CALCULATING THE CLIMATIC IMPACTS OF INCREASED CO$_2$: THE ISSUE OF MODEL VALIDATION

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ABSTRACT

It is commonly believed that increases in man-made greenhouse gases could cause large increases in surface and lower atmospheric temperatures with disastrous global and regional environmental consequences. Because the expected human-made climate forcings are relatively small when compared to various other natural (both internal and external) background and forcing factors, we focus on the important question of climate model validation. We review common deficiencies in general circulation model calculations of atmospheric temperature, surface temperature, precipitation and their complex space-time variability associated with the multiply interacting climate components and feedbacks. These deficiencies also impact our understanding of how Earth’s climate responses to external forcing agents such as the natural variations of incoming radiant and particle energies linked to changes in the Sun. We also review examples of expected climatic effects of anthropogenic CO$_2$ forcing.

1. Some Difficulties in Simulating Climate Variables

Consider the nominal, globally-averaged number of 2.5 W m$^{-2}$ that is associated with the total radiative warming by all anthropogenic greenhouse gases (GHGs). Or, a doubling of CO$_2$ concentration$^1$ uniformly mixed throughout the atmosphere that adds about 4 W m$^{-2}$ to the troposphere-surface system.

In order to appreciate the scientific difficulties associated with finding climatic changes induced by the anthropogenic CO$_2$ forcing, one may start by analyzing the energy budget of the climate system. First, consider the “artificial flux adjustments$^2$, some as large as 100 W m$^{-2}$ locally, utilized by certain GCMs to minimize unwanted drift in the ocean-atmosphere coupled system (e.g., Murphy 1995; Glecker & Weare 1997; Cai & Gordon 1999; Yu & Mechoso 1999). Next, consider the uncertain global energy budgets that vary by at least 10 W m$^{-2}$ in the empirically deduced fluxes of shortwave and longwave radiation, and latent and sensible heat within the surface-atmosphere system (see Table 1 of Kiehl & Trenberth 1997).

These artificially-modified and uncertain energy balance components impose severe constraints on our ability to find the climatic imprint of a mere 4 W m$^{-2}$ associated with anthropogenic CO$_2$ forcing over 100 to 200 years. Those uncertainties explain why all current GCM studies of the climatic impacts of increased atmospheric CO$_2$ are expressed in terms of relative change based on control, or unforced, experiments that are known a priori to be incomplete in their forcing and feedback physics.$^2$ More important, it is premature to conclude — based only on the rate of change of forcing (e.g., 4 W m$^{-2}$ for anthropogenic CO$_2$ versus the 0.4 W m$^{-2}$ for July insolation changes at 60°N by the Earth’s

$^1$In addition to the heat flux adjustment considered here, nonphysical flux adjustments for freshwater, salinity and wind stress (momentum) are also applied in many contemporary GCMs.

$^2$In Soon et al. (1999), we briefly summarized the problems associated with, for example, models’ underestimation or incorrect prediction of natural climate change on decade to century timescales. Some of the problems may be connected to difficulties in dealing with many of the suspected climate forcings, such as volcanic eruptions, stratospheric ozone variations, sulfate aerosol changes and solar particle and light variations. Another strongly coupled predicament is the inability of short climate records to capture the essential range of natural variability that would provide confidence in probability assessments of potential climatic changes on decades to centuries.

Fig. 1.— (a) Illustration of the cold-temperature bias problem in the troposphere in simulations produced by 14 different GCMs. Indicated in each box are the model temperature biases relative to observations [From Johnson 1997]. Regions 1, 3 and 5 gave unanimous verdicts for the models’ cold bias. (b) Note that the cold-bias problem (most GCMs curves lie to the left of the observed temperature line labeled TOVS) extends into the stratosphere. [From Pawson et al. 2000]

orbital variations in about 100 years as contrasted by Houghton 1991) — that the climatic effects of man-made CO2 will overwhelm the more persistent effects of a positional change in the Earth’s rotation axis and orbit. The latter type of climate change is suspected to be the cause of historical glacial and inter-glacial climate oscillations, while the potential influence of added CO2 can only be guessed from our experiences in climate modeling.

Historical evidence also indicates that large, abrupt climatic change occurs naturally and not uncommonly (e.g., Alley 2000). In historical records, phase differences seen between atmospheric CO2 and proxy-temperature indicate that atmospheric CO2 sometimes follows rather than leads temperature and biosphere changes (e.g., Priem 1997; Dettinger & Ghil 1998; Fischer et al. 1999; Indermühle et al. 1999). Our point is that in order to have the anthropogenic or natural CO2 forcing as the cause or trigger for rapid climate change, various complex climatic feedback and amplification mechanisms must operate. Most of those mechanisms for rapid climatic change are neither sufficiently known nor understood (e.g., Marotzke 2000; Stocker & Marchal 2000).

[Apparently, a fast trigger like increased atmospheric methane from rapid release of trapped methane hydrates in permafrosts and on continental margins may be a key ingredient for amplification or feedback leading to large climatic change (Kennett et al. 2000).]

If natural and largely uncontrollable factors that yield rapid climate change are common, are humans capable of actively modifying climate for the better? Such a question has been posed and cautiously answered in the negative, e.g., by Kellogg & Schneider (1974). Given current concerns about rapid climate change, several geoengineering proposals are being revived and debated in the literatures (e.g., Schneider 1996; Govindasamy & Caldeira 2000). We argue that even if climate is hyper-sensitive to small perturbations in radiative forcing, the task of understanding climate processes must still be first accomplished before any effective actions can be taken.
1.1. Temperature

How well do GCMs actually simulate atmospheric temperatures? As emphasized by Johnson (1997), it has been known since IPCC (1990) that all GCMs suffer from the "general coldness problem," particularly in the lower tropical troposphere and upper polar troposphere (regions 1, 3 and 5 in Figure 1a). This problem exists in 104 out of 105 possible outcomes from 35 different simulations by 14 climate models. Boer et al. (1992) have labeled such common deficiencies as 'systematic,' 'tenacious,' 'insensitive,' 'universal,' and 'essential.'

What causes the systematic errors? Johnson (1997) suggested that temperature responses of GCMs could suffer from extreme sensitivity to systematic aphysical entropy sources introduced by spurious numerical diffusion, Gibbs oscillations and inadequacy of sub-grid-scale parameterizations. The analysis of Egger (1999) seems to support this suggestion and calls for the evaluation of high order statistical moments like entropies to check on the quality of numerical schemes in climate models.

The coldness problem also extends to the stratosphere (Figure 1b), where Pawson et al. (2000) showed that the cold bias is more uniformly distributed. Therefore, they suggest that this particular problem is most likely associated with underestimation of radiative heating rates (i.e., too little absorption of solar radiation by ozone in the near infrared) or too much longwave emission in the middle atmosphere. Other needed critical improvements relate to the physical representation of gravity wave momentum deposition in the stratosphere and mesosphere, as well as problems associated with the generation of gravity waves in the troposphere (McIntyre 1999).

How about surface temperatures? Notable here is the recent evaluation by Bell et al. (2000) of the interannual changes in surface temperature of the control (unforced) experiments from 16 different coupled ocean-atmosphere GCMs of the CMIP. Bell et al. found that the majority of the GCMs significantly underestimate the observed, detrended global surface temperature variability over the oceans (Figure 2's panel b) while overestimating the variability over land (Figure 2's panel c). The most decisive illustration of the biased results from all GCMs comes from the ratio of the over-land to over-ocean temperature variability in panel (d) of Figure 2. The authors mention factors such as external forcing agents (CO₂, solar variability and volcanic eruption) and GCMs' underestimation of ENSO variability as possible causes of the systematic discrepancy between observed and GCM-predicted interannual temperature changes. They eventually pin the discrepancy to non-physical representations of land surfaces that lead to low soil moisture (which yields artificially greater land temperature variability) than more realistic land surface schemes. Bell et al. also point out another problem faced by many GCMs: too much variability in the model's surface temperatures both over land and sea at high latitudes. Here, excessive interannual variability in the coverage of snow and sea ice in the GCMs is noted.

Fig. 2.— Comparisons of detrended 1959-1998 observed surface temperature variability with the unforced results from 16 different GCMs of the CMIP. (Temperature variability is calculated from the r.m.s. standard deviation of the 40 annually averaged data.) The statistically significant difference in the observed and GCM ratios of the land/ocean variability (panel d) has been shown to be associated with the unphysical parameterization of land surface processes. [From Bell et al. 2000]

The result of Bell et al. (2000) is not surprising,

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4 Coupled Model Intercomparison Project.

5 El Niño-Southern Oscillation.
1.2. Precipitation

Soden (2000) documented another important but puzzling behavior in the current generation of GCMs. In this case, the systematic problem comes from the inability of the ensemble of some 30 different atmospheric GCMs in the AMIP\(^6\) to produce the interannual changes in the precipitation observed over the Tropics (averaged over 30\(^\circ\)N and 30\(^\circ\)S). Figure 3 highlights the important comparison of the agreement for the GCM simulations of the amount of water vapor, tropospheric temperature at 200 mb and outgoing longwave radiation (OLR) versus the disagreement for precipitation and net downward longwave radiation to the surface. This comparison emphasizes that the agreements are fortuitous because the atmospheric GCMs were forced with observed sea surface temperatures (SSTs), while the modeled interannual variabilities of the hydrologic cycles are seriously underestimated by a factor of three to four. From the hint of the relatively constant value of the downward longwave flux reaching the surface (Figure 3’s panel e), Soden (2000) points to possible systematic problems in current GCM representations of low-lying boundary layer clouds. The study, however, cannot exclude possible errors in the precipitation data from satellites and thus calls for improved precipitation products.

Another problem in hydrology is the the unphysical, negative specific humidity (!) associated with the steep topography of the Northern Hemisphere extra-tropics (see Rasch & Williamson 1990; Schneider et al. 1999).

1.3. Clouds

As an illustration of the representation of clouds in GCMs, we show in Figure 4 the parameterization of the large-scale formation of cloud cover that is used in one state-of-the-art GCM (Yang et al. 2000). Cloud cover is very sensitive to relative humidity, \(U\), and to both \(U_s\), the saturated relative humidity within the cloud, and \(U_{gh}\), the threshold relative humidity at which condensation begins. The creators of this GCM discuss, for example, how the formula is used to tune

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\(^{6}\)Atmospheric Modeling Intercomparison Project.
Table 1: Observations and predictions of seasonal and annual Northern Hemisphere (NH) equator-to-pole surface temperature gradients (in °C per 5° latitude; EPG) and ocean-land surface temperature contrasts (in °C; OLC). [From Jain et al. 1999]

<table>
<thead>
<tr>
<th></th>
<th>EPG</th>
<th>OLC</th>
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<tr>
<td></td>
<td>Annual</td>
<td>Summer</td>
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<tr>
<td></td>
<td>(JJA)</td>
<td>(DJF)</td>
</tr>
<tr>
<td>NH observations</td>
<td>-3.1</td>
<td>-2.0</td>
</tr>
<tr>
<td>GCM unforced</td>
<td>-2.9</td>
<td>-1.7</td>
</tr>
<tr>
<td>GCM CO₂-forced</td>
<td>-2.7</td>
<td>-1.6</td>
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Fig. 4.— On the large sensitivity of parameterized cloud cover (contrasted by cases A, B and C) to relative humidity, \( U_r \), and to values of \( U_{\phi} \), the saturated relative humidity within the cloud and \( U_{\phi 0} \), the threshold relative humidity at which condensation begins. [From Yang et al. 2000]

Clearly, the parameterization of cloud formation processes remains a major challenge in the climate modeling enterprise.

2. Expected Outcomes of CO₂ Forcing

Given the difficulties and unknowns in parameterizations of important climatic processes and variables, what do models predict for an increased CO₂ forcing scenario? Let’s look at three examples.

First, is the change in CO₂ forcing expected to alter the character of the seasonal temperature cycle? If so, how do predictions compare to what has been observed, at least over the last few decades?

Jain et al. (1999) examined this question by considering three parameters for the Northern Hemisphere (NH) surface temperature: (a) the mean temperature’s amplitude and phase; (b) the equator-to-pole surface temperature gradient (EPG); and (c) the ocean-land surface temperature contrast (OLC).

A comparison between observed and modeled EPG and OLC climatologies is summarized in Table 1. The results show that changes expected from the added CO₂ forcing are typically smaller than the differences between the unforced GCM and observed values in EPG and OLC. So, detecting differential CO₂ effects in seasonal differences in EPG and OLC is not straightforward.

Jain et al. (1999) also found significant differences between observed interannual and decadal trends for both EPG and OLC and results from CO₂-forced climate
Fig. 5.— Predicted large changes (20-50% reductions in overturning rate by 2100 AD) in the thermohaline circulation (THC) under [a] a CO$_2$-forced scenario for six different coupled climate models [from Rahmstorf 1999] and [b] a state-of-the-art MPI GCM with improved spatial resolution of tropical ocean [from Latif et al. 2000]. The quantity shown is the maximum North Atlantic overturning flowrate in Svedrups ($10^6$ m$^3$ s$^{-1}$) at a depth of about 2000 m. Apparently, with an improved representation of the air-sea interactions in the Tropics, the major weakening (or even collapse under stronger and persistent forcing) of the THC predicted by earlier GCMs no longer holds true.

experiments. For example, the CO$_2$-forced run predicts a statistically significant increase in amplitude (and delay in phase) for the seasonal cycle of OLC, but no such change is observed. Worst yet, even the unforced experiment yielded a statistically significant increase in the amplitude of the OLC seasonal cycle, which makes the search for a CO$_2$-forced signal in this parameter almost impossible. Furthermore, it was found that the amplitude of the annual cycle of the NH surface temperature decreases in a way consistent with CO$_2$-forced experiments. But the observed trend in seasonal phase shows an advance of the seasons, contradicting the delay predicted by the models. Jain et al. offered three explanations for the disagreement: model flux corrections, significant impact of low-frequency natural variability and sampling limitation in observational data. Therefore, seasonal cycles are probably not useful “fingerprints” for the impact of anthropogenic CO$_2$.

Next, consider clouds. Given the complexity of representing relevant processes for clouds, can one find a probable CO$_2$-forced imprint in them?

First, as Yao & Del Gino (1999) have commented, it is misleading to claim that under a CO$_2$-induced warming climate with more evaporation, an increasing cloud cover is expected, because cloud cover depends more closely on relative humidity than specific humidity. Under CO$_2$ doubling experiments with different parameterization schemes, Yao & Del Gino (1999) predicted a decrease in global cloud cover but showed that there is an increase in middle- and high-latitude continental cloudiness. They also cautioned that because “a physical basis for parameterizing cloud cover does not yet exist,” all predictions about cloud changes should be viewed critically.

Other authors, like Senior (1999), have emphasized the importance of including parameterizations of interactive cloud radiative properties and called for a common diagnostic outputlike the water path length within the cloud in control (unforced) experiments. Rotstayn (1999) implemented detailed microphysical processes of a prognostic cloud scheme in a GCM and found a large difference in the climate sensitivity from an experiment with a diagnostic treatment of clouds. A stronger water vapor feedback was noted in the run with the prognostic cloud scheme than in the run with the diagnostic scheme, which in turn caused a strong upward shift of the tropopause upon warming. Rotstayn found that an artificial restriction on the maximum heights of high clouds in the diagnostic scheme largely explained the differences in the climatic responses. It is in the midst of this incremental learning that we conclude there are no reliable predictions of expected responses of clouds to increased CO$_2$ in the air.
Third, consider the oceans. Under an increased atmospheric CO$_2$ forcing, one commonly predicted transient response is the weakening of the North Atlantic thermohaline circulation (THC) owing to the net increase in freshwater fluxes (e.g., Dixon et al. 1999; Rahmstorf & Ganopolski 1999; Russell & Rind 1999; Wood et al. 1999; see Figure 5a). In one GCM experiment, Russell & Rind (1999) explained that despite a global warming of 1.4°C near the time of CO$_2$ doubling, large regional coolings of up to 4°C occurred in both the North Atlantic Ocean (56-80°N, 35°W-45°E) and South Pacific (near Ross Sea, 60-72°S, 165°E-115°W),\(^7\) because of reduced meridional poleward heat transfer over the North Atlantic and local convection over the South Pacific.

More important, and somewhat surprising, Latif et al. (2000) have just reported a new stabilization mechanism that results in no THC weakening (see Figure 5b). Their MPI\(^8\) state-of-the-art coupled ocean-atmosphere GCM resolved the tropical oceans at a meridional scale of 0.5° rather than the more typical scale of 2-6°, and made the MPI GCM better adapted for studying the ENSO phenomenon. When forced under an increasing CO$_2$ scenario, it produced no weakening of the THC. Latif et al. showed that anomalously high salinities in the tropical Atlantic (initiated by excess freshening over the equatorial Pacific) were advected poleward to the sinking region of the THC, and the effect is apparently sufficient to compensate for local increases in freshwater influx. Hence, with the additional stabilizing degree of freedom from the tropical oceans, the THC remains unchanged in the CO$_2$-forced experiment. Thus, there is no credible expectation of a "disastrous" change in the oceanic circulation over the North Atlantic under a CO$_2$-forced climate.

### 3. Discussion

Many questions remain open regarding what one can conclude from the current generation of GCMs about the CO$_2$-induced modifications of Earth’s climate. The climatic impacts of increases in atmospheric CO$_2$ are not robustly ascertained. In fact, even the range of modeled global warming remains large and not physically well constrained (e.g., Forest et al. 2000). For example, the aggregate of various GCMs gives a global climate sensitivity that ranges from 1.5 to 4.5°C (e.g., p. 34 of IPCC 1996) for an equilibrium response to a doubling of atmospheric CO$_2$ concentration. Räisänen (1999) optimistically emphasized that many of the seemingly qualitative inter-model disagreements in CO$_2$-forced climate responses (including differing signs of predicted response in variables such as precipitation and soil moisture) could be attributed largely to differences in the internal variabilities of different climate models.

On the other hand, Forest et al. (2000) utilized the MIT statistical-dynamical climate model to quantify the probability of expected outcomes by performing a large number of sensitivity runs, i.e., by varying the cloud feedback and the rate of heat uptake by the deep ocean. They found that the IPCC’s range of equilibrium climate sensitivity of 1.5 to 4.5°C corresponds roughly to only an 80% confidence interval under a particular optimal value of global-mean vertical thermal diffusivity below the ocean’s mixed layer. The 95% probability range for the climate sensitivity is quantified by Forest et al. to be 0.7 to 5.1°C. In the final analysis, Forest et al. (2000) gave the more relevant result for transient responses to a doubling of atmospheric CO$_2$ to be an increase in global temperature between 0.5 and 3.3°C at the 95% confidence level.

**Attribution of causes of recent climatic change.** Other more specific attempts to “fingerprint” CO$_2$ forcing by comparing observed and modeled changes in the structure of vertical temperature profiles\(^9\) have

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\(^7\) See, however, a later paper by Russell et al. (2000), where the predicted regional changes over the Southern Ocean are admitted to be unreliable because of the model’s excessive sea ice variability. The high-latitude southern ocean is also well-documented to suffer from large climate drift (Cai & Gordon 1999). For example, within 100 years of coupling the atmosphere to the ocean, the Antarctic Circumpolar Current intensifies by 30 Sv (from 157 to 187 Sv), despite the use of flux adjustment. Cai & Gordon identified the instability of convection pattern in the Southern Ocean to be the primary cause of the problem.

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\(^9\) Here, we also wish to add that the commonly misapplied claim of surface or tropospheric warming together with (lower) stratospheric cooling as a “fingerprint” of CO$_2$ is in fact false. Such a pattern of change is a natural behavior of the atmosphere associated with potential vorticity anomalies in the upper air’s flow structure (see e.g., Hoskins et al. 1985; Liu & Schuurmans 1990). This note is relevant because it precludes any affirmative statements being made about the unique detection of anthropogenic CO$_2$ “fingerprints” unless more is understood about natural atmospheric variability.
revealed more insights into areas for improved model physics, such as the unrealistically coherent coupling between the tropical lapse rate and mean temperature for variability over timescales of 3 to 10 years (e.g., Gillett et al. 2000). Recent efforts, such as that of Bengtsson et al. (1999), have highlighted the inconsistency between the differing observed surface and tropospheric temperature trends and the simulated GCM trends that include forcing factors like the combined anthropogenic GHGs, anthropogenic sulfate aerosols (both direct and indirect effects), stratospheric aerosols from Mount Pinatubo eruption, as well as changes in the distribution of tropospheric and stratospheric ozone. In addition, Roeckner et al. (1999) discuss how adding other forcing components, like direct and indirect aerosol effects, to the GHG forcing has led to a somewhat unexpected weakening in the intensity of the global hydrologic cycle.

*Nonlinear dynamical perspective on climate change.* A somewhat different interpretation of recent climate change is also possible (Corti et al. 1999; Palmer 1999). In an analysis of the Northern Hemisphere’s 500-mb geopotential heights, the authors show that the signal since the 1950s could essentially be projected in terms of the modes of four naturally occurring, shorter-term, atmospheric circulation regimes.\(^{10}\) Then, climate variability, viewed as oscillations among these quasi-stationary weather regimes, can be quantified by changes in the probability density function associated with each regime. Indeed, Palmer and colleagues proposed that the impact of anthropogenic CO\(_2\) forcing may be revealed as a projection onto modes of these natural circulation patterns and weather regimes. But there is no guarantee that the underlying structure of the weather regimes would remain the same under the perturbation of a different or stronger forcing.

Next, the authors showed that recent observed changes could be interpreted primarily as the increasing probability associated with the Cold-Ocean-Warm-Land circulation pattern (COWL regime as earlier studied by Wallace et al. 1995 or regime labeled cluster A in Corti et al. 1999), perhaps consistent with the projection of anthropogenic CO\(_2\) forcing. In this view, the authors proposed to resolve the contentious discrepancy between the rising trend in surface temperature versus the relative constancy of the lower tropospheric temperature (i.e., as summarized in the report of NRC 2000). The rationale employed was that most of the recent hemispheric-mean temperature change is associated with the COWL pattern. And since the COWL pattern is primarily a surface phenomenon, one can therefore expect to find a stronger anthropogenic CO\(_2\)-forced temperature imprint at the surface than in the troposphere. Away from the surface, the land-sea contrast weakens significantly, so that no imprint of anthropogenic thermal forcing anomalies persist there.

None of the current GCMs has yet simulated such a pattern of observed change. The strongest anthropogenic CO\(_2\) pattern of response in GCMs is still expected in the middle to high troposphere, simply because of the dominance of direct radiative effects. How the surface and the column of air in the troposphere are coupled is not well understood. This particular problem is likely to modify conclusions of much recent exploratory research efforts to partition roles between various natural (volcanic, solar and internal unforced climate variability) and anthropogenic forcings (CO\(_2\), sulphate aerosols and ozone) that adopted either instrumental or proxy surface temperatures as their sole evidential constraints (Lean et al. 1995; Soon et al. 1996; Overpeck et al. 1997; Mann et al. 1998; Tett et al. 1999; Andronova & Schlesinger 2000; Crowley 2000).

A further question left unanswered by Corti et al. (1999) is why increased CO\(_2\) should lead to an increase in the residence frequency of the COWL regime. Any of several warming influences may contribute to the positive bias of COWL because the main physical cause of the pattern is the differential heat capacity between land and sea. In this respect, it is important to point out that the COWL pattern is a robust feature of unforced climate experiments under various air-sea coupling schemes tested by Broccoli et al. (1998). But as emphasized by those authors, even though a direct comparison of observations with model-derived unforced patterns and changes “has implications for the detection of climate change, [they] do not intend to attribute the recent warming of Northern Hemisphere land to specific causes.” Broccoli et al. thus concluded that separating forced and unforced changes in observational records is difficult and ambiguous.

Interpreting climate change under such a non-linear dynamical perspective imposes a strong requirement that GCMs accurately simulate natural circulation regimes and their associated variabilities down to regional and synoptic scales.\textsuperscript{11} This particular requirement is especially difficult to fulfill, because the global radiative forcing of a few W m\textsuperscript{-2} expected from anthropogenic CO\textsubscript{2} is so small compared to the uncertain energy budgets of various components of the climate system as well as flux errors in model parameterizations of physical processes. Consequently, significant challenges in numerical weather and climate modeling remain.

\textit{New observational scheme.} To obtain more confidence in climate modeling, a substantial advancement in observational capability is needed. Improved precision, accuracy, and global coverage are all important requirements. For example, Schneider (1994) has estimated that a globally averaged accuracy of at least 0.5 W m\textsuperscript{-2} in net solar-IR radiative forcing is needed in order to realistically resolve the present unacceptably large range of estimates of climate sensitivity. In this respect, Goody \textit{et al.} (1998) have recently proposed the complementary scheme of interferometric measurements of spectrally resolved thermal radiance and radio occultation measurements of refractivity (with help from GPS\textsuperscript{12} satellites) that can achieve global coverage with an absolute accuracy of 1 cm\textsuperscript{-1} in spectral resolution and 0.1 K in thermal brightness temperature. The sensitivity of 0.1 K is needed to quantify expected warming from increased greenhouse gases in one decade, while the resolution of 1 cm\textsuperscript{-1} is needed to aim towards recognizing differences in possible spectral radiance fingerprints among several causes (see e.g., Figures 6 and 7 of Goody \textit{et al.} 1998). With the promised high vertical resolution of about 1 km, the complementary thermal radiances and GPS refractivity measurements may lead to a better understanding of clouds. These observational schemes offer hope, not only to critically test climate model predictions, but to provide for early detection of anthropogenic CO\textsubscript{2} effects before they may become too large.

\footnote{This requirement has led Palmer to say that this possible shift in detection strategy towards very local patterns of change is "the very antithesis of the global greenhouse effect."}

\footnote{Global Positioning System.}

4. Social Comments

This talk has been largely an apology for our lack of understanding of Earth's climate system. To date, we do not know whether man-made CO\textsubscript{2} has caused, or will cause, the climate to change for better or for worse. There is clear evidence for beneficial effects of enhanced CO\textsubscript{2} on plants (Idso & Idso 1994); but the complete aspects of CO\textsubscript{2} impacts on society are not so easily evaluated. There are widely differing views on plausible theoretical expectations of anthropogenic CO\textsubscript{2} effects, ranging from dominant radiative imprints in the upper and middle troposphere (based on GCMs results) to nonlinear dynamical responses. At the current level of understanding, a disastrous global and regional environmental change from increasing atmospheric CO\textsubscript{2} is neither a quantifiable nor a scientific proposition.

As for a second opinion on our evaluation of climate models' systematic errors, the thoughts of Bryson (1993) are applicable: "A model is \textit{nothing more [sic.]} than a formal statement of how the modeler believes that the part of the world of his concern actually works. It may be simple or complex. ... Because of the size and complexity of the climate system, no set of equations, and thus no mathematical model, has yet been devised to describe or simulate adequately the complete behavior of the system. ... it may be many years before computer capacity and \textit{human knowledge [sic.]} are adequate for a reasonable simulation. This is not to say that present computer simulations are useless—they are simply not terribly good yet. For example, the average error of the largest, most complex GCM simulations of the present rainfall is well over 100 percent. The temperature errors are impressively large also—up to twenty degrees Centigrade for Antarctica, ten degrees in the Arctic, and two to five degrees elsewhere. The main models in use all have similar errors, but this is hardly surprising, since they are all essentially clones of each other."

Thus, the problems in our inability to simulate present-day climate change are substantial. The perspective from nonlinear dynamics — which suggests that "confidence in a model used for climate simulation will be increased if the same model is successful when used in a forecasting mode" (IPCC 1990, as quoted in Palmer 1999) — also portends a most difficult task ahead.
Oreskes et al. (1994) has further reminded us that because natural systems are never closed and model results are always non-unique, it is impossible to have a verified and validated numerical climate model. Therefore, the proper role of a model is to challenge existing formulations (i.e., a climate model is built to test proposed mechanisms of climate change) rather than to predict unconstrained scenarios of change by adding CO₂ to the atmosphere.

Available documentary evidence tells us that climate change significantly influences human activity. It is thus high time for us to address the scientific question of whether the reverse influence could really be detectable on a global extent, especially from the increased anthropogenic CO₂ in our air. As a start, it would certainly be helpful for all climate scientists and many more from other fields of research, including economists, social scientists, and law-makers interested in public policy, to begin working together to distinguish between what one may consider climate uncertainties versus what one should admit as climate unknowns.

Acknowledgments

This work was supported by the National Aeronautics and Space Administration (Grant NAG5-7635). W. Soon thanks Manolo Vázquez, chairperson of this first Solar and Space Weather (SOLSPA) Euroconference organizing committee, for the kind invitation and travel support. E. S. P. acknowledges the support of the Long Island University Faculty Research Released Time program.

References


Overpeck, J., and 17 co-authors, Arctic environmental change of the last four centuries, Science, 278, 1251–1256, 1997.


