distinctions remain important today and the complementary ways of defining uncertainty in terms of ranges of values and clearly stated degrees of confidence are being used in the IPCC Fourth Assessment Report (AR4) to be completed in 2007.

In this paper I will summarize the treatment of uncertainties used in the Third Assessment Report (TAR) and then discuss the evolution of that approach that is now being used in the AR4. This evolution emerged through a series of IPCC activities including a concept paper on the

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treatment of uncertainties [2], an IPCC Workshop on Uncertainties and Risk in Climate Change [3], and a cross-Working Group discussion that led to agreement on an Uncertainty Guidance Note [4] for use by the lead authors of all Working Groups. The IPCC Uncertainty Guidance Note, is presented here as an appendix to this paper.

1 The treatment of uncertainty in the IPCC TAR

As noted earlier, IPCC assessments have recognized a distinction between two types of uncertainty. Those expressed as ranges for some quantity of interest and those expressed as the degree of confidence that experts have in the understanding that underlies some finding. Assessment of each type of uncertainty requires expert judgment although this is more obvious in the latter case. Defining the degrees of confidence in different aspects of science is also a particular responsibility of any science assessment and so this type of uncertainty becomes more important in assessment reports than it is in typical scientific papers.

The Working Group I contribution to the IPCC Second Assessment Report noted the need for objective and consistent ways of determining and stating levels of confidence in climate change science [5]. In order to meet that challenge for the TAR, a guidance paper was developed and finalized after two rounds of peer review [6].

Moss and Schneider [6] presented a multi-step approach to the determination and description of uncertainties that clearly recognized the role of expert judgment and emphasized the need for transparency in stating how these judgments were made. This landmark paper recommended careful characterization of the sources of uncertainty, coverage of the ranges given in the literature, and consistent use of confidence descriptors. The requirement for objectivity noted by the Second Assessment Report was effectively met by ensuring that the information used by the authors when assigning confidence levels was traceable to the scientific literature. The requirement of consistency was addressed by introducing specific terms with assigned meanings for degrees of confidence on either a quantitative or a qualitative scale. The quantitative scale introduced confidence levels in five different ranges defined probabilistically as discussed further below. The qualitative scale was simpler and intended for situations where authors would feel unable to give a probabilistic result. In this case, authors were asked to classify both the amount of evidence available and the degree of consensus among experts as either high or low.

Although there had been several related studies and some limited use of standardized language to express uncertainties prior to the TAR, this IPCC report became the first science assessment to attempt to do so across many disciplines and for a broad international readership. The use of the “likelihood” language became a feature of the Working Group I and Working Group II contributions to the TAR, particularly their Summaries for Policymakers (SPMs), and was debated carefully by government delegates during the IPCC line by line approval process for these summary documents. Since the TAR, the approach of defining specific language to express levels of confidence in terms of probabilistic scales has been used in several other multi-author assessments [7−8] largely following the IPCC approach set out by Moss and Schneider [6].

However, despite its acceptance in many parts of the TAR, a divergence in usage of the terminology defined by Moss and Schneider [6] emerged between Working Groups I and II in the latter stages of preparing their assessments. One obvious manifestation of this divergence was the use of two additional terms by Working Group I to cover extremely high or low probabilistic ranges. However, the difference in usage runs much deeper than this and becomes apparent from an analysis of the language used in the two Working Group reports.

Working Group II kept close to the original guidance paper and in particular used the calibrated language defined there to express the authors’ degrees of confidence in key findings. Thus the relevant footnote of the Working Group II SPM reads as follows:

In this Summary for Policymakers, the following words have been used where appropriate to indicate judgmental estimates of confidence (based upon the collective judgment of the authors using the observational evidence, modeling results, and theory that they have examined): very high (95% *or greater*)*, high* (67%−95%)*, medium* (33%−67%)*, low* (5%−33%)*, and very low* (5% *or less*)*.*

A typical use of the language from the Working Group II SPM, consistent with this definition, is:

Thus, from the collective evidence, there is high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems.

The different usage in the Working Group I report stemmed from the fact that, in the corresponding literature, many of the key findings were backed by large observational datasets and that probabilistic techniques for estimation of results were widely used and understood in the Working Group I community. Thus the Working Group I authors felt they had less need to rely on expert judgment and could place more reliance on statistical analyses. This emerged in the Working Group I report through the introduction of the term likelihood. The relevant footnote in the Working Group I SPM thus reads:

In this Summary for Policymakers and in the Technical Summary, the following words have been used where appropriate to indicate judgmental estimates of confidence: virtually certain (*greater than* 99% *chance that a result is true*)*; very likely* (90%−99% *chance*)*; likely* (66%−90% *chance*)*; medium likelihood* (33%−66% *chance*)*; unlikely* (10%−33% *chance*)*; very unlikely* (1%−10% *chance*)*; exceptionally unlikely* (*less than* 1% *chance*)*. The reader is referred to individual chapters for more details.*

Although the difference in wording is subtle, the Working Group I approach shifts the emphasis to whether a result is true, rather than how confident the authors are in their assessment. A typical example of this different usage from the Working Group I SPM is:

It is very likely that precipitation has increased by 0.5% *to* 1% *per decade in the* 20*th century over most mid- and high-latitudes of the Northern Hemisphere continents...*

Thus the two different science communities adapted the recommendations in Moss and Schneider [6] to deal with their slightly different circumstances.

2 New considerations of uncertainty for the AR4

In the early stages of planning the AR4 it was realised that the issue of consistent treatment of uncertainty across the Working Groups deserved further consideration. A concept paper [2] endorsed the approach pioneered by Moss and Schneider [6] but noted the divergence between Working Groups I and II in the TAR as discussed above. It also noted several new developments in the underlying literature concerning the treatment of uncertainties and the very different approach to uncertainties in the scientific and technological areas covered by Working Group III. These developments were reviewed during an IPCC Workshop on "Describing Scientific Uncertainties in Climate Change to Support Analysis of Risk and of Options". Some of the general findings of this workshop included:

(1) recognition that the use of uncertainty in risk analysis can provide a focused approach to describing uncertainty;

(2) that uncertainty generally increases going from global to regional scales;

(3) that the distinction between "statistical" uncertainty associated with parameters or observational values that are not known precisely, and "structural" uncertainty where important relationships between variables or their functional form may not have been identified correctly, needs to be more broadly recognized and assessed.

(4) that author teams need to be aware of tendencies to become overly confident in initial assessments;

(5) that there is an increasing use of probability distribution functions both for estimating and presenting uncertainties but that these should only be used where there is high confidence in the underlying science.

The workshop also discussed the distinction between likelihood and confidence touched on above and the results of that are discussed further in the next section.

In this brief paper there is not space to consider many of the other issues that have been discussed in the development of a consistent approach to uncertainties across all three working groups. In particular, this paper does not consider the treatment of uncertainties in assessments of the socio-economic literature covered by Working Group III. While much progress has been made in this area relative to the TAR, some issues are still subject to debate, e.g. the question as to whether and how probabilities might be assigned to different socio-economic scenarios for the future.

3 Likelihood versus confidence

A key issue in developing guidance on uncertainty for the AR4 was to resolve the issue of whether the diverging approaches used by Working Groups I and II in the TAR should be brought together again into a single scale, or whether the distinction should be clarified and preserved in the AR4. The workshop agreed to the latter approach. This decision, to more clearly separate likelihood from confidence, has withstood subsequent critique and discussion across all Working Groups and is now accepted as a genuine advance in the treatment of uncertainty to be used in the AR4.

Likelihood, as defined in the workshop, expresses the chance of a defined outcome in the physical world and is estimated using expert judgment.

Confidence, as defined in the workshop, expresses the degree of understanding and / or consensus among experts and is a statement about expert judgment.

Many people have noted that the concepts of confidence and likelihood often appear to be closely linked, leading to the suggestion that they could be merged. For example, it would seem irrational to make a statement that some result was expected with a high likelihood if it were based on an area of science where there was only low confidence. If one has low confidence then any assigned likelihoods should be moderate rather than extreme. Figure 1 shows a schematic with separate dimensions for likelihood and confidence in which the cases marked A and B correspond to the irrational cases of assigning high or low likelihood when there is only low confidence.

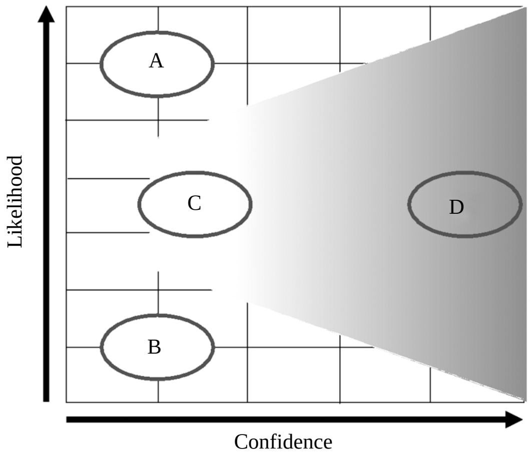

Fig. 1 Schematic depicting the inter-relationship between likelihood and confidence represented by two separate axes increasing towards the top and right, respectively. The shaded area represents the region in which findings are most sensibly expressed. Cases denoted by A and B, i.e. where one might associate very high or low likelihood with a very low confidence in the science, are not normally encountered. The distinction between the two dimensions of confidence and likelihood can be clearly seen by contrasting cases C and D as discussed in the text.

However, this inter-relationship between the two concepts does not mean they can be merged and the distinction between them may be best clarified through further examples. One can rationally associate high confidence with low likelihood, e.g. many scientists have expressed a high confidence that a complete collapse of the Western Antarctic Ice Sheet is very unlikely by 2100. Thus these two aspects of uncertainty clearly do not have to be positively correlated. More significantly, we can associate either high or low confidence with a medium likelihood (about as likely as not). For example, we can have very high confidence that tossing a coin will turn up heads about 50% of the time (D), and this situation is very different from one where we might be forced to assign a medium likelihood due to lack of knowledge and low confidence (C). Thus the cases marked C and D in Figure 1 represent very different situations and it is important that the language used to describe uncertainties is able to distinguish between them.

The Uncertainty Guidance Note (see Appendix) provides for this separation of the concepts of likelihood and confidence and provides the authors of the AR4 with two different scales and terminology to express either concept according to which is more appropriate for the issue being discussed. One of the side effects of this separation has been to challenge those scientists who are accustomed to only expressing their results in terms of likelihood, to now recognize that confidence is something different. This in turn should lead to a deeper consideration of structural uncertainties, e.g. to the potential for incompleteness in models.

4 The Uncertainty Guidance Note

The Uncertainty Guidance Note for lead authors of the AR4 was discussed and reviewed extensively by the lead authors of all three working groups. Thus while it reflects the outcomes of the IPCC Workshop on Uncertainty and Risk, it also summarizes a great deal of subsequent discussion as to how these should be implemented in preparing the Working Group contributions to the AR4.

The Guidance Note has deliberately been kept as brief as possible and it follows an operational sequence clearly structured around the preparation of an assessment. Thus the need to plan to deal with issues of uncertainty and expert judgment within author teams is stressed first. Recommendations from the TAR guidance paper to critically review the literature carefully for its treatment of uncertainties are repeated again for the AR4. From such a review it is expected that the authors will be able to develop a classification of the different sources of uncertainty that may apply, and it is noted that these should include both the "structural" uncertainties that arise from incomplete understanding as well as the statistical or "value" uncertainties that arise from limited measurements.

Authors are reminded that they will need to make expert judgments in their assessment and again the recommendations from the TAR are repeated, that the basis for such judgments should be clearly stated. The Uncertainty Guidance Note proposes a hierarchical approach when trying to decide how to describe uncertainties in a specific situation. This was adapted from a similar approach proposed by Kandlikar *et al.* [9] after completion of the TAR. This hierarchy leads from areas where there may be low scientific confidence and where probabilistic approaches are unavailable, to areas of high scientific confidence and where probabilistic approaches are well established.

Once the authors have developed their framework for classifying errors and decided how these can best be explained, the Uncertainty Guidance Note proposes the use of calibrated language which is consistent with but represents an extension of that recommended for the TAR. Three tables of defined terms are provided, compared to two used in the TAR. The addition now is to allow for separation of the terms likelihood and confidence as discussed above. The likelihood scale is the same as used by Working Group I in the TAR, and the confidence scale matches that used by Working Group II although it is now defined in more qualitative terms.

Finally it is important to recognize that the Uncertainty Guidance Note allows for extension of the defined terms and use of additional approaches to uncertainty taken from the relevant literature. Thus this document is intended to be the common core required for consistency across the three working groups but does not create a barrier to further work within each working group that remains consistent with this core.

5 Conclusions

The wide ranging and inter-disciplinary discussion of uncertainty and risk that took place during preparations for the AR4 has led to a richer language and more comprehensive structure for determining and describing uncertainties. While these approaches are clearly rooted in the Guidance Paper for the TAR, they also reflect a real evolution in our thinking and one of their key results has been to draw out more clearly the distinction between the assessed likelihood of specific outcomes and the confidence that the science community has in its ability to determine such likelihood. It is also interesting to note that this distinction was present in the first assessment report.

There are subtleties in language involved in treating uncertainties that are not always familiar to all scientists. However, it is hoped that these concepts elaborated during the preparation of the AR4 will become more clearly recognized through their use in the IPCC and other assessments.

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Appendix

Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties ①

The following notes are intended to assist Lead Authors (LAs) of the Fourth Assessment Report (AR4) to deal with uncertainties consistently. They address approaches to developing expert judgments, evaluating uncertainties, and communicating uncertainty and confidence in findings that arise in the context of the assessment process. Where alternative approaches are used in the relevant literature, those should be used but where possible related to the approaches given here. Further background material and more detailed coverage of these issues are available in the guidance paper on uncertainties developed for the Third Assessment Report [1] and the report of an IPCC Workshop on Uncertainty and Risk [2].

The working group reports will assess material from different disciplines and will cover a diversity of approaches to uncertainty, reflecting differences in the underlying literature. In particular, the nature of information, indicators and analyses used in the natural sciences is quite different from that used in the social sciences. WG I focuses on the former, WG III on the latter, and WG II covers both. The purpose of this guidance note is to define common approaches and language that can be used broadly across all three working groups. Each working group may need to supplement these notes with more specific guidance on particular issues consistent with the common approach given here.

Plan to treat issues of uncertainty and confidence

1. Consider approaches to uncertainty in your chapter at an early stage. Prioritize issues for analysis. Identify key policy relevant findings as they emerge and give greater attention to assessing uncertainties and confidence in those. Avoid trivializing statements just to increase their confidence.

2. Determine the areas in your chapter where a range of views may need to be described, and those where LAs may need to form a collective view on uncertainty or confidence. Agree on a carefully moderated (chaired) and balanced process for doing this.

Review the information available

3. Consider all plausible sources of uncertainty using a systematic typology of uncertainty such as the simple one shown in Table 1. Many studies have shown that structural uncertainty, as defined in Table 1, tends to be underestimated by experts [3]. Consider previous estimates of ranges, distributions, or other measures of uncertainty and the extent to which they cover all plausible sources of uncertainty.

4. Assess issues of risk where supported by published work. Where probabilistic approaches are available, consider ranges of outcomes and their associated likelihoods with attention to outcomes of potential high consequence. An alternative approach is to provide information for decisions that would be robust in the sense of avoiding adverse outcomes for a wide range of future possibilities [4−5]. (Note that the term “risk” has several different usages. If used it should be defined in context.)

Make expert judgments

5. Be prepared to make expert judgments and explain those by providing a traceable account of the steps used to arrive at estimates of uncertainty or confidence for key findings, e.g. an agreed hierarchy of information, standards of evidence applied, approaches to combining or reconciling multiple lines of evidence, and explanation of critical factors.

6. Be aware of a tendency for a group to converge on an expressed view and become overconfident in it [3]. Views and estimates can also become anchored on previous versions or values to a greater extent than is justified. Recognize when individual views are adjusting as a result of group interactions and allow adequate time for such changes in viewpoint to be reviewed.

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① This Uncertainty Guidance Note was originally published by the Intergovernmental Panel on Climate Change on its web site at: http://www.ipcc.ch/activity/uncertaintyguidancenote.pdf

Table 1　A simple typology of uncertainties

Type	Indicative examples of sources	Typical approaches or considerations
Unpredictability	Projections of human behaviour not easily amenable to prediction (e.g. evolution of political systems) Chaotic components of complex systems	Use of scenarios spanning a plausible range, clearly stating assumptions, limits considered, and subjective judgments Ranges from ensembles of model runs
Structural uncertainty	Inadequate models, incomplete or competing conceptual frameworks, lack of agreement on model structure, ambiguous system boundaries or definitions, significant processes or relationships wrongly specified or not considered	Specify assumptions and system definitions clearly, compare models with observations for a range of conditions, assess maturity of the underlying science and degree to which understanding is based on fundamental concepts tested in other areas
Value uncertainty	Missing, inaccurate or non-representative data, inappropriate spatial or temporal resolution, poorly known or changing model parameters	Analysis of statistical properties of sets of values (observations, model ensemble results, etc); bootstrap and hierarchical statistical tests; comparison of models with observations

Use the appropriate level of precision to describe findings

7. Assess the current level of understanding on key issues and precede statements on confidence or uncertainty with a general summary of the corresponding state of knowledge. Table 2 below provides a consistent language for this.

8. Develop clear statements for key findings that are quantitative and give explicit time frames as far as possible. Define carefully the corresponding variables or outcomes, their context, and any conditional assumptions. Where scenarios are used, explain the range of assumptions and how they affect the outcome. Then consider the most appropriate way to describe the relevant uncertainties or level of confidence by going as far down the hierarchy given below as you feel appropriate (from expressions of less to more confidence and less to more probabilistic approaches) [6]:

A. Direction of change is ambiguous or the issue assessed is not amenable to prediction: Describe the governing factors, key indicators, and relationships. If a trend could be either positive or negative, explain the pre-conditions or evidence for each.

B. An expected trend or direction can be identified (increase, decrease, no significant change): Explain the basis for this and the extent to which opposite changes would not be expected. Include changes that have a reasonable likelihood even where they are not certain. If you describe a collective level of confidence in words, use the language options in Table 2 or 3.

C. An order of magnitude can be given for the degree of change (i.e. sign and magnitude to within a factor of 10): Explain the basis for estimates given and indicate assumptions made. The order of magnitude should not change for reasonable ranges in such assumptions. If you describe a collective level of confidence in words, use the language options in Table 2 or 3.

D. A range can be given for the change in a variable as upper and lower bounds, or as the 5th and 95th percentiles, based on objective analysis or expert judgment: Explain the basis for the range given, noting factors that determine the outer bounds. If you cannot be confident in the range, use a less precise approach. If you describe a collective level of confidence or likelihood of an outcome in words, use the language options in Tables 3 or 4.

E. A likelihood or probability of occurrence can be determined for an event or for representative outcomes, e.g. based on multiple observations, model ensemble runs, or expert judgment: State any assumptions made and estimate the role of structural uncertainties. Describe likelihoods using the calibrated language given in Table 4 or present them quantitatively.

F. A probability distribution can be determined for changes in a continuous variable either objectively or through use of a formal quantitative survey of expert views: Present the PDF graphically and/or provide the 5th and 95th percentiles of the distribution. Explain the methodology used to produce the PDF, any assumptions made, and estimate the role of structural uncertainties.

Table 2 Qualitatively defined levels of understanding

Level of agreement or consensus →			
	High agreement limited evidence	......	High agreement much evidence
	......	......	......
	Low agreement limited evidence	......	Low agreement much evidence

Amount of evidence (theory, observations, models) →

Table 3 Quantitatively calibrated levels of confidence

Terminology	Degree of confidence in being correct
Very High confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Table 4 Likelihood Scale

Terminology	Degree of confidence in being correct
Virtually certain	> 99% probability of occurrence
Very likely	> 90% probability
Likely	> 66% probability
About as likely as not	33% to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Exceptionally unlikely	< 1% probability

Communicate carefully, using calibrated language

9. Be aware that the way in which a statement is framed will have an effect on how it is interpreted [7]. (A 10% chance of dying is interpreted more negatively than a 90% chance of surviving.) Use neutral language, avoid value laden statements, consider redundant statements to ensure balance (e.g. chances of dying and of surviving), and express different but comparable risks in a consistent way.

10. To avoid the uncertainty perceived by the reader being different from that intended, use language that minimizes possible misinterpretation and ambiguity. Note that terms such as “virtually certain”, “probable”, or “likely”, can engage the reader effectively, but may be interpreted very differently by different people unless some calibration scale is provided [8-9].

11. Three forms of language are given in Tables 2, 3 and 4 to describe different aspects of confidence and uncertainty and to provide consistency across the AR4.

12. Table 2 considers both the amount of evidence available in support of findings and the degree of consensus among experts on its interpretation. The terms defined here are intended to be used in a relative sense to summarize judgments of the scientific understanding relevant to an issue, or to express uncertainty in a finding where there is no basis for making more quantitative statements. A finer scale for describing either the amount of evidence (columns) or degree of consensus (rows) may be introduced where appropriate, however, if a mid-range category is used authors should avoid over-using

that as a "safe" option that communicates little information to the reader. Where the level of confidence is "high agreement much evidence", or where otherwise appropriate, describe uncertainties using Table 3 or 4.

13. A level of confidence, as defined in Table 3, can be used to characterize uncertainty that is based on expert judgment as to the correctness of a model, an analysis or a statement. The last two terms in this scale should be reserved for areas of major concern that need to be considered from a risk or opportunity perspective, and the reason for their use should be carefully explained.

14. Likelihood, as defined in Table 4, refers to a probabilistic assessment of some well defined outcome having occurred or occurring in the future. The categories defined in this table should be considered as having "fuzzy" boundaries. Use other probability ranges where more appropriate but do not then use the terminology in table 4. Likelihood may be based on quantitative analysis or an elicitation of expert views. The central range of this scale should not be used to express a lack of knowledge−see paragraph 12 and Table 2 for that situation. There is evidence that readers may adjust their interpretation of this likelihood language according to the magnitude of perceived potential consequences [10−11].

15. Consider the use of tabular, diagrammatic or graphical approaches to show the primary sources of uncertainties in key findings, the range of outcomes, and the factors and relationships determining levels of confidence.

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