

**DO THE UNCERTAINTY RANGES IN THE IPCC AND U.S.  
NATIONAL ASSESSMENTS ACCOUNT ADEQUATELY FOR  
POSSIBLY OVERLOOKED CLIMATIC INFLUENCES?**

*An Editorial Comment*

In an accompanying editorial essay, Pielke (2002) argues that at least two important forcings have not been treated in the recently published assessments of the Intergovernmental Panel on Climate Change (IPCC, 2001) and the U.S. Global Change Research Program (NAST, 2000, 2001). Pielke opens his essay by suggesting that, if the failure to treat the effects of anthropogenic land cover change and the biological effect of increased carbon dioxide is important, the general circulation model results on which the assessments are based could be realistic for the wrong physical reasons. He concludes his essay by indicating that, unless these processes can be shown to be insignificant, then the assessments are sensitivity studies rather than vulnerability assessments. Several of Pielke's points do indeed merit close examination.

**1. Forcings versus Feedbacks**

Through the course of the three IPCC assessments of climate change science (IPCC, 1990, 1996, 2001), there has been an effort to move beyond consideration of the potential climatic influences of carbon dioxide and other greenhouse gases alone to include consideration of the roles of all possible forcings, including, for example, changes in the loadings of aerosols of various types and the variations of solar radiation. At the same time, the treatment of feedbacks in the models has also been expanded, with attempts being made, for example, to treat the indirect forcing of aerosols created by changing cloud optical properties. Whether the changes in each model's representations of forcings and feedbacks are leading to models and results in which we can have more confidence is, at least to some extent, continually being evaluated through model testing and intercomparison studies. IPCC's (2001) evaluation is that models are indeed improving, but there is also clear recognition that the models are not yet complete and that shortcomings remain.

With respect to forcings, although recent attention of the IPCC has been most focused on the influences of aerosols, the IPCC authors did this year (as opposed to five years ago) accommodate a review comment by Pielke (passed on by the U.S. Government as part of its set of review comments; see [http://www.state.gov/www/global/global\\_issues/climate/000600\\_ipcc1\\_subm.html](http://www.state.gov/www/global/global_issues/climate/000600_ipcc1_subm.html)) that the forcing effects of



land cover change should indeed be considered. Thus, the new IPCC Working Group I report (IPCC, 2001) includes a graphical representation of the various forcing factors and now includes a category for changes in land use, although it considers only the albedo contribution to the potential change in forcing. The IPCC report indicates that this forcing has been about  $-0.2 \text{ W m}^{-2}$  since 1750, with an indication that the range of such studies finds a forcing of from about 0 to  $-0.4 \text{ W m}^{-2}$  and that the overall level of scientific understanding is very low. A recent study by Govindasamy et al. (2001) adds a longer time perspective to this estimate, suggesting that the albedo influence of land cover change over the past 1000 years could have been a factor contributing to the apparent Northern Hemisphere cooling over the last 1000 years of about  $0.02 \text{ }^\circ\text{C century}^{-1}$  evident in the results of, for example, Mann et al. (1999).

Whereas the IPCC suggests that the global average of the land cover effect has been a cooling influence (generally with dark forests replaced by brighter grasslands and deserts), Pielke (2002) cites studies suggesting a wide range of potential biophysical, biogeochemical, and biogeographic effects on the landscape that have the potential of contributing to a net warming influence. These include the effects of changes in vegetation cover on reflectivity, evapotranspiration, hydrology, etc. and the effects of changes in  $\text{CO}_2$  concentration on evapotranspiration, vegetation cover, etc. What seems to be getting murky in these analyses, however, is what should be considered a forcing and what should be considered a feedback. By tradition, the forcing is the initial imposed external influence (usually referenced to the tropopause) and the feedbacks are what happens as a result of adjustments of the system in response to the initial forcing.

When the climate was represented by models incorporating only the physics of the atmosphere and oceans, this was relatively clear-cut (although not always, as for a while the stratospheric temperature adjustment was originally counted as a forcing when energy balance models were being used but was later considered part of the feedbacks when explicitly treated in the GCMs). Now that interactive land surface vegetation and biogeochemical cycles are being included in Earth system models, it is more difficult to draw the line. For example, the new Hadley Centre model (Cox et al., 2000) includes, in its projections of future changes, interactive  $\text{CO}_2$  and vegetation, incorporating most of the processes as feedbacks (e.g.  $\text{CO}_2$  fertilization) that Pielke is suggesting be considered as part of the imposed forcings. In recognition, perhaps, of the number and types of processes related to land cover that are now being treated in GCMs as feedbacks, the IPCC has included as a forcing only the initial change in reflectivity caused by changes in land cover (e.g. by deforestation). Pielke is correct that many models have not included a number of these feedbacks, so perhaps the various processes should instead have been considered external forcing factors, but this is no longer as convincingly the case. Further, feedbacks can be positive as well as negative (e.g. Betts 2000). However, in cases where the effects of changes in land cover are being investigated, it may well be that the initial effect of changes in, for example, evapotranspiration, should

be considered a forcing rather than a response when multiplying the forcing by a climate sensitivity to get an estimate of the expected response, although this would require developing an estimate of the equivalent change in tropospheric radiative flux if this formulation is to be maintained.

Until the most recent IPCC report, the way through this thicket was to presume that the range of climate sensitivities of 1.5 to 4.5 °C per CO<sub>2</sub> doubling accounted for both uncertainties in treatments of the feedbacks that were included in the models and also provided an allowance for feedbacks that were not included in the models. This approach was justified on the grounds that the sensitivity range was derived not only from the results of GCMs, but was also consistent with the historical record and paleoclimatic evidence. That is, if the sensitivity is greater than about 4.5 °C, then the global average temperature would likely have been bouncing all over the place as a result of changes in the frequency of volcanic eruptions or of relatively small changes in the solar output; conversely, if the sensitivity is less than about 1.5 °C, then it is virtually impossible to explain glacial cycling given the forcings of which we are aware. Based on this perspective, then, projections for the 21st century made by the IPCC in earlier assessments, even though they did not explicitly include changes in land cover and related feedbacks, could be said to have included an allowance, equivalent to a scientific safety factor, for the acknowledged fact that the models were not complete. Were this still the case, Pielke's suggested omissions could be seen as implicitly accounted for in the estimated global average temperature response (although not in the regional response), even if being able to include them directly might have made the projections somewhat more accurate.

However, the approach has changed in the IPCC Third Assessment Report. With very little real discussion of its significance being included in the report, there has been a change in how the projected range of temperatures for the year 2100 is developed. Rather than use the time-tested approach that has been used since the Charney report (NRC, 1979), this time the IPCC has generated an estimate of its range of projected temperatures based on results from seven GCMs that have a range of climate sensitivities. Basically, what was done, as has been done in the past, was to use an energy balance model to estimate the climate sensitivity (and other climatic factors, including especially the rate of ocean heat uptake) for each of a set of GCMs run on a particular emissions scenario (or scenarios). The estimated climate sensitivities for the seven models ranged from 1.7 to 4.2 °C for a doubling of the CO<sub>2</sub> concentration. While it is interesting that these results all fell within the traditional 1.5 to 4.5 °C range, the new wrinkle in IPCC (2001) was to use this range of sensitivities as the basis for projecting the range of model-derived changes in global average temperature.

It seems to me that this decision introduces a number of problems (and a number of these points were unsuccessfully made to the IPCC authors in comments during the later stages of the review process):

- (a) The temperature projections of a warming of 1.4 to 5.8 °C in 2100 as given in IPCC (2001) are now not directly comparable to the results from earlier assessments in that the estimation technique has changed. While the primary reasons for the change from the IPCC (1996) estimated range of 1 to 3.5 °C were the changes in the projected aerosol loading (mainly due to projected reductions in sulfate emissions) and, secondarily, in the projected changes in tropospheric ozone concentrations, there is an element of the change due to the change of technique for developing the estimate; unfortunately, this contribution is not indicated explicitly. While IPCC can call each of the derived ranges their best estimates, even though prepared using different techniques, it seems to me that it would have been helpful to more fully discuss the ramifications of this change in approach.
- (b) Although the fitting technique was used on 7 of the 9 models for which results are presented in IPCC (2001), it did not work for one model because its apparent sensitivity seemed to change over time (which might occur if some feedbacks – like the melting of Arctic sea ice – are not smoothly varying) and was not applied to another due to incomplete information at the time of analysis. An important issue in applying this technique is that the range of sensitivities will depend on which models are included and which are not. What is to happen as new models come along, as old models are withdrawn, etc.? In addition, because the average of the estimates of climate sensitivity was used by the IPCC to suggest a central temperature range, the average sensitivity (which happened this time to be 2.8 °C and thus conveniently split the IPCC (1990) value of 3.0 °C and the IPCC (1996) value of 2.5 °C) could well change over time as the mix of models changes. What we face for the future seems to me to be an unstable range of estimates, even in the absence of changes in emissions scenarios. While use of a probabilistic approach (e.g. Wigley and Raper 2001) may help to stabilize the estimates, aspects of this problem will still remain.
- (c) Of particular relevance for the discussion here is that it is most assuredly clear that the models are not now complete. There would seem to be no basis for thinking that the set of 7 models represents both the upper and lower bound of possible responses, especially because each model is likely designed to aim for a central value of sensitivity rather than a bounding value. Hence, there is no safety factor, except perhaps by chance, that would allow for the net effect of the feedback factors of processes that are not yet included being to push the sensitivity beyond the bounds provided by the 7 models.
- (d) Finally, the use of the instrumental and paleoclimatic records has been changed. Rather than these data being used in a complementary way to derive empirically based bounds of the climate sensitivity, these data are instead used to create filters through which the models must pass in order to be considered sufficiently verified to be included in the considered set of models. That is, it is expected that, as a condition of their inclusion, the models should provide at

least a reasonable representation of the 20th century changes in temperature, and it is likely in the near future it will be expected that they also participate in simulating paleoclimatic variations in climate (e.g., as reported by the Paleoclimate Model Intercomparison Project, Jousame and Taylor, 2000). This is clearly important to work toward; however, it does introduce all sorts of issues about the validity of the tests due to limits in the understanding of the causes and mechanisms of past changes in climate. Such tests also introduce some arbitrariness. We could, for example, surely find tests that all models will fail. As one example, we could insist that the models replicated the Cretaceous; however, because we do not yet understand how the poles could have been so warm without the tropics being warmer, a question would arise about whether the models were missing feedbacks or forcings. At the same time, existing models can explain quite a number of features of climatic changes and variations, and so clearly merit some level of confidence.

As part of the final IPCC revision process, the U.S. Government asked that consideration be given to adding lines to the diagram showing what the projected temperature changes would be for climate sensitivities of 1.5 and 4.5°C, thereby trying to create outer limits consistent with previous assessments. This turned out not to be possible because the fittings with the simple model also involve matching multiple factors for each model, and so how to define the limiting cases was not straightforward (see IPCC, 2001, p. 577). We are thus left with a new range of projected temperature increases that are entirely model-based, which is actually a charge some critics have made incorrectly in the past, but which is now closer to being the situation. What is particularly interesting now, however, is that the creation of tests for models based on observations has likely improved the overall credibility of the set of models. This process has also resulted in a somewhat narrower rather than a wider band of possible sensitivities, a situation that had been hoped for in the past. That this is starting to occur, albeit with the misgivings indicated above, is encouraging.

## 2. Prediction versus Projection

Based on the failure to treat the various land cover processes that are suggested, Pielke (2002) also suggests that '[i]f climate prediction is not possible beyond some time scale, a focus on vulnerability is the preferred scientific approach to provide policymakers with useful information'. This statement seems to me to confound two issues that merit further attention.

Regarding the first, both IPCC and the U.S. National Assessment are very careful in their usage of the word *projection* rather than *prediction*. For these groups, the distinction is meant to convey a very significant difference that is too often being ignored by critics of these reports. Acknowledging Pielke's point that at least some dictionaries are not yet capturing these subtleties (although my 1999 Webster's II

New College Dictionary defines projection as a ‘plan for a future course of action’ rather than a prediction), I would argue that the differences in these two words are roughly as follows:

- *A prediction is a probabilistic statement that something will happen in the future based on conditions that are known today and assumptions about the physical processes that will determine these changes.* A prediction generally assumes that future changes in factors other than those being predicted will not have a significant influence on what is to happen. In this sense, a prediction is most influenced by the ‘initial conditions’, that is, predictions depend on the current conditions that are known through observations. Thus, a weather prediction indicating a major snowstorm will develop over the next few days is based on the state of the atmosphere today (and its conditions in the recent past) and not on unpredictable changes of other potentially influential factors that serve as ‘boundary conditions’, such as how ocean temperatures or human activities may change over the next few days. A prediction is made probabilistic by accounting for various types of uncertainties, for example, in the accuracy of observations, in the chaotic state of the atmosphere, etc. For decision-makers, what is important is that a prediction is a statement about an event that is likely to occur no matter what they do (i.e., policymakers cannot change tomorrow’s weather).
- *A projection is usually a probabilistic statement that it is possible that something will happen in the future if certain conditions develop.* In contrast to a prediction, a projection specifically allows for significant changes in the set of ‘boundary conditions’ that might influence the prediction. As a result, what emerges are conclusions of the type ‘if this happens, then this is what is expected’. The simplest type of projection is to extrapolate into the future assuming all of the boundary conditions remain the same or that the same trends prevail. For projections extending well out into the future, however, this is often a poor assumption, so scenarios (or story-lines) are developed of what could happen given various assumptions and judgments. For example, IPCC (2001) *projects* a range of possible temperature increases for the 21st century that calculations indicate would result in the event that the world follows a number of plausible story-lines concerning population and economic growth, energy technologies and emissions, and demographics and international relationships (see IPCC, 2000) – but also assuming no agreements to limit emissions due to concerns about climate change. By considering how the resulting changes in atmospheric composition would affect the climate using seven different climate models, each with its own particular climate sensitivity, the projections of climate change accounted, to a reasonable extent, for a wide range of possibilities of both societal development and climate behavior. Given this approach, projections are clearly indications of what could happen if certain assumed conditions prevail in the future – they are neither a predic-

tion nor a forecast of what will or is likely to happen. For decision-makers, a projection is thus an indication of a possibility, and normally of one that could be influenced by their actions.

In contrast to this set of distinctions, Pielke (2002) presents a hierarchy of terms going from sensitivity studies to scenarios to projections to perfect foresight. I would suggest that *prediction* (and even *forecast*) needs to be inserted between *projections* and perfect *foresight*, which is something that may never be achieved in trying to look ahead a week, much less a century or more.

With the definitions for prediction and projection given above, present capabilities suggest some skill for predictions out to seasonal to perhaps interannual time scales due to the dominance of ENSO as a factor in contributing to climate fluctuations (and Landsea and Knaff (2000) even raise questions about whether skillful predictions can be made to these time scales). I am not aware of any scientist arguing that we can predict ahead for a century – in fact, the IPCC Emissions Scenarios report (IPCC, 2000) argues that no preference should be given to any particular one of the possible story-lines (and recognizes that the actual outcome will likely be different than all of them). Some years ago the Gallup organization surveyed AGU and AMS members and asked about the confidence to be put in predictions of the future. That there was low confidence should not have been surprising, given how the term ‘prediction’ was being used. I would argue that, therefore, the results should not have been interpreted (as sometimes did occur) as bringing into question the notion that increasing concentrations of greenhouse gases will cause a noticeable warming. A more interesting question might have been ‘What confidence range is encompassed by the range of IPCC projections?’

Confusion still prevails over use of these terms. Recently, for example, some have criticized the IPCC results, citing Hansen et al. (1998) as indicating that reliable predictions of future warming cannot be made because of uncertainties in predictions of radiative forcing (due mainly to uncertainties in emissions scenarios). The charge is actually vacuous in that the IPCC does not claim to be making a reliable prediction for a hundred years ahead. Instead, the IPCC carefully states that it is making projections of a range of possible future conditions based on a range of emissions scenarios and climate sensitivities. There was much interest, but no success, in getting the IPCC participants to provide some sort of probabilistic distribution that might give a more likely set of outcomes (Allen et al., 2001). In lieu of this, IPCC WG I does show a shaded area of possible outcomes that is based on the average climate sensitivity and all possible emission scenarios, but this is also not indicated as a prediction. Indeed, while this range of about 2 to 4.5 °C may encompass what might be the result if events transpired as was assumed, constructing this range using the central value of one parameter (climate sensitivity) and the full range of the other primary parameter (emissions) is not a particularly satisfactory approach. Some investigators (e.g., Schneider, 2001; Reilly et al., 2001; Wigley and Raper, 2001) are now engaged in efforts to develop probabilistic estimates,

although getting full IPCC concurrence on any of these approaches will likely be slow.

The U.S. National Assessment was also circumspect in its use of the terms relating to prognostications. While the IPCC range was generated based on emissions scenarios covering a very wide range, most studies done as part of the National Assessment were able, in the initial effort, to assess the potential consequences of the climatic changes simulated by only two climate models, both of which used essentially the same emissions scenario (albeit one with a net forcing near the middle of IPCC projections for the 21st century). For this reason, the National Assessment Synthesis Team (NAST) explicitly indicated that, in exploring potential vulnerability to climate change, these two model outputs should not be viewed as projections of what is likely to happen, but as plausible scenarios of the types of changes that could occur. Expert judgments were then used as the basis for interpreting the results of the limited set of scenario studies, using a carefully defined lexicon of relative likelihood (NAST 2000, 2001). While using the climate scenarios in, for example, vegetation models does give numerical results, the expert judgments that were made were generalizations from the model simulations – virtually all of the conclusions were qualitative and caveated, recognizing that quantitative projections will require significant further research and evaluation. Nonetheless, the National Assessment does provide some indications of the types of issues that are likely to arise over coming decades in a way that can allow prudent consideration of possible adaptive steps.

In any case, what seems to me to be important is for the scientific community to make sure to clearly differentiate between the terms *prediction* and *projection*. Although these terms are sometimes used interchangeably, the differences are critical and need to be carefully explained to the public (and to some of our colleagues).

### 3. Vulnerability versus Sensitivity

Because the IPCC Assessment and the US National Assessment did not consider climate simulations that included all feedbacks and forcings, Pielke (2002) argues that these efforts must be considered sensitivity studies rather than vulnerability analyses. That is, they represent only a partial treatment of the full set of partial derivatives, and so do not represent the total derivative.

It is certainly true that these two, and all other, assessments are incomplete – there will always be more factors to include, and surely other factors that we do not yet recognize. Thus, strictly speaking, as Pielke suggests, these studies are multi-factor sensitivity studies. However, in considering this issue's importance for decision-makers, what must also be considered is the relative magnitude of the terms that are included and excluded. The question to be asked is whether these analyses include the dominant terms and whether the excluded terms are likely to be small, recognizing that the boundaries here are somewhat fuzzy. While the IPCC



(1990) report focused virtually exclusively on changes in greenhouse gas concentrations, and so is indeed a sensitivity study, the IPCC (1996) report began the treatment of the important influence of changes in sulfate aerosol concentrations, and so is closer to being a projection. For the IPCC (2001) assessment, there is an even more thorough treatment of the various types of aerosols and initial treatments of changes in ozone concentrations and the effects of changes in reflectivity of the land surface (although only for the past. That model simulations including these factors (and the natural influences of volcanic aerosols and solar variations) are now providing quite plausible representations of the climate of the 20th century is a good indication that the set of terms being included is reasonably complete, even if there is surely more to be done (e.g., Stott et al., 2000; IPCC 2001). For example, there does seem to be a need to better explain the warming of the late 19th century (e.g., see Crowley, 2000), but the discrepancies from observations are generally of order one to a few tenths of a degree in global average temperature, and so natural variability could also be playing a role.

With regard to projections for the 21st century, the crucial question is whether the forcings and feedbacks that are now included contain all of the dominant terms. Of the missing terms suggested by Pielke (2002), for example, it is difficult to see how they might grow as rapidly as will the potential influence of the increasing change in the CO<sub>2</sub> concentration if fossil fuel use grows in a largely unconstrained manner. Many studies foresee the CO<sub>2</sub> concentration exceeding first a doubling and then nearing a tripling of the preindustrial value. On the other hand, were there to be massive reductions in CO<sub>2</sub> emissions and an international agreement that sought to keep decadal average temperature changes to less than, say, one or two tenths of a degree, then it is quite likely that a much more complete treatment of all of the various forcing terms would be needed.

#### 4. Summary

In assessing the value of the information for policymakers, the adequacy of what has been done is likely to depend very much on the potential uses for the results. As long as emissions continue on their upward curve, it seems to me that the IPCC results serve quite adequately as plausible futures for considering broad-scale issues of potential consequences and adaptation and the need for mitigation, even if the results are not yet sufficient to really fine-tune a prospective climate management strategy. Were sharp reductions in emissions in prospect, however, providing accurate projections would require much additional consideration of forcings of the type mentioned by Pielke. For this reason, it seems to me particularly important for all of us to be very careful in both what is claimed and what is not, and this requires great care in using and explaining terms and approaches. There are indeed uncertainties and limitations that need to be explained and explored. There are

also, however, at least for some situations, very useful insights that emerge from the studies that the IPCC and National Assessment have been able to undertake.

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