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MODELING CLIMATE CHANGE IN THE ABSENCE OF CLIMATE CHANGE DATA

Editorial Comment

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Practitioners of climate change prediction base many of their future climate scenarios on general circulation models (GCMs), each model with differing assumptions and parameter requirements (c.f. Washington and Meehl, 1984; Hansen *et al.*, 1984; Schlesinger and Zhao, 1988; Manabe and Wetherald, 1987; and reviews by Smith *et al.*, 1992 and Grotch, 1988). For representing the atmosphere, GCMs typically contain equations for calculating motion of particles, thermodynamics and radiation, and continuity of water vapor. Hydrology and heat balance are usually included for continents, and sea ice and heat balance are included for oceans (MacDonald, 1990).

The current issue of this journal contains a paper by Van Blarcum *et al.* (1995) that predicts runoff from nine high-latitude rivers under a doubled CO_2 atmosphere. The paper is important since river flow is an indicator variable for climate change (MacDonald, 1990). The authors show that precipitation will increase under the imposed perturbations and that owing to higher temperatures earlier in the year that cause the snow pack to melt sooner, runoff will also increase. They base their simulations on output from a GCM coupled with an interesting water routing scheme they have devised. (The reader is directed to Hostetler (1994) for a discussion of the problems of coupling hydrologic and atmospheric models.)

Van Blarcum *et al.* present nine plots of observed precipitation, snow mass and river runoff with the model standard run ($1 \times CO_2$ in their notation) shown for each river. They then overlay these plots with results from their doubled CO_2 scenario ($2 \times CO_2$). With regard to runoff, the $2 \times CO_2$ plots show runoff higher than the $1 \times CO_2$ or standard run plots through most of the year. However, some $1 \times CO_2$ runoff plots are higher than the observed curves and agreement is lacking between the observed and the GCM-generated precipitation.

When base data, the observed plots, are not matched by model output, what may one conclude about the GCM that produced the precipitation amounts for the water routing routines? Can models driven by GCM output be trusted to predict results from anticipated climate change?

Climate models have been used to hindcast climate 65 million years ago (Barron *et al.*, 1981) and to forecast precipitation changes in a doubled CO_2 atmosphere (Wigley and Jones, 1985). Climate change models have been linked to other models to predict deforestation (Shukla *et al.*, 1990) and runoff from large catchments (Morassutti, 1992) under increased greenhouse gas scenarios.

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With the advent of GCMs and the climate change predictions they produced, other researchers began to perturb existing models or construct new models to ascertain the effects of increased CO_2 on the global CO_2 budget (Tans *et al.*, 1990), on evapotranspiration (Rosenberg *et al.*, 1989), streamflow (Aston, 1984; Idso and Brazel, 1984; Skiles and Hanson, 1994), water budgets (Bultot *et al.*, 1988a, b; Leavesley, 1994) and on ecosystems (Parton *et al.*, 1994). Given a major conclusion of some climate-change work that CO_2 concentration will double over the next fifty to one hundred years (MacDonald, 1989), others began to predict with field and greenhouse studies, but without models, the consequences of this change for ecosystems (see the review by Bazzaz, 1990).

The above cited studies usually report a means whereby the models used have been verified and validated so that the reader could place some confidence in the conclusions of the studies. For the purposes of this comment, verification is taken to mean that a model produces output of correct magnitude and with the correct units from input of known magnitude and units. Validation is taken to mean that model output has been compared to some standard whether that standard consists of historical records or actual measurements (runoff records are an example of the former and CO_2-fertilized vegetation growth measurements are an example of the latter).

The modeling literature is replete with methodologies for validating simulation models; some early examples are Caswell (1976), Overton (1977), Mankin *et al.* (1975), Gentil and Blake, (1981), Leggett and Williams (1981), Donigian (1983), and Ören (1981). There are also papers that attempt to establish a rubric so that confusion over terminology can be eliminated (Innis *et al.*, 1977; Loehle, 1983). In virtually all published schemes for forcing a model to produce output congruent with some standard, the authors refer to existing data. It is a major tenant in this early validation literature that validation data exist; the idea that validation data may be non-existent is never considered.

In the case of climate change, however, signals from the planet are noisy and difficult to decipher, and there has been a notorious lack of agreement on what they mean. Studies predicting what the hydrosphere and biosphere will be like in a changed world are speculation done in the absence of validation data.

Here a long discourse could be presented about how a predictive model is a calculation tool built according to an hypothesis or theory as to how a system works. One could conclude that validation of a theory is a problem of induction and cite Popper (1965) who argued that proof of a theory by induction is not possible (see the discussion in Loehle, 1983). Hence, predictive models cannot be validated.

Further, one could take the view by Oreskes *et al.* (1994) that validation of numerical models of natural systems is impossible. In their cogently written article and in spite of their conclusion, the authors allow that modeling does have some uses, among them that modeling results can offer evidence to strengthen or corroborate an existing hypothesis, a view different from Popper's.

Setting these arguments aside, one could use the model classification framework propounded by Mankin *et al.* (1975) wherein models can be: (a) useful and valid; (b) useful and invalid; (c) useless and valid; and (d) useless and invalid. In this scheme, a valid model produces output that corresponds to the behavior of the system under all conditions of interest while a useful model accurately represents some of the system behavior under consideration. It has been argued (Levins, 1966) that any model is useful since any plausible relationship probably exists in the modeled system, so a valid but useless model does not exist by definition. An invalid but useful model duplicates some behavior of the system. Also, the authors expect that a valid model has no behavior which does not correspond to the system's behavior. Since such a perfect model does not exist, the real validation question becomes how much of the system behavior the model can predict correctly, all of which assumes there are real data to compare with model output.

Readers of the climate change literature know that GCMs are built and used with current understanding of the physics of the climate system. Models built to use GCM output, likewise are constructed with care. Modelers know detail about facets of the system they model; they have validated components of their models by comparing output to observed data and expect a certain verisimilitude within the model structure and from model output. To answer the questions above, GCMs are constructed with the best understanding and representation of system behavior, they are constantly refined and added to (for example Sud *et al.*, 1990), and many GCMs have been tested by hindcasting earth's previous climates (Broccoli and Manabe, 1987). With the foregoing, GCMs then fall within the invalid but useful classification of Mankin *et al.* (1975). Thus, simulation of future climate is done with the anticipation that some system behavior will be correct.

What lifts future climate prediction out of the realm of omphaloskepsis is that qualitative validation of GCMs and GCM output does occur. One can discern from perusal of the literature several criteria for this kind of evaluation that may be summarized as:

1. The model produces predictions about the system that are so reasonable that a person knowledgeable about the system knew it all along.
2. The model produces predictions about the system that no one thought of before, but once they are pointed out, are so reasonable as to be undeniable.
3. The model produces predictions about the system which are reasonable but point to interesting conclusions that are counterintuitive or contrary to current theory or conjecture.
4. The model produces predictions which violate all reasonableness.

The ramifications for criterion 1 are that such conclusions contribute to the credibility of the model. For 2, such conclusions not only serve to validate the model, but also justify its construction. Regarding 3, the effort that went into building the model justifies itself by pointing out these interesting areas and that these are important for further investigation. And 4 tends to put the model and the underlying assumptions and theories used to construct it under suspicion.

The GCM model used in the Van Blarcum *et al.* study is invalid in the Mankin *et al.* scheme because it does not correctly model every known circumstance of the system; in this instance it has not been tuned to match the observed precipitation records for the study watersheds. Increased river flow for large catchments under increased atmospheric CO_2 has been predicted before (e.g. Bultot *et al.* 1988a, b; Morassutti, 1992), so the same conclusion for high-latitude rivers is new and valuable, but not particularly startling. The water routing and allocation model used by Van Blarcum *et al.* therefore fits under the qualitative evaluation criterion 1 above with the explicit proviso that the study was done in the absence of actual, confirming data. The value of such exercises is that they serve to reinforce other studies of river flow under increased CO_2 concentrations; that many studies have the same results tends to lend credence to the conclusion of increased river flow. Other values of such studies are that continued discussion of model sensitivities is stimulated, model assumptions are brought into question and the need for further model refinement is shown.

Climate change prediction exercises are done with invalid GCMs and in the absence of validation data. Until such time as concrete climate change data become available, particularly for runoff and river flow, validation of GCM output will remain a qualitative exercise. Authors using GCM output need to state the confidence they place in those predictions and the reasons for their confidence.

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