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Rob Swart, Lenny Bernstein, Minh Ha-Duong, Arthur Petersen

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Abstract

Dealing consistently with risk and uncertainty across the IPCC reports is a difficult challenge. Huge practical difficulties arise from the Panel's scale and interdisciplinary context, the complexity of the climate change issue and its political context. This paper reviews a few key issues on the foundations of uncertainty analysis, focusing on the objective and subjective views on uncertainty, on precise and imprecise information, and on the differences between the behavior of natural systems and human choice. It summarizes the history of the treatment of uncertainty by the IPCC, and discusses the applicability of the revised IPCC Guidance Note for the Fourth Assessment Report (AR4) in general, with special attention to costs and potentials of mitigation options. One of the key findings is that there is reason to agree to disagree: the fundamental differences between the issues covered by the IPCC's three interdisciplinary Working Groups, between the type of information available, and between the dominant paradigms of the practitioners, legitimately lead to different approaches. We argue that properly using the Guidance, adding a pedigree analysis for key findings, and particularly communicating the diverse nature of uncertainty to the users of the assessment would increase the quality of the assessment since it would provide information about the nature of the uncertainties in addition to their magnitude and the confidence assessors have in their findings. We make a number of concrete recommendations for improvements over earlier assessments.

1. Introduction

Since its inception, the Intergovernmental Panel on Climate Change (IPCC) has given increasing attention to the management and reporting of uncertainties. Since the start of the IPCC, the author teams of the different Working Groups (WGs) have differed in terms of the level of attention paid to, and methods applied for, assessing uncertainty. Most visibly attention has been given to the communication of uncertainties by the natural scientists in the areas of climate science and impacts, and to a lesser extent, or at least very differently, by social scientists in the assessment of vulnerability, sources of greenhouse gas emissions, and adaptation and mitigation options. For the Third Assessment Report (TAR), an effort was made to enhance consistency in the treatment of uncertainties by the various WGs. This led to fairly consistent treatment of uncertainties within but not across WGs. WG I focused on uncertainties in climatic processes and probabilities and WG II on risks and confidence levels, on the basis of a guidance paper prepared for all WGs at the beginning of the writing process. These guidelines were hardly used by the authors of WG III (primarily economists and other social scientists), who continued to address uncertainties less systematically and in a different fashion. The issues covered by the social scientists have a different nature from those covered by the natural scientists, adding uncertainties related to human choice to the lack of scientific understanding of the systems which determine climatic changes and associated impacts.

Processes within the scientific community and interactions with the external world of policy makers and other stakeholders are critical for the robustness of findings (e.g., Craye et al., 2005), and hence frameworks other than the IPCC may lead to different results. However, in this paper, we take the position and procedures of the IPCC as an intermediary between science and policy as a given, and do not discuss alternative ways of communicating scientific climate change research and associated uncertainties, ways

that may or may not be more effective. Still, within the limits of the IPCC, even if its procedures are fixed in negotiated documents, there may be opportunities for adapting procedures to improve uncertainty communication.

This paper is based in two qualitative methods: the authors' observations as IPCC participants, and IPCC document analysis. It discusses typologies of uncertainties relevant to climate change in general and mitigation in particular (Section 2), the history of the treatment of uncertainties by the IPCC (Section 3), the challenges of addressing uncertainties from diverse perspectives, taking costs and potentials of mitigation options as a case study (Section 4), and finally it proposes how improvements can be made in future IPCC reports, focusing on WG III, the WG to which the first three authors of this papers currently contribute (Section 5).

2. Typologies of uncertainties relevant to climate change

Dealing consistently with risk and uncertainty across the IPCC reports is a difficult challenge. Huge practical difficulties arise from the Panel's scale alone: any coordination in a very heterogeneous community is difficult, especially when there is no single authoritative management's point of view, but thousands of scientists contributing on a voluntary basis from all parts of the world. Moreover, climate change assessments are written in a very interdisciplinary context by climatologists, engineers, ecologists, economists, political scientists and other experts. These difficulties of scale and interdisciplinarity are compounded by the complexity of the climate issue and the link of the IPCC process to the political negotiations. These technical and philosophical problems are not completely new. Indeed researchers of all kinds have thought about the nature of knowledge and ignorance for centuries. Reviewing a few key issues on the foundations of uncertainty analysis sets the context for this paper by identifying more precisely the difficulties facing the IPCC.

Towards a common goal: to improve the assessment and communication of uncertainties

What should be the IPCC goal in elaborating common guidelines on uncertainties for its future reports, and how much convergence should be aimed for? In our view, the guidelines' primary goal is to encourage the authors to describe the full range of uncertainties and multiplicity of views in a transparent fashion. In order to reach this goal, the guidelines should (a) establish a vocabulary to describe levels of confidence or of probability consistent across all WGs and from one report to the next; (b) educate the writing teams with the basic elements of the science (or art) of uncertainty communication; (c) establish the view that different approaches to scientific knowledge and uncertainty are legitimate, and (d) enable the authors to help the readers of the assessment understand not only how large uncertainties are and how confident the assessors are about their findings, but also the nature and origin of the uncertainties.

Additionally, recommendations to the writing teams should be based on the state of the art in the scientific understanding of risk and uncertainty communication. They should fit well with the models of risk, uncertainty, rationality and decision making used by the researchers. At the same time, they should be convenient to follow by IPCC authors. They should lead to effective communication of the risk and uncertainty aspects of the assessment to the intended audience. Such a set of guidelines would be valuable well beyond the IPCC community, to other international academic bodies concerned with risks and uncertainties. For example, the authors of the Millennium Ecosystem Assessment (e.g., MA, 2005) used – with mixed success - the earlier experience from the IPCC Third Assessment, adapting the “likelihood” scale of WG I and the qualitative scale from the IPCC Third Assessment Report (TAR) Guidance (see below). A similar IPCC-derived approach was used by the Arctic Climate Impact Assessment (ACIA, 2004).

Recognizing epistemic philosophical controversies, and agreeing to disagree

Uncertainties can have different “locations”, different “levels” (statistical uncertainty, scenario uncertainty and recognized ignorance), a different nature, a different qualification of the knowledge base, and they involve value-ladenness of choices.

Uncertainties arise at different “locations” (elements) of the assessment process (Figure 1, see also Walker et al., 2003; Janssen et al., 2003). First, they depend on the context of the assessment and the ecological, technological, economic, social and political questions that the assessment addresses: how do we define the problem, and which choices do we make in this definition? Second, uncertainties arise at the level of observations (measurements for natural phenomena and some socio-economic statistics, possibly survey data for other socio-economic, political and cultural issues) and how the data from observations are turned into indicators used in the assessment (e.g. by combinations of variables, statistical methods). Third, various types of uncertainties arise when models are used, such as choices of parameters and model relationships, soft- and hardware implementation of those relationships, selection of input data. Fourth, uncertainties are introduced when outputs are processed, e.g. through the formulation of statements and key findings, and by constructing indicators to communicate these findings.

Expert judgment is generally used in all steps of an assessment. For example, Kloprogge et al. (2005) conducted a workshop-supported analysis of two indicators from the 5th Dutch Environmental Outlook, the projected change in the length of the growing season as a result of climate change, and deaths and hospital admittances due to ozone exposure. For the first indicator, 7 discrete steps in the assessment process were identified, involving 19 explicit or implicit assumptions. For the second indicator, 5 steps and 18 assumptions were identified. These assumptions were mapped and prioritized, their value-ladenness was analyzed, and communication of the prioritized assumptions and their value-ladenness was discussed. This

was a major effort for only two indicators at the national level. Doing the same thing for the much larger number of indicators reported in IPCC assessments by author teams would be next to impossible. In some cases, authors can rely on uncertainty analyses reported in the peer reviewed literature that forms the basis for the assessment, but in many cases, they have to judge the uncertainties without that information.

Experts can relatively easily agree on the different locations of uncertainty in assessments. But they are divided on how to further characterize this uncertainty. More than a century of philosophical discussion on uncertainty has shown that there are divisions which cannot be resolved. For the sake of simplicity, we address three of the most fundamental differences between uncertainty approaches, namely those between the objective and the subjective (Bayesian) views of uncertainty, and those between precise, probabilistic risk and imprecise uncertainty, and those between uncertainties in natural systems and human choice and intentionality. We reduce the uncertainty problem to these dimensions only to illustrate more systematically in the following that a diverse approach to uncertainty communication is not only legitimate, but can enhance the quality of the assessment.

- The division between the objective and the subjective views of probabilities is the oldest. Objective views of probabilities include the classical approach (probability is the proportion of favorable cases over total cases), the frequentist approach (probability is the limit of frequency in the long run (von Mises, 1957)), and the propensity approach (probability is a physical tendency (Popper, 1959)). These views are objective in that probability is seen to be an intrinsic property of the system being studied. This is opposed to the Bayesian point of view, in which probabilities refer to degrees of belief (de Finetti, 1937; Savage, 1954).
- The distinction between risk and uncertainty is also very old (Knight, 1921). It describes the difference between situations where information can legitimately be represented using precise probabilities (risk), and situations where the information is too imprecise to use a probability distribution (uncertainty). The standard definition of risk is the combination of the

probability of an event and its consequences, which is consistent with, but more general than, the simple “product of probability times loss.” As for uncertainty, it may be simpler to define it negatively, that is all other forms of ignorance about a system for which we don’t have well founded precise probabilities¹. This does not mean that uncertainty is always out of reach of rigorous formal analysis. This does not mean that all kinds uncertainty are out of reach of rigorous formal analysis, see for example the imprecise probabilities approaches in Walley (1991) or Ellsberg (1967). See also Ha-Duong (this issue).

- The third dimension is the difference between uncertainty in natural systems and uncertainty in human and social systems. The former are causal: the past determines the future. However, human systems are intentional, so the arrow of time can be reversed: long term goals can determine the present. Intentionality also implies that Laplace’s principle of indifference (all outcomes are equally probable) should be replaced by a principle of optimization: assume that agents in the system will choose what they think is best rather than acting randomly. Thus, game theory is more relevant than probability theory for analyzing these systems.

Both objective and subjective sources of information can be precise or imprecise. Imprecision occurs in the frequentist setting when the sample size is small, and in the subjective setting when experts are deeply uncertain and cannot give precise probabilities, and hence cannot quantify risk. In climate change assessment, information about the unknown future is important, notably because of the role of human choice captured by the causal/intentionality dimension above. From a policy point of view it can be important to distinguish between the uncertainties

¹ Risk and uncertainty in some definitions do not capture the full range of what we do not know. Wynne (1992) distinguishes in addition to *risk* (known odds) and *uncertainty* (unknown odds but parameters largely known) also *ignorance* (where we ‘don’t know what we don’t know’) and – spanning uncertainty and ignorance – *indeterminacy* (where causal chains or networks are open. The later two aspects are either implicitly or explicitly (e.g. when describing surprises) included in IPCC assessments and captured in the broad definition of uncertainty that we adopt in this paper.

related to lack of knowledge about the way biogeochemical and socio-economic systems function and those related to the understanding of the role of human choice².

Critically for an interdisciplinary panel, traditional experimental sciences methods have typically relied on the objective (frequentist) and precise approach to information, while social sciences methods have tended to use more subjective (Bayesian) and imprecise approaches. Experimental sciences seek to determine precise objective frequencies based on a large body of observations, and experiments are (at least assumed) reproducible. Social sciences rarely have replicated controlled experiments or even complete observations, and often the most adequate description of knowledge available is narrative. This leads to imprecise theories, which are also subjective in that they are based on actions of humans observed by other humans.

The distinction between experimental sciences and social sciences methods is not a hard rule, especially given the central position of economics. When there are missing data or a small number of observations, experimental results also can be very imprecise. In the natural science of climate, which is largely an observational science, imprecisions reign, since some critical data are scarce and experimentation with the climate system is impossible. On the other hand, there are social objects such as financial markets, which lend themselves well to an objective (frequentist) approach. Nevertheless, some debates on uncertainty within IPCC circles (for example on the question of future emission levels as a function of socio-economic scenario and resulting climate change) can be seen as discussions between the imprecise-subjective and the precise-objective positions.

² In a similar vein, Allen et al. (2004) recommend that WG I distinguish between scenario uncertainty (different emissions paths), natural variability, and response uncertainty (incomplete knowledge of timescales and feedback processes). Briscoe (2004), in an overview of inputs into a US hearing on communicating scientific uncertainties, noted that the science of climate change is affected by two main types of uncertainty: unknown aspects of how the climate system works and of how human actions will impact climate change.

What are the challenges in dealing with the objective-subjective, the precise-imprecise, and the causal-intentional dimensions in an interdisciplinary panel? Since the guidelines' primary goal is to encourage very diverse authors to describe uncertainties, unanimity on either the objective or the subjective side is not only impossible, it is also useless. A normative vocabulary meaningful only for one philosophical position is likely not to be used by everybody³. The challenge is to disentangle the various dimensions.

3. History of treating uncertainties by the IPCC

IPCC typologies

Tables 1 and 2 present the simple typologies distinguished in the TAR (Moss and Schneider, 2000) and AR4 (IPCC, 2005) guidance notes. The first table lists basic 'sources' of uncertainty, in the way one would list the possible causes of failure of a complicated machine. The machine here is called a model (scientific theories can be viewed as models). Thus, the table supposes implicitly that there is a Truth to be discovered, and uncertainty is the product of defective or

³ We argue that contrary to the objective/subjective difference, from a purely theoretical point of view, the distinction between theories of risk (precise) and uncertainty (imprecise) is not philosophically irreducible. Truth and belief are fundamentally different concepts, but precise probabilities can be seen as the limit case of imprecise probabilities, when the imprecision is zero. Probabilistic reasoning is by far the best understood method consistent with the dominant precise approach in science. But in reality, situations where precise probabilities are not well defined cannot be avoided, e.g., in assessments of future developments the imprecision can never be reduced to zero. Mathematical procedures to deal with imprecision are much less developed, in spite of a growing body of empirical and theoretical literature on imprecise probabilities or fuzzy logic (Walley, 1993).

limited means of knowledge. While the first two sets of uncertainty sources in Table 1 can often be quantified, the third “other” sources of uncertainty generally cannot. Table 2 demonstrates the evolution of a broader view on the issue of uncertainty, as it relates to objective as well as subjective types of uncertainty, indicative examples of sources, and typical approaches and considerations. The human dimensions of uncertainty get a bigger role as a cause for unpredictability. Below, we discuss the development of the treatment of uncertainties in the history of the IPCC in more detail.

First, second and third IPCC assessment reports

In the IPCC First and Second Assessment Reports, uncertainty management and treatment was not systematically addressed across WGs. At the stage of the First Assessment Report (1990), the question whether climate change was a real problem dominated the assessment, with a primary role for the climatologists of WG I. This WG set the standard for the rigorous procedures that were later formalized for all WGs. The political importance of the questions whether climate change was occurring, and if so, whether human actions contributed to it, put pressure on the authors to focus on the scientific uncertainties to provide a balanced answer. The review procedures employed and the scope of participation in the production of the WG I report ensured that sufficient attention was being paid to uncertainties.

In the IPCC First Assessment Report (1990), the WG I executive summary started with what the authors were certain of and what they were confident about, thus taking a Bayesian perspective. They used strong words like “predict”, a term which would nowadays rightly be avoided. Uncertainty management was not yet centrally guided, but was left at the discretion of the authors. For WG II (Impacts) and WG III (Response

Strategies)⁴, the review procedures were not yet very rigorous and uncertainties were not a major topic of debate. The formulation of key findings did take uncertainties into account, albeit not in any consistent manner. Two pages were used to describe the scenarios – as a description of uncertainty about the future – used in the WG III report. The Summary for Policymakers contains a few sentences stressing several uncertainties, e.g. those related to the difficulty of making regional estimates of climate-change impacts.

In the Second Assessment Report (1996), WG I dropped the usage of uncertainty terms in its main policy messages, but added a special section on uncertainties. While much attention was paid to reaching consensus about the appropriate formulation of statements taking into account the uncertainties (“The balance of evidence suggests..⁵”), no common language was used. “Predicting” was replaced by “projecting” climatic changes on the basis of a set of scenarios⁶. In its concluding chapter on advancing the understanding, WG I mentions the need for a more formal and consistent approach to uncertainties in the future. WG II, which during the Second Assessment covered scientific-technical analyses of impacts, adaptations and mitigation of climate change, assigned low, medium or high levels of confidence to the major findings of the chapters in the executive summaries, like WG I in the First Assessment Report taking a Bayesian approach. WG III covered the economic and social dimensions of climate change. Managing and reporting uncertainties was not a key focus in the WG III assessment, in which uncertainties were captured through reporting of ranges from the literature and scenario-based what-if analyses of costs of response action.

⁴ The responsibilities of WG II and WG III have changed since the First Assessment Report. WG II now addresses impacts, adaptation and vulnerability, while WG III addresses mitigation.

⁵ In fact, this formulation was designed during the Plenary meeting jointly by IPCC delegates and lead authors.

⁶ A prediction or forecast is the result of an attempt to produce a most likely description or estimate of the actual evolution of a variable in the future, e.g. at seasonal, interannual or long-term time scales. Projections are based on simulations by models with various input assumptions, concerning, e.g., future socio-economic and technological developments. They generally do not have likelihoods attached to them.

Table 1: Examples of sources of uncertainty in IPCC TAR uncertainty guidelines

<i>Problems with data</i>
1. Missing components or errors in the data
2. “Noise” in the data associated with biased or incomplete observations
3. Random sampling error and biases (non-representativeness) in a sample
<i>Problems with models</i>
4. Known processes but unknown functional relationships or errors in the structure of the model
5. Known structure but unknown or erroneous values of some important parameters
6. Known historical data and model structure, but reasons to believe parameters or model structure will change over time
7. Uncertainty regarding the predictability (e.g., chaotic or stochastic behavior) of the system or effect
8. Uncertainties introduced by approximation techniques used to solve a set of equations that characterize the model.
<i>Other sources of uncertainty</i>
9. Ambiguously defined concepts and terminology
10. Inappropriate spatial/temporal units
11. Inappropriateness of/lack of confidence in underlying assumptions
12. Uncertainty due to projections of human behavior (e.g., future consumption patterns, or technological change), which is distinct from uncertainty due to “natural” sources (e.g., climate sensitivity, chaos)
Source : Moss and Schneider (2000)

Table 2: The simple typology of uncertainties in IPCC AR4 guidelines

Type	Indicative examples of sources	Typical approaches and considerations
Unpredictability	Projections of human behavior 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.

Source: IPCC Guidance Note (IPCC, 2005)

Box 1: Summary of steps recommended for assessing uncertainty in the TAR

1. For each of the major findings you expect to be developed in your chapter, *identify the most important factors and uncertainties that are likely to affect the conclusions*. Also specify which important factors/variables are being treated exogenously or fixed, as it will almost always be the case that some important components will be treated in this way when addressing the complex phenomena examined in the TAR.
2. *Document ranges and distributions in the literature*, including sources of information on the key causes of uncertainty. Note that it is important to consider the types of evidence available to support a finding (e.g., distinguish findings that are well established through observations and tested theory from those that are not so established).
3. Given the nature of the uncertainties and state of science, *make an initial determination of the appropriate level of precision*—is the state of science such that only qualitative estimates are possible, or is quantification possible, and if so, to how many significant digits? As the assessment proceeds, recalibrate level of precision in response to your assessment of new information.
4. Quantitatively or qualitatively *characterise the distribution of values that a parameter, variable, or outcome may take*. First identify the end points of the range that the writing team establishes, and/or any high consequence, low probability outcomes or “outliers.” Particular care needs to be taken to specify what portion of the range is included in the estimate (e.g., this is a 90% confidence interval) and what the range is based on. Then provide an assessment of the general shape (e.g., uniform, bell, bimodal, skewed, symmetric) of the distribution. Finally, provide your assessment of the central tendency of the distribution (if appropriate).
5. Using the terms described below, *rate and describe the state of scientific information* on which the conclusions and/or estimates (i.e. from step 4) are based.

6. *Prepare a “traceable account” of how the estimates were constructed that describes the writing team’s reasons for adopting a particular probability distribution, including important lines of evidence used, standards of evidence applied, approaches to combining/reconciling multiple lines of evidence, explicit explanations of methods for aggregation, and critical uncertainties.*
7. *OPTIONAL: Use formal probabilistic frameworks for assessing expert judgment (i.e. decision-analytic techniques), as appropriate for each writing team.*

Source: Moss and Schneider (2000)

In preparation for the TAR (2001), a strong demand for a more systematic approach to uncertainties was identified - as recommended by WG I in the Second Assessment Report, and the subsequent discussion led to a so-called cross-cutting “Guidance Paper” (Moss and Schneider, 2000). The paper summarized the most relevant literature, explored experiences in the Second Assessment Report, and proposed a methodology (see Box 1). It also suggested options for usage of quantitative terms for confidence levels, continuing the Bayesian perspective of the earlier assessments and qualitative terms to describe the level of understanding based on both the amount of evidence available and the degree of consensus among experts in the TAR. While both types of terminologies again suggest a Bayesian perspective, the latter could be considered more imprecise than the former. A difference between disciplines or WGs was not made, implicitly suggesting a common approach for all WGs, issues and disciplines.

The discussion in the author teams focused mainly on the choice of the most appropriate terminology for the summaries rather than on a consistent application of all 7 steps of Box 1 throughout the assessment. WG II largely adopted the proposed levels of confidence. WG I authors amended the guidance by adding a “virtually certain” category

and developing a different terminology for describing quantified levels of likelihood. Their definition of likelihoods refers to judgmental estimates of confidence. WG III authors were encouraged to use the guidance, but – with a few exceptions - ignored it, feeling that the proposed approach did not address their perspectives on uncertainty. Also in WG III, the attention of the Lead Authors focused most on the terms in the two tables (step 5), but eventually these were judged to be less appropriate for the social scientists of WG III. However, even without explicitly referring to the Guidance Note, other elements of the suggested approach were applied, albeit not systematically, across all WG III chapters (notably steps 1-4).

One may wonder why the authors, who were generally sympathetic to the guidance, still focused mainly on the terminology. One important reason is practical: the lack of time and the pressing existence of other competing priorities -- IPCC authors are “volunteers” who have a full set of non-IPCC professional obligations -- and the simplicity of using just a scale in a table rather than diving deeper into the much richer guidelines. Another reason may be that scratching only the surface of the complex uncertainty domain by focusing on a relatively easily managed part of it, allows the assessors to continue with only a minimal change in their usual working methods. Also, intentionally or unintentionally, more political considerations may have played a role. A more thorough reflection on the scientific methods and framing of problems could be seen as a threat to the status of these methods and framings and to the existing culture in the associated disciplines (Craye, 2006).

The fact that the authors focused much on the terms has to be seen in the light of the finding that readers of the report interpret the words very differently. The fact that the TAR defined the meaning of words used to describe probabilities did not appear to influence how people then interpreted those words (Patt and Schrag, 2003; Patt and Dessai, 2005). More precisely, these authors found that among a sample of COP 9

participants, the numerical interpretation of “unlikely, perhaps very unlikely” climate change did not depend on whether they had read the IPCC TAR. This suggests that the IPCC WG I likelihood scale is more a means to ensure consistency among authors than a means to alleviate the known cognitive bias with probabilistic information among readers.

Differences between Working Groups in the TAR

Are the differences between the three WGs real, and if so what might be the reasons that a fully consistent treatment of uncertainties across the three groups – and hence across disciplines – may be infeasible or undesirable? In order to evaluate the way uncertainties were reported in the TAR, we have focused on five key issues for each WG.

For WG I, we looked at observed temperature changes, observed concentrations and radiative forcing, attribution to anthropogenic causes, future average climate changes, and future changes in climate extremes. Most of these issues are dominated by uncertainties in the physical sciences related to observations in the natural world. These are often determined by uncertainties related to natural variability of observed variables and lack of understanding about physical and chemical processes. Much information is available, e.g. from world-wide observations of atmospheric, terrestrial and marine variables over long periods. Here the IPCC deals with what could be regarded as relatively precise and objective information which could be conducive to a frequentist attitude. As Manning (2003) notes, notably the physical scientists prefer to consider uncertainty in objective terms, in relationship to measurements, repeatability of results, and with bounds for systematic errors. However, lack of consistency between different available data sets and high data variability within data sets may explain WG I eventually adopted a subjective perspective, with a (precise) likelihood scale capturing

degrees of certainty, according to definitions implicitly based on “judgmental estimates of confidence”. In the WG I TAR ranges for outcomes usually were given and explained. However, the more explicitly subjective “confidence levels” which are used by WG II, could lead readers to erroneously interpret the difference between WGs I and II as one between objective and subjective findings, rather than one between precise and imprecise information (see further below).

In general, WG I opted for the quantitative likelihood terminology (cf. Table 3 for the revised AR4 version) for all the five issues considered. One may question this one-size-fits-all approach, since some issues are characterized by much more imprecise information. This is the case when the reliability of models or future developments are discussed. In attributing climate-change to anthropogenic causes, for instance, both observations and models were used. WG I authors used their subjective judgments to make confidence statements about both the (imprecise) quality of the models to make confidence statements and the (precise) frequency distribution of the outcomes (Petersen, 2006). For future scenarios, the likelihood scales suggest a level of knowledge about the future that does not exist. Furthermore, in speaking about the future, the conditionality of future developments (e.g. climatic changes) on future human choices needs to be acknowledged.

For WG II, we looked at observed climate change impacts, projected impacts of extremes, projected economic impacts, projected impacts on sectors and projected impacts in regions. In WG II the biological sciences are more important than in WG I and social sciences come in when vulnerability, impacts and adaptation are assessed. The interactions in biological systems and between these systems and physical-chemical and social systems, are more complex, are dependent on human choices and actions, and are more subject to the different perspectives of the assessors. Unlike WG I data, most WG II data have relatively short time series of observations, lack global coverage, and

lack a set of globally agreed definitions and measurements techniques. Changes in various systems (e.g. ecosystems) may be observed, but a large number of assumptions are required to relate these observations to climate change. The imprecise nature of the available information explains why it is more difficult to agree on likelihoods of findings in a group of diverse authors in a WG II chapter team. Being more explicit about the reliance on imprecise information and subjective confidence levels therefore seems an appropriate way for WG II to address the higher complexity and subjectivity of its findings, avoiding the impression of objective and precise knowledge.

There are just a few occasions in the TAR where WG II appears to be inconsistent. One example is the confusing usage of likelihood levels with respect to the projected changes during the 21st century in extreme climate phenomena. This is derived from the usage of these terms by WG I that is questioned above, and is unavoidable since one IPCC WG cannot change the uncertainty assessment of another WG. In only a few instances qualitative levels of understanding are used (cf. Table 5 for the revised AR4 version).

The terminologies in both WG I and II are based on a subjective, Bayesian perspective. The difference can be explained by the availability of more precise information in WG I as compared to the more imprecise information available to WG II. One could even regard the likelihood and confidence scales as fitting in two domains: the likelihood scale in the precise-imprecise domain and the confidence levels in the objective-subjective domain. The objective, frequentist history in the dominant WG I disciplines (Manning, 2003) may also be an explanatory factor for the only implicit subjectivity in the definitions by WG I, as compared to the explicitly subjective confidence levels of WG II. This may be legitimate, but from an uncertainty communication point of view there is a risk - maybe not to scientific analysts, but certainly to a policy audience – that “likelihoods” could unintentionally be interpreted as more objective than “confidence levels” and hence be awarded a higher level of “truth”, while it is only the consensus

judgment of the authors for the section in which the conclusion appears (a subset of the full lead author teams and an even smaller subset of the 2500 scientists contributing to the assessments as lead or contributing authors or as reviewers).⁷ That such a risk is real, may be illustrated by Patt (2005), who finds that readers may respond differently to information about confidence levels if these are framed according to (dis-)agreement between the IPCC experts or according to the outcomes of computer models.

For WG III, we looked at GHG emissions, GHG mitigation potential, short-term costs and benefits, long-term costs and benefits (stabilization of GHG concentrations), and spill-over effects. In WG III the scale further tips to include social, institutional, cultural and political issues characterized by different perspectives and human choices and thus into subjective, imprecise, and volition territory. The information basis is weaker than in the other WGs, since these variables are usually not covered by long-term statistical time series. WG III did not use the various options for the terminology, even though the qualitative levels of understanding could have been applied (Table 5, in a few cases such as potentials – see discussion further below). The authors opted for addressing uncertainty differently, mainly through presentation of ranges of outcomes and explanation of the underlying assumptions. In the Special Report on Emissions Scenarios (SRES) that was used for the TAR, the authors explicitly have not attached any probabilities to emissions scenarios⁸. Projections for short-term emissions (e.g., 2010) were not explicitly discussed, but this may change in the AR4 to increase the relevance of the report that is to be published just before the Kyoto target period of 2008-2012. For such short term projections, it may be interesting to consider using the

⁷ The author's judgment is subjected to review and may therefore become considered representative for a larger group of experts. However, it is crucial to ensure a spectrum of views within the lead-authors team charged with crafting uncertainty statements.

⁸ Pittock et al. (2001) and Schneider (2001, 2002) have suggested to attach probabilities to scenarios of climate change to serve policy makers, but Gruebler and Nakicenovic (2001) have provided counter arguments. The debate continues. It reflects, to some extent, the tension of the causal-intentional dimension; the SRES authors prefer to keep the human choice dimension explicit, while other prefer to take a subjective risk approach. See also Box 3.

confidence scale, while carefully describing assumptions as to policies and socio-economic driving forces.

When addressing costs and benefits of particular levels of mitigation policies (e.g. implementing the Kyoto Protocol or reaching particular levels of GHG stabilization), the authors have reported a range of outcomes from the literature and clarified the differences (steps 1-4 in Box 1) rather than attempting to arrive at a best (or most likely) guess or assign confidence levels. An interesting exception is that in their assessment of potentials of technological options in various economic sectors, the authors of the chapter on the technological and economic potential of greenhouse gas emission reduction options did attempt to make a best guess and estimated probabilities of these potentials being achieved. However, this “best guess” suffered from the weakness that for different options and for different sectors the potential for mitigation was not assessed against the same baseline development, leading to unquantified inconsistencies. The term “potential” was related to a poorly defined new term “socio-economic potential”. In this way, the probability levels obscured the dependency of the achievement of the potential of options on factors such as the development and implementation of policies as well as on “autonomous” societal developments.

A word count of the three WG TAR reports confirmed the differences between the three groups (for details see <http://www.centre-cired.fr/forum/article428.html>). For example, “uncertain” was found about twice as often in WG I as in WG II and about three times as often as in WG III. “Proba” was found in WG II almost three times as often as in WG I and four times as often as in WG III, and similarly “risk was used more than four times as often by WG II than by WG III, while it was hardly used by WG I. In contrast, “choice” was found almost three times as often in WG III as in WG II, and “decision”, a word hardly found in WG I, was found twice as often in WG III as in WG II. According to this simple word count, uncertainty dominates WG I; risk, WG II; and choice, WG III.

Parker (2006) evaluated the IPCC experience with uncertainty management focusing on how the evidential basis of findings could be evaluated, how the qualitative scale could be adjusted, and how the treatments of uncertainties could be further coordinated and tailored. Coming to this issue from another angle, she also concludes that diversity in uncertainty communications is required, and suggests that a tailor-made, chapter-specific approach could be developed for future assessments, involving experts beyond the climate science community, e.g. philosophy of science and risk assessment experts. We do not recommend standardizing uncertainty communication procedures, but harmonizing them more loosely so that they are transparent and consistent, but leave room for choosing the most suitable approach for specific issues. It is beyond the scope of this paper to discuss all elements of uncertainty communication in the context of climate change⁹

In summary, it may be more difficult for the readers to understand and interpret the different approaches to uncertainty communication by different WGs, but there are legitimate reasons why these differences exist. The different types of information (observations, model calculations, scenarios, and volition) and the different levels of evidence and agreement make the application of different approaches not only legitimate, but desirable.

Comprehensiveness of assessing uncertainties by the IPCC

⁹ E.g. we did not discuss important issues such as communicating relative importance of uncertainties, the possibilities of addressing robustness rather than the uncertainty of findings, and the importance of graphical representation of uncertainties for communication with users.

Comprehensively addressing uncertainties across all dimensions is unrealistically time-consuming (see also section 2). A systematic analysis taking into account the various elements of matrix 1 has not been taken, not even for a selected number of key messages. It is not surprising that IPCC reports emphasize the formulation of messages. The other elements have not been ignored and are often discussed during the assessment of the available literature. For the authors of WGs I and II, who generally use consistent terms within their group, this implies that the readers of the assessment may end up being well informed about the levels of confidence or likelihood of key statements in the summaries, but generally are not told the basis for the uncertainty quantification. This approach has the advantage of using consistent terminology, but disadvantages in that the terminology is not transparent, that - notwithstanding the definition provided - the words means different things to different people, and that readers are less informed about the basis of the reported (high or low) likelihood or confidence level (uncertainties in the basic data, in model simulations, in the influence of human choices?).

In WG III the emphasis has been on explaining the determinants of outcomes, rather than quantifying likelihoods or confidence levels. For example, how are technological potentials and their costs defined and calculated, and how do different definitions and methods affect the outcomes? This has the disadvantage of the absence of a common terminology, but the advantage of helping the readers to understand the background of the results of the assessment. This analysis however has not been done in the systematic and comprehensive way of the Klopogge et al. (2005) example.

Summaries for Policymakers (SPMs) are the parts of IPCC reports that are most carefully scrutinized by governments and most widely read. The political sensitivity of the statements in SPMs requires that their uncertainty be carefully described. Especially in WG III, with social scientists from all regions and very different schools of thought, agreement about controversial issues such as costs of response measures is a tough job.

For this reason, much attention has been focused on the way IPCC authors describe uncertainty in the SPMs. However, this is only one of many things that needs to be done to develop a high-quality assessment that is approved by the over 100 countries that typically attend an IPCC Plenary.

In preparation for the AR4, an Uncertainty Guidance Note was prepared (IPCC, 2005), to a large extent based on discussions during an IPCC workshop (Manning et al., 2004) and discussions between Lead Authors of all WGs during and after their first meetings in the second half of 2004. Agreement has been reached on this Guidance Note, and its application was tested in preparing preliminary drafts of the AR4 report. One innovative aspect of this Guidance Note is the introduction of a hierarchy in the application of preferred approaches, dependent on the amount and character of the available information and the level of agreement between the assessors (see Box 2).

The 4th IPCC Assessment: update of Uncertainty Guidance

The quantitative likelihood scales, confidence levels, and qualitative levels of understanding of the TAR were updated for the AR4 (Tables 3, 4 and 5). As discussed above, the different types of terminologies could be considered to fall in different domains and hence the terminology of Tables 3, 4 and 5 can be complementary, e.g. one can have high confidence (Table 4) in a low likelihood (Table 3) and simultaneously provide more information about the arguments for the assignment of the confidence and/or likelihood levels (Table 5). One could consider the confidence terminology as a second order probability when it is combined with the likelihood terminology. In order not to confuse the reader, IPCC (2005) however recommends to avoid the use of more than one terminology for one issue. Here, expectations about what readers can understand have been weighted more heavily than scientific considerations to provide a comprehensive picture of uncertainties. We would argue that the use of the qualitative

scale proposed by IPCC and much more attention to explaining the basis of key findings provide complementary information in a form that is less likely to confuse readers.

Box 2: Hierarchy of uncertainty approaches as a function of availability and character of information and level of agreement

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 3 or 4.

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 3 or 4.

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 4 or 5.

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 5 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.

Source: IPCC, 2005

Table 5 provides additional insights as compared to Tables 3 and 4. Since only few socio-economic issues are suitable for the usage of quantitative uncertainty terminology, Table 5 is particularly relevant for WG III, and can be expanded by authors to arrive at more differentiation than the TAR 2*2 matrix with qualitative terminology that was proposed by Moss and Schneider (2000)¹⁰. Experience during the TAR demonstrated that different interpretation of the qualitative terms (speculative, established but incomplete, well established, competing explanations) can lead to confusion or incorrect communication. Therefore the terms have been replaced by terminologies capturing both dimensions of the matrix. The fact that the new Guidance allows for a more diverse approach addresses some of the problems that we have identified in the previous section. We note, however, that the Guidance does not specifically distinguish between the different dimensions, notably the distinction between natural system uncertainty and human choices.

¹⁰ Interestingly, it has been suggested that the matrix not only can be used as qualifiers for key statements, but also can be filled with response options organized according to the level of consensus and evidence.

Terminology	Likelihood of the occurrence/ outcome
<i>Virtually certain</i>	> 99% probability of occurrence
<i>Very likely</i>	> 90% probability
<i>Likely</i>	> 66% probability
<i>About as likely as not</i>	33 to 66% probability
<i>Unlikely</i>	< 33% probability
<i>Very unlikely</i>	< 10% probability
<i>Exceptionally unlikely</i>	< 1% probability

Table 3: Likelihood scale. Source: IPCC (2005)

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

Table 4. Quantitatively calibrated levels of confidence. Source: IPCC (2005)

Level of agreement or consensus ↑	<i>High agreement limited evidence</i>	...	<i>High agreement much evidence</i>

	<i>Low agreement limited evidence</i>	...	<i>Low agreement much evidence</i>
	Amount of evidence (theory, observations, models) →		

Table 5. Qualitatively calibrated levels of confidence. Source: IPCC (2005)

4. Spotlight on: costs and potentials

To evaluate the possible application of the Guidance in WG III, we focus on the issue of costs and potentials in more detail, since one of the policy-relevant questions likely to be of most interest to readers of WG III's contribution to AR4 is: What are the costs of and potential for GHG mitigation in the short to medium term (e.g., to 2030)? The answer to this question will be highly uncertain, and communicating that uncertainty to policymakers and other readers will be a major challenge. We look first at the sources of uncertainty in the answers to questions, then at the challenges for communicating those uncertainties. Sources of uncertainty about costs include the need for a baseline, the vagueness of the concept, structural systemic change in the long term, and human choices.

1. The first source of uncertainty is in the assumed reference scenario, i.e. the description of the world of 2030, which includes assumptions on system behaviour and human choice. For determining costs and potentials in 2030 in the AR4, WG III has initially chosen to look at two scenarios for 2030, SRES A1 and B2 (Price, et al., 2006). The A1 scenario is for a world of "... very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies." The B2 world is one "in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in ... A1..." (Nakicenovic, et al, 2000).

A1 and B2 are both baseline scenarios, i.e., they contain no overt efforts to control GHG emissions. As such, they are not realistic descriptions of the world. However, the scenarios are still useful because they provide baselines against which the potential for

new technology can be tested, independent of whether it is adopted voluntarily or to meet a legally binding target. Probabilities are not assigned (see Box 3).

2. The definition of the term “potential” introduces a second source of uncertainty. Several different measures of potential exist. At the high end, technical potential estimates the performance of the technology, independent of cost considerations. At the low end, market potential estimates the extent to which the technology is likely to be used, given its cost, competitive technology, government regulation, consumer preferences and all of the other factors that affect the market. These two measures of potential will give very different estimates. For estimating mitigation potential and cost, WG III intends to use an intermediate measure: economic potential, which is defined as the cost of GHG mitigation when non-market social costs and benefits are added to market costs and benefits, and when social discount rates (about 5% in the short to medium term) are used instead of private discount rates (typically 15% or higher). If sufficient information is available, this approach can provide a mitigation supply curve, i.e., the amount of GHG mitigation that could be achieved in 2030 as a function of the cost expressed in $\$/\text{tCO}_2$.

A top-down approach will generate reasonable estimates, provided there are no “paradigm-changing” technological changes. For example, if there were a breakthrough in hydrogen fuel cell technology that made this approach attractive for both vehicle and stationary source use, large amounts of hydrogen would be required, and large amounts of CO_2 suitable for carbon capture and storage (CCS) would be generated. CCS technology could be implemented much more rapidly than generally assumed, and global CO_2 emissions reduced more cheaply than currently anticipated. Surprises can also happen in the other direction. A breakdown of political will to control GHGs could lead to fewer incentives to apply existing technology and higher emissions.

Box 3: IPCC scenarios and probabilities

IPCC recommends using a set of six “illustrative SRES scenarios” to cover the range of future GHG emission levels in evaluations of future, climate change and its impacts, and mitigation and adaptation options. Many observers believe that some of these illustrative scenarios are less likely than others, particularly the two that provide the highest and lowest emissions in 2100. This had led to suggestions that probabilities be assigned to six scenarios as a way of reducing uncertainty. We do not agree for two reasons. First, from a methodological standpoint, scenarios are images of the future. They are not predictions or forecasts (Nakicenovic, et al, 2000). Assigning probabilities to scenarios turns them into forecasts, which requires a set of judgments that the team that developed the SRES scenarios was not asked to make. Second, all of the SRES scenarios are unrealistic because they, by design, do not take into account the efforts being made around the world to reduce GHG emissions. These efforts can only grow with the passage of time, making the SRES scenarios even less realistic. The scope of these efforts and their success in reducing emissions is highly uncertain. Assigning probabilities to the SRES scenarios does nothing to reduce the uncertainty around the effectiveness of mitigation efforts or the uncertainty around future emission levels.

However, assigning probabilities could provide a greater aura of certainty to these highly uncertain projections. Among others, Reilly et al. (2001) have criticized the IPCC for not providing a probability estimate of anthropogenic warming in the 21st century. In response, Allen et al (2001) note three reasons: the difficulty of assigning probabilities to socio-economic trends (see above), the difficulty of obtaining consensus ranges for qualities like climate sensitivity, and the possibility of a non-linear response in the carbon cycle or ocean circulation to very high, late 21st century greenhouse gas concentrations. For future scenario exercises, assigning different subjective, imprecise levels of plausibility to different scenarios could be explored. This would be preferable

to assigning quantified probabilities, which may suggest to readers that objective and precise information about the future is available. This would be in addition to explicitly recognizing the role of human choice in shaping the future.

3. Projections of cost create a third set of uncertainties. While all of the technology that WG III will be considering has been invented, some of it (e.g. the hydrogen fuel cell) is in the early phases of the development cycle, and could see large changes from projected costs over the next 25 years. Technologies that prove cheaper than currently estimated will take larger shares of the market; technologies that prove more expensive are unlikely to be implemented.

4. The fourth set of uncertainties involves the way in which technological improvement will be implemented, again involving assumptions about human choices. Improved energy efficiency, which is a major component of GHG mitigation technology, can be used to reduce fossil-fuel consumption, and thus CO₂ emissions, or it can be used to improve output in some fashion. Vehicle efficiency in the U.S. is a classic example of this choice. The actual efficiency of automotive engines in the U.S. has improved steadily (AuYeung, Haywood and Schafer, 2001). However, this improvement has not translated into reduced fuel usage, but into greater vehicle size, power, or luxury.

Given all of these uncertainties, it seems fairly clear that WG III will not be able to assign either probabilities or confidence levels to its estimates of mitigation cost or potential. Even qualitative terminology, e.g. well-established, is unlikely to be appropriate. The challenge for WG III will be to explain to policymakers and other readers the process used to develop its estimates, and the uncertainties involved, in sufficient detail to allow them to judge the validity of the numbers.

We propose that for issues such as costs and potentials of options, conclusions in terms of probabilities should be avoided. In the ongoing discussion in WG III on costs and potentials, guidelines are being formulated for reporting. These include the reporting of discount rates; the year and region for which the costs are estimated; the type, definition and level of the costs; the reference case; the preferred units; and the type of potential. This description should allow readers to judge the meaning of the results being presented. It will also identify when it is possible to sum sectoral or regional information into global totals.

5. Discussion and recommendations: handling uncertainties in future IPCC assessments

A broader approach rather than a scale

It is tempting to organize guidelines on uncertainty around a general scale going from totally certain (or totally true) to totally unknowable. Unfortunately a strict hierarchical classification is hard to find in the domain of risks and uncertainty. The most important insight arising from an interdisciplinary assessment on uncertainty is its conceptual diversity.

There have been attempts at systematic taxonomies of uncertainty (see, e.g. Smithson, 1989, Walker et al., 2003; Janssen et al., 2003, see also Section 2). However, although a uniform taxonomic approach is a very systematic way to explore concepts, it may not be the most appropriate approach within the context of guidelines for hundreds of authors. As discussed above, using a multi-dimensional typology of uncertainty is quite complex, and may result in a vocabulary that is precise in a technical context but ineffective at communication. Also, while the above discussion of the objective/subjective, the precise/imprecise, the causal/intentionality dimensions of uncertainty is key for demonstrating the importance of diversity in uncertainty

treatment, it is not necessarily the best way to structure the uncertainty communication framework.

Funtowicz and Ravetz (1990) have proposed a rich framework to address different aspects of uncertainty. In this framework, called NUSAP: a quantitative analysis of the available data (the Numerical, Unit, and Spread steps) is followed by a more qualitative analysis (the Assessment and Pedigree steps). This approach can in theory be considered to be quite useful for the IPCC. This approach would eventually aim to qualify the reports' findings, which are mostly statements about the future of complex dynamic systems involving the human will, in a multidimensional fashion with a few relevant descriptors to help the reader assess which degree of confidence he or she wants to place in the findings. The approach has been successfully explored in recent years (van der Sluijs et al., 2005; see also <http://www.nusap.net/>). However, since it requires a large amount of effort to implement and report the approach properly, the reality of the IPCC process with many competing claims for time and resources makes its full application there unrealistic.

However, it is worth exploring whether some elements of the approach could be adopted to broaden the current IPCC practice. One option would be to enhance reporting of pedigree. In this context, “pedigree” not referring to ancestry, but to an evaluative description of the mode of production of the information. It rates aspects of the information such as the way indicators have been defined, how data were collected, analyzed and reviewed, and the institutional culture involved (Funtowicz and Ravetz, 1990).

Organizing diversity in IPCC statements

In principle the various ways of describing uncertainties can be complementary.

According to Manning et al. (2004), identifying and explaining the determinants of uncertainty including issues as definitions of variables, assumptions regarding system

boundaries affecting the method used, and existence of competing conceptual frameworks, is often more relevant than trying to quantify those uncertainties. In all WGs, the uncertainty approach should be dependent on the issue at stake: e.g., different questions may lead to different choices for the kind of terminology to be used.

It is tempting to summarize the discussion above for organizing actual statements about the various issues in the various WGs according to the dominant philosophy regarding uncertainties and their level of precision (objective/frequentist versus subjective/Bayesian and precise versus imprecise), the distinction between natural system uncertainty and human choice, and the preferred approach regarding communication of the uncertainties. We recognize that the uncertainty philosophy is in the eyes of the beholder, but on the other hand we think that the discourse about particular issues is generally dominated by one of the philosophies. And as we concluded in section 2, the objective/subjective distinction is fundamental. As to the preferred approaches, they can be complementary rather than mutually exclusive. In Figure 2 we make an attempt to illustrate this by grouping types of statements for the various issues and placing them in different, but overlapping areas for the three dimensions discussed in this paper. In the Figure, dimensions change from uncertainties in natural systems, a frequentist perspective and precise information dominating in the left top corner to intentionality in human systems, a bayesian perspective, and imprecise information dominating in the right bottom corner of the Figure.

A specific challenge is to locate costs and potentials of mitigation options in this Figure and to determine an appropriate approach for these issues. If costs and potentials could be precisely defined and statistically tracked, they could be regarded as frequentist and put in the left top corner of the Figure. But as discussed in the previous section, in practice they are not, so we prefer to consider information about these issues as subjective and imprecise and put them in the right bottom corner. Although one can

quarrel about details and exceptions, roughly one can superimpose the hierarchical approach of the IPCC Guidance Note on the matrix (grey shaded arrow), and thus conclude that generally, the hierarchy captures in a stylized way the multi-dimensional nature of the uncertainty information, clearly an improvement over earlier attempts. While preferred communication methods vary going from the top left to the bottom right of the Figure, as discussed above they can be complementary. One could consider in the future if even more explicit acknowledgements of the different dimensions would be desirable and feasible.

Conclusions and recommendations

What lessons can we draw from the evaluation of the treatment of uncertainties in the TAR and the new insights discussed above? We summarize the most important ones in Box 4. Although some scientists in WG I may have a predominantly objective, frequentist perspective, in the TAR both WG I and II eventually chose a subjective definition of uncertainty terms following IPCC guidance documents. That they selected different terminologies we relate to the availability of precise or imprecise information. WG III authors did not use any consistent methodology. We partly explain this by the dominance in this WG of the human choice dimension, which is not explicitly covered by the IPCC guidance. While these differences across WGs may be confusing to readers, we argue that it is, in fact, both legitimate and appropriate. A one-size-fits-all approach would obscure important differences in the type of uncertainties for the users. The questions which are addressed by the three WGs differ, and hence also the approach towards uncertainty should differ. The new IPCC Uncertainty Guidance Note proposes a simple, pragmatic and one-dimensional hierarchy in addressing such differences: from explaining the determinants of uncertainty, to using qualitative terms of understanding, to using quantitative confidence levels, to quantitative likelihood scales, while at the same time carefully and comprehensively explaining the underlying assumptions. We

think the AR4 guidance provides important additional direction compared to the TAR guidance. The guidance could be developed further for future assessments, *inter alia*, by further elaborating the diversity into more tailor-made approaches for different issues or Working Groups.

How can the uncertainty communication in future assessments be improved more specifically? We suggest for WG I that in the next assessment a clear distinction should be made between findings based on observations, findings based on observations and models (such as attribution of climate change to anthropogenic causes) and findings based on future scenarios that involve human choice. This recommendation also applies to the other WGs. The distinction between observations, theory and models was also proposed in the original TAR guidance, which suggested a plot with four axes, corresponding to the confidence in (1) the theory, (2) the observations, (3) the models and (4) the consensus within a field (Giles, 2002). Since theories are usually based on observations and both feed into models, they are not independent of the other categories. We do not suggest theories as a separate category. Instead, we distinguish the human choice category because of its relevance from a policy perspective.

Based on the above considerations we would favor a qualitative approach over the quantitative likelihood scale for issues that involve complex modeling and/or human choice. As Allen et al (2001) note, while it may be more convenient for some purposes if more of the uncertainties were summarized numerically by the IPCC, this approach would no longer provide an accurate representation of current, scientific knowledge. Even for topics for which relatively objective and precise information is available, controversy is possible in the communication of uncertainty information. Recently the so-called “hockey stick” graph was heavily criticized (McIntyre and McKittrick, 2003, 2005). What can be learned from this experience is that even more attention should be given to the selection of graphs (or tables) and explaining why they have been selected,

preferably always including different sources of information in the same graph (or table).

For future assessments we recommend that outliers are given more attention, since these are very relevant for policy makers.

For WG II, we find the usage of a confidence scale appropriate for many issues, but recommend the complementary usage of the qualitative scale, with proper explanation of underlying assumptions, especially for issues which involve model calculations and assumptions about human actions, and following a pedigree approach for key findings. We suggest avoiding the incidental use of the likelihood scale by WG II. Where the use of the likelihood scale is unavoidable, e.g., in case of quotations from WG I, WG II should note the reason for the usage of these terms. Statements that depend on human choices, e.g. in adaptation, have to be clearly acknowledged.

Key questions in WG III deal with quantitative estimates of current and future greenhouse emissions and their reduction potential, and costs of response options. The approach and terminology used when addressing these issues depend on the kind of question to be answered. If the question would be “what are the most likely costs of implementing the Kyoto Protocol?” the answer would necessarily be conditional - depending on a large number of assumptions regarding the design of policies and measures, and demographic, economic and technological developments – but it could theoretically be answered in a subjective fashion, e.g. by expert elicitation. A more interesting question however may be “how do the costs of implementing the Kyoto Protocol depend on the design of policies”? Or, “what are robust options to reach the Kyoto Protocol targets with minimal costs?” These questions require a different, qualitative approach to uncertainties and an explicit recognition of the role of human choice.

In WG III, the difference of views on costs of mitigation between “top-down” economic modelers and “bottom-up” technological experts is a well-known example, where different paradigms lead to widely different results. In the TAR, explaining these differences was one of the key elements of the SPM. The same applies to the SRES scenarios, where different scenario families describe different views on how the future may unfold, rather than attempt to describe a most likely future. New ways of addressing scenario uncertainty are currently being explored, like imprecise probabilities (Tonn, 2005), possibility theory (Ha-Duong, 2005) and utilizing belief functions (Kriegler and Held, 2005). It is unlikely that such new approaches will lead to results in time to be included in the AR4 assessment, but it is likely that results can be included in scenario development work that may feed into a future assessment report.

Box 4: Recommendations for future assessment reports

A. AR4: apply Uncertainty Guidance Note, taking special care to:

- Distinguish between findings based on observations, based on models and based on future scenarios including human choice
- Carefully explain definitions of indicators and assumptions underlying outcomes, including outliers
- For selected key indicators and findings, adopt a more extensive pedigree approach.
- Avoid usage of probabilities for future scenarios
- Use qualitative terminology for describing uncertainty related to costs and potentials of response options

B. Long-term: further enhance uncertainty guidance, including:

- Further develop uncertainty guidance to structure communication methods according to diversity of uncertainty perspectives
- Develop a systematic way of communicating uncertainties related to human choice and intentionality
- Develop a more rigorous and comprehensive process of analysing uncertainties focussing on the key findings, e.g. applying (elements of) the NUSAP approach

Describing and explaining outliers should get more attention. For example, with usually wide ranges of estimates for costs of options proponents of mitigation measure tend to use the lowest estimates and adversaries the highest. Bringing out more clearly the conditions for these more extreme estimates puts the results more in perspective. We have elaborated on the uncertainties related to potentials and associated costs of options. Most important is to provide appropriate explanations of the various sources of

uncertainties, such as the baseline scenario used, the definition and coverage of potential” and “costs”, and technological improvements assumed.

For the longer term, we recommend that for future assessment reports, the current Guidance be further developed to structure communication methods according to the various uncertainty dimensions, explicitly including methods to deal with uncertainty related to human choice. We suggest that all WGs adopt more thorough procedures for analyzing the “pedigree” of uncertainties affecting their most relevant key findings and outcomes, carefully explaining the basis of differences in outcomes. This would be similar to the “traceability account” that was recommended by Moss and Schneider (2000) for the TAR, but not implemented. Use of a limited pedigree approach would lead to a more diversified and informative treatments of uncertainty in assessment reports. It is already too late in the process to implement this recommendation for the AR4, but it would be quite informative to do a pedigree analysis on selected AR4 findings after its publication. If such an effort were successful, it would enhance the possibility of a formal application of a more comprehensive uncertainty treatment for future IPCC and other assessments, in line with recommendations already formulated for the TAR. In addition, it would be useful to develop a practical guide for how to implement a pedigree approach, for future IPCC or other assessments. Such a guide should be added to the general Guidance.

This paper has focused on one important issue: diversity of methods. A diversified communication of uncertainties with a concise pedigree description for key findings would improve the quality of the assessments because it allows the readers not only to understand how large the uncertainties are, and how confident the assessors are about them, but also what their nature and origin is.

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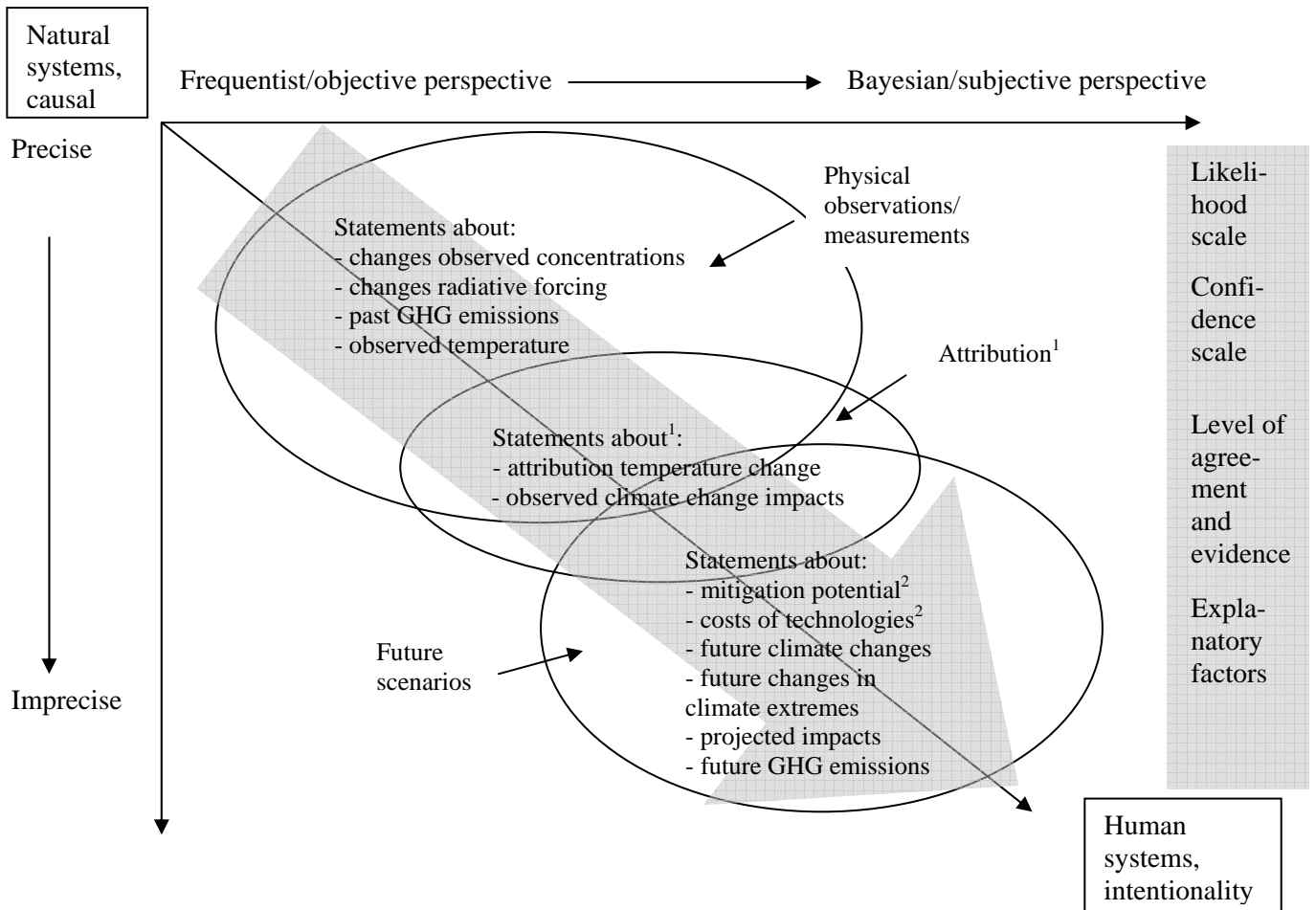
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Location of uncertainty ↓	Level of uncertainty (from determinism, through probability and possibility, to ignorance)			Nature of uncertainty		Qualification of knowledge base			Value-ladenness of choices		
	Statistical uncertainty	Scenario uncertainty	Recognised ignorance	Epis-temic	Variability	-	0	+	-	0	+
Context											
Expert judgment											
M C D E L	Structure										
	Implementation										
	Parameters										
	Inputs										
Data											
Outputs											

Figure 1. A typology of uncertainty, represented as an uncertainty matrix. Adapted from Janssen et al. 2003.



¹ Attribution of temperature change to anthropogenic causes, attribution of ecosystem and other changes to climate change.
² These statements could move up and left if there would be full consistency between definitions and assumptions about policies and baseline scenarios.

Figure 2: Approximate relationship between the dominant uncertainty philosophy, precision of information, statements about key IPCC issues, and uncertainty communication approaches

