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"Prediction" or "Projection"?

The Nomenclature of Climate Science

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A survey among climate scientists is used to examine the terminology concerning two key concepts in climate science, namely, *predictions* and *projections*, as used among climate scientists. The survey data suggest that the terminology used by the Intergovernmental Panel on Climate Change is not adopted, or only loosely adopted, by a significant minority of scientists. Contrary to established guidelines, approximately 29% of the respondents associate *probable* developments with projections, and approximately 20% of the respondents associate *possible* developments with predictions.

Keywords: *climate change; climate models; prediction; projection; survey of climate scientists*

In climate sciences, two types of calculations are performed to assess the future climate for the coming decades and centuries. The first type is typically called a *scenario simulation* (Meehl et al., 2005), and the second type is called *decadal climate prediction* (Keenlyside, Latif, Jungclaus, Kornblueh, & Roeckner, 2008). Both activities involve the use of dynamical climate models based on a numerical representation of all relevant processes.

In this article, using the results of a survey of climate scientists (Bray & von Storch, 2008), we examine the use of two technical terms, namely, *prediction* and *projection*, as used by climate scientists when speaking about "simulations of future climate." These two terms are often, inappropriately, interchanged when discussing the science of climate change.

The interest in the deployment of such nomenclature might first appear somewhat trivial, merely a matter of semantics. Both terms, *prediction* and *projections*, are common in conventional scientific discourse as well as in

common speech, but they are subject to different interpretations and connotations. Thus, the use, if not explicitly specified, has the potential to cause problems not only in the communication of climate science in the broader scientific realm but also in the understanding by the public at large, potentially influencing policy decisions, policy design, and policy implementation and public perceptions of climate change.

"Prediction" conveys a sense of certainty while "projection" is associated more with the possibility of something happening given a certain set of plausible, but not necessarily probable, circumstances. A prediction can be used to design specific response strategies, while a projection, or more precisely a series of projections, provides a range on which to consider a range of response strategies. The uncertainty of the assumptions used in making *projections*, which indeed is what climate science often makes, is not always clearly conveyed. For example, a recent book by Mann and Kump (2008), prominent U.S. climate science personalities, is titled, *Dire Predictions: Understanding Global Warming. The Illustrated Guide to the Findings of the IPCC*. This is especially problematic as the International Panel of Climate Change explicitly suggests refraining from the use of the term *prediction*. Gavin Schmidt, the NASA Goddard Institute for Space Studies and Center for Climate Systems Research, provided the following definitions at the Swiss Global Change Day, 2008: "Predictions: Estimated outcomes under highly specific conditions—not restricted to the future! Projections: Predictions conditional on a future scenario (forced component). Forecasts: Predictions dependent on scenario and initial conditions" (Schmidt, 2008, Slide 5). The seemingly interchangeable use of the terms, while perhaps meaningful in specialist discourse, loses it nuances when presented to a less specialist audience. This potential for confusion is obvious in the following example of sea level rise. Assuming that the sea level in the Netherlands would rise by 50 cm by the end of this century is what the Intergovernmental Panel on Climate Change (IPCC) suggests as a possibility when atmospheric greenhouse gas concentrations continue to rise—as considered plausible by economists—this is one projection; assuming an efficient reduction of emissions, the projection would indicate a lesser rise—another projection; if the melting of the ice sheets is faster than often believed, then a group of experts do not rule out a sea level rise of 1.30 m for the Dutch coast—yet another projection (Vellinga et al., 2008). Obviously, the public response to a 1.30-m sea level rise (as compared with the 50 cm rise) at the end of this century as a "probable" development (a prediction) would be very different than when this number is declared possible but not really likely (a projection).

Predictions or Forecasts; Projections or Scenarios

Before analyzing how climate scientists use the terms, we first clarify the climate model calculations of which we speak and then assess how the terms are typically employed in the broader patterns of communication, starting with lay definitions found in everyday discourse and working through to the more specific operational definitions of the IPCC and other scientists.

In the calculation of both "decadal forecasts" and "scenario simulations," an *initial state* of the climate system—ocean, atmosphere, cryosphere, and so on—is needed, as is a scenario of changing forcing conditions, such as the quantity of greenhouse gases in the atmosphere according to patterns of human behavior. The details of the state of the atmosphere at the initial time (the start of the model run) have little if any impact on modeled climate development after a few weeks of simulated time. The details of the initial soil conditions become insignificant after the simulation of a few years, those of the ocean after many years or even decades. The state of the ice sheets might influence the development of the climate system for much longer times.

In both cases of constructing perspectives for the climatic future, "decadal forecasts" and "scenario simulations," certain prescriptions about the future development of some "external forcings" are needed. Foremost among these are the release of climatically relevant substances into the atmosphere.

Consequently, the development of the climate system, as simulated by the model run, is determined by the initial state of the climate system, by external forcing, and by the inherently unpredictable (internal) variability of the climate system. During an *initial phase* of this development, the climate system is dominated by the initial state, allowing for the specification of the "most probable" development of the climate system. The length of this phase is unknown, but arguably not more than a few decades. As the simulated time increases, the highly uncertain external forcings and internal variability become the dominant factors in determining the simulation of future climate. This results in the ability to generate *short-term predictions* and *long-term projections*.

In both cases, any statement about a "probability" hinges on an assessment of the probability of the conditioning elements, namely, the initial state of the climate system and the forcing scenario. Here, a key difference emerges—the initial state is known within given bounds, while the forcing scenario is an educated guess, without an associated probability.[1]

Recently, scientists have made significant progress in exploiting initial state information for determining "decadal forecasts" (cf. Keenlyside et al.,2008). In the case of scenarios, however, the critical element "future emissions" cannot be specified with any accuracy—at least not for an extended time—as the magnitude of emissions depend upon uncertain factors such as human demographic patterns and energy use patterns, to mention just two. Therefore, these developments are presented as "scenarios"(von Storch, 2007), that is, as possible, plausible, and internally consistent, but not necessarily probable, developments. Given that the forcing is not "most probable," but merely "possible," the response of the modeled climate system can only be described as a "possible" and not the "most probable" future state of the climate.

The IPCC provides the following operational definitions for the climate sciences: "A *projection* is a potential future evolution of a quantity or set of quantities" and "A climate *prediction* or climate forecast is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or long-term time scales." The IPCC document continues with the following definition:

> Climate *projections* are distinguished from climate *predictions* in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. (Baede, n.d.)

The terms *projection* and *prediction* also enjoy wide use in the public sphere and in the broader scientific community. *The New Shorter Oxford English Dictionary* (Brown, 1993) provides the following definitions: "*Prediction* refers to the announcement of an event that will occur in the future, to foretell the future; [a forecast]" and "*Forecast* is a conjectural estimate, based on present indications, of something in the future, especially of coming weather; [a prediction]." This is the sense that is most familiar to the public.

The more specialized vocabulary of statistics informs us the following:

> In general, *prediction* is the process of determining the magnitude of statistical variates at some future point of time. In statistical contexts the word may also occur in slightly different meanings; e.g., in a regression equation expressing a dependent variate y in terms of dependent x's, the value given for y by specified values of x's is called the 'predicted' value even when no

> temporal element is involved. 'Projection' is used in two connected senses. (1) In relation to a time series it means a future value calculated according to predetermined changes in the assumptions of the environment. (2) More recently, it has been used in probability theory to denote the conditional expectation of a variate. Since a regression equation gives the expectation of the dependent variate conditional upon values of the predicted ("independent") variates and such equations are used for forecasting or prediction, the usages are connected. (Marriott, 2004)

Indeed, the projections of possible future climate change may be considered *conditional projections*—conditioned on the validity of the assumed forcing scenarios—thus making this complex set of terminology more difficult to use.

The term *prediction* has often been avoided within the global change debate because it can easily be misinterpreted by nonexperts due to its use in numerical weather prediction (Giorgi, 2005).

> Essentially, a projection of climate change differs from a prediction in that a scenario of future emissions is assumed without giving it any specific likelihood of occurrence. A projection thus tells us what the climate response would be when assuming a future forcing scenario. (Giorgi, 2005, pp. 252-253)

For those readers wishing to pursue the use of the terms within the climate sciences, Giorgi (2005) provides an excellent detailed account.

Using Terminology: Empirical Evidence

The following analysis explores the question of how climate scientists perceive the products of their efforts, as a *projection* or as a *prediction.* The results of a recent survey of climate scientists (Bray & von Storch, 2008) are used for the analysis. Invitations were sent to 2,059 potential respondents. The response rate was approximately 18% (375 responses). This response rate for a Web-based survey is within acceptable limits (cf. Tse-Hua & Fan, 2008).

Most of the respondents are employed in an academic-degree-granting institute or in a government/publicly funded, non-degree-granting institute and are involved with the physics of the climate system, including modeling, model development, data acquisition, theory development, and so on, of climate change. As it is this physics-modeling group that produces the literature concerning future climate prospects, the following analysis will assess if they perceive their efforts to produce projections or predictions.

Table 1
A Description of the Most Probable Outcome Best Defines . . .

	Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid				
A projection	79	27.9	29.2	29.2
A prediction	176	62.2	64.9	94.1
Other	16	5.7	5.9	100.0
Total	271	95.8	100.0	
Missing	12	4.2		
Total	283	100.0		

Table 2
A Description of a Possible Outcome Best Defines . . .

	Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid				
A projection	190	67.1	70.4	70.4
A prediction	55	19.4	20.4	90.7
Other	25	8.8	9.3	100.0
Total	270	95.4	100.0	
Missing	13	4.6		
Total	283	100.0		

Consequently, the analysis is based on the subsamples of respondents who stated their place of employment as being an academic-degree-granting institute or a government/publicly funded, non-degree-granting institute. The subsample is further limited to only those claiming the nature of their work to include physics of the climate system (i.e., modeling, model development, data acquisition, theory development, etc.), resulting in a subsample size of 283 respondents.

To gain an understanding of how respondents perceived the meaning of *projection* and *prediction*, two explicit questions were posed in the survey. Respondents were asked to respond to "A description of the most probable outcome best defines (1) a projection; (2) a prediction; (3) Other" and to "A description of a possible outcome best defines a (1) projection; (2) prediction; (3) other." The frequencies of responses are presented in Tables 1 and 2.

Using the IPCC definitions, as presented above, it seems that approximately 29% of the respondents would be prone to misuse or misunderstand the use

Table 3
From the Output of Global Climate Models, Climate Scientists Are More Inclined to Make . . .

	Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid				
A projection	195	68.9	71.7	71.7
A prediction	65	23.0	23.9	95.6
Other	12	4.2	4.4	100.0
Total	272	96.1	100.0	
Missing	11	3.9		
Total	283	100.0		

of the term *prediction.* However, this is with a tendency toward caution, claiming that science does not make predictions and that even the *most probable* outcome is still only a *projection* (Table 1). It is when we turn to the act of pronouncing a possible outcome as being a *prediction* that the inherent possibility of misinformation arises, and about 20% of the climate scientists responded with the claim that a description of a possible outcome does indeed describe a *prediction* (Table 2).

If we move from mere semantics to the more specific products of climate science, we find a similar tendency. Climate scientists were asked, "From the output of global climate models, climate scientists are more inclined to make (1) a projection; (2) a prediction; (3) other." Almost 24% of the respondents in the subsample of climate scientists claim that output of global climate models constitutes *predictions* (see Table 3).

To take the analysis a little deeper and avoid the possibility of confusion over semantics, we take a further subsample of respondents so that the analysis only includes those whose describe a "possible" outcome they define as a *projection*, as per the IPCC operational definition:

> Projections—A projection is a potential future evolution of a quantity or set of quantities, often computed with the aid of a model. Projections are distinguished from *predictions* in order to emphasize that projections involve assumptions concerning, for example, future. . . . Climate projection—A *projection* of the response of the *climate system* to *emission or concentration scenarios* of *greenhouse gases* and *aerosols,* or *radiative forcing* scenarios, often based upon simulations by *climate models.* . . . Climate projections are distinguished from *climate predictions* in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario

Table 4
From the Output of Global Climate Models, Climate Scientists Are More Inclined to Make . . .[a]

	Frequency	Percentage	Valid Percentage	Cumulative Percentage
Valid				
A projection	158	83.2	83.6	83.6
A prediction	28	14.7	14.8	98.4
Other	3	1.6	1.6	100.0
Total	189	99.5	100.0	
Missing	1	.5		
Total	190	100.0		

a. Subsample of respondents = from academic-degree-granting institute or government/publicly funded research institute, non-degree-granting; nature of work best described as physics of the climate system (modeling, model development, data acquisition, theory development, etc.), and description of possible outcomes defines a *projection*.

> used, which are based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realised. (Baede, n.d.)

In short, the subsample is of those scientists who answered that a description of a *possible* outcome best defines a projection; this subsample appears to agree with the IPCC definitions of the terms. Table 4 indicates that still a relatively large proportion (approximately 15%) of the respondents who are aware of the operational definitions as prescribed by the IPCC would claim that model output can be translated into *predictions*.

Conclusion

In conclusion, this brief analysis indicates that many respondents express some confusion concerning the terminology, with approximately 29% of the respondents associating *probable* with *projections* and approximately 20% of the respondents associating *possible* with *prediction.* Furthermore, about 15% of the people working in climate science who accept and recognize the definitions according to the IPCC understand models to produce *predictions*.

It is easy to see the confusion and points of contention when the terminology becomes crucial to complex understanding and interpretation,

as in the case of climate change and subsequent policy decisions. A prediction, in the sense of a probable development, represents a more or less certainty, while a projection conveys a sense of *possible* developments and indicates a range of different, often alternative developments. Yet *prediction* is the common term found in the media: "Sea Level May Rise 40 Percent Higher Than Predicted, Study Says" (Roach, 2006); "Sea Level Rising Faster Than Predicted: Climate-Change Figures Since 1990 Offer Test of IPCC Projections" (Hopkins, 2007); "Climate Change is 'Faster and More Extreme' Than Feared" (Eccleston, 2008). However, in fairness, *prediction* might be the result of translation between science and the media. If such is indeed the case then it is the responsibility of the scientist to make his or her statements explicit.

Predictions can be used to design strategies to best respond to a given development, for example, by enforcing new rules for adaptation (e.g., elevated dyke heights, anticipating a certain increase in storm surge heights at a certain time horizon). Projections, on the other hand, are a tool to describe the range of possible developments, some of which may be remote but cannot be excluded. Thus, projections are a tool to explore the "space of options" (e.g., von Storch, Gönnert, & Meine, 2008). When predictions are misinterpreted as mere possibilities, the informational value of the predictions will not be fully exploited. When projections are mislabeled as "probable" developments, the inherent uncertainty is underestimated and the full range of response options is poorly considered.

Note

1. To make circumstances a bit more complex, the forcing may possibly be predicted for a limited time, for instance, as continuing the recent trend for some time, say a decade or two. Then, a probability is associated with the forcing and, consequently, also with the climate projection.

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