CLIMATE MODEL SENSITIVITY, PALEOCLIMATE AND FUTURE CLIMATE CHANGE

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ABSTRACT

Radiatively active trace gases such as CO_2, methane, nitrous oxide and chlorofluorocarbons warm the surface-troposphere system by increasing the infrared opacity of the atmosphere. Climate models have been used to estimate the warming associated with future increases in these gases. An important issue is the sensitivity, or the amount of climate response associated with a given amount of radiative forcing. Models currently used for climate change studies differ substantially in their sensitivity, and these differences contribute prominently to the uncertainty in estimating the magnitude and rate of future climate change. The observed climate record can be used to calibrate the sensitivity of climate models. Calibration based on the instrumental record (the last ~100 years) has the advantage of using direct observations of climatic parameters with relatively dense spatial coverage, but suffers from uncertainties about sources of climate forcing other than greenhouse gases and the possibility that natural climate variability may be comparable in magnitude to the greenhouse gas-induced change. In contrast, calibration using paleoclimate data from the late Quaternary involves larger changes in forcing, most of which are relatively well-documented, but is subject to the inherent uncertainties of reconstructing past climate from a variety of sometimes sparsely-distributed proxy data. While better monitoring of ongoing changes in climate forcing and response may be the best way to calibrate climate model sensitivity, paleoclimate information can provide much-needed insights into climate model performance, particularly as improvements occur in the quantity and quality of paleoclimate data.

1. INTRODUCTION

Climate models are among the primary tools used to estimate the possible changes in climate due to anthropogenic greenhouse gases. Because of their importance in this

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regard, a great deal of recent attention has been focused on the issue of climate model sensitivity, or the amount of climate response associated with a given amount of radiative forcing. Some of the work of the Intergovernmental Panel on Climate Change (IPCC) Working Group I concerned the differences in sensitivity among the various climate models that have been used to study anthropogenic climate change (Mitchell et al., 1990).

The development of climate models has generally proceeded toward increased spatial resolution, the addition of interactions with other parts of the climate system (e. g., ocean dynamics, land surface processes) and more detailed, physically-based representations of subgrid scale processes. While these developments are predicated on the belief that they will lead to improved model performance, it is often difficult to determine whether they lead to a more realistic sensitivity, even if they can be shown to improve the simulation of the present climate. After all, the perfect simulation of the present climate is not a sufficient condition for the accurate simulation of climate change associated with a given forcing. Even the simulation of interannual variability, though a very important test of climate model performance (Gates, 1992), may not test model sensitivity to changes in forcing comparable in magnitude to the change in greenhouse gas forcing expected during the next century.

One possible technique for evaluating climate model sensitivity is the use of information about past climate. This essay addresses the viability of this method and attempts to identify its strengths and weaknesses. To provide some perspective, it begins with a brief discussion of the physics of the so-called "greenhouse effect." This is followed by a review of results from studies of the climate response to enhanced greenhouse forcing conducted with a hierarchy of climate models. With that background, the evaluation of climate model sensitivity using the instrumental climate record and the paleoclimate record are discussed. The paper concludes with a discussion of the prospects for improved calibration of model sensitivity.

2. PHYSICS OF THE GREENHOUSE EFFECT

A number of trace constituents of the earth's atmosphere are radiatively active in the thermal infrared portion of the electromagnetic spectrum. The most important of these is CO_2; others include methane, nitrous oxide, and the chlorofluorocarbons CFC-11 and CFC-12. The evidence is strong that human activities are increasing the atmospheric concentrations of these gases. (This is obvious in the case of the CFCs, since they have no natural sources.) While the volumetric increase of CO_2 is much larger than those of the other greenhouse gases, the combined radiative effect of the other gases is comparable due to their infrared absorption properties. Wuebbles and Edmonds (1991) provide a review of the sources (both natural and man-made), sinks and radiative effects of the greenhouse gases.

Increases of greenhouse gases produce a warming of the troposphere by the following mechanism. Assume that the earth is in thermal equilibrium, and thus the incoming solar radiation is balanced by outgoing longwave radiation of equal magnitude. The Stefan-Boltzmann law allows the calculation of an effective radiating temperature (T_e) for the earth that depends only on the amount of incoming radiation and the planetary albedo. The computed T_e of ~255 K is lower than the earth's mean surface temperature of ~288 K; since the tropospheric temperature decreases with height, this implies that the effective radiating level lies well above (5-6 km) the surface. The elevated effective radiating level is due to the presence of greenhouse gases in the atmosphere, which act to shield (by virtue of their infrared opacity) the warmer, lower atmosphere from emitting to space. If greenhouse gas concentrations are increased, the atmosphere becomes more opaque to thermal infrared radiation. This increases the degree of shielding, and raises the altitude of the effective radiating level further still. Thus the longwave emission will take place at a lower temperature, resulting in a decrease in the amount of outgoing radiation. This perturbs the thermal equilibrium. A warming of the troposphere results that raises the temperature at all levels, including the effective radiating level, and thus restores thermal equilibrium (Manabe, 1983).

Feedbacks involving other parts of the climate system can amplify this direct warming. For instance, the increase of temperature results in an increase in saturation vapor pressure and, accordingly, the moisture-holding capacity and water vapor content of the troposphere. Since water vapor is also a greenhouse gas, this leads to a further increase in the infrared opacity of the atmosphere and a further warming by the above mechanism. The existence of this water vapor feedback, which provides an important amplification of climate model sensitivity (Manabe and Wetherald, 1967; Hansen et al., 1984), has been supported by an analysis of observational data (Raval and Ramanathan, 1989). Another important feedback is the snow-ice-albedo feedback, in which the warming results in a decrease of the area of snow and ice cover. Since snow and ice have relatively high surface albedos, more solar radiation is absorbed as a result, leading to a further increase in temperature (Budyko, 1969; Sellers, 1969). The snow-ice-albedo feedback is also positive. Other feedbacks may also be important, such as those involving cloud amount and height (Hansen et al., 1984; Wetherald and Manabe, 1985), but there is more uncertainty surrounding both the sign and magnitude of these feedbacks.

3. CLIMATE MODEL ESTIMATES OF SENSITIVITY TO CO_2

Most climate model studies of the effects of increased greenhouse gases on climate have considered only changes in CO_2. This practice arose at a time when the radiative significance of other trace gases was not widely known. While the combined effects of the other greenhouse gases are important and their increases constitute a significant radiative perturbation, the practice of representing their effect in terms of "equivalent CO_2" continues. Although the vertical distribution of the radiative forcing associated with the other trace gases is different from that of CO_2 (Wang et al., 1991), the rough similarity of their climatic effects in the troposphere suggests that this approximation is not too bad when considering changes in surface air temperature. Thus the climate response to a doubling of atmospheric CO_2 is used in this paper as a benchmark for climate model sensitivity to greenhouse gas perturbations.

Climate models have been used to investigate the impact of greenhouse gases on the earth's climate for more than 25 years. The state of the art has progressed dramatically during this period, from relatively simple one-dimensional models of radiative-convective equilibrium to three-dimensional models of the coupled atmosphere-ocean system. The development of a hierarchy of climate models for the study of climate change due to anthropogenic increases in greenhouse gases has led to a variety of research studies. Most of these can be separated into two categories based on their experimental design. Using terminology taken from the IPCC Scientific Assessment (Cubasch and Cess, 1990), these are equilibrium response studies and time-dependent response studies. Such experiments will be the primary subjects of this section.

Equilibrium response studies typically consist of two climate model integrations, each with a different prescribed greenhouse gas content. These integrations are continued until the simulated climate of each is in balance with its radiative forcing, then the two simulated climates are compared to obtain the response to the change in greenhouse gases. The early studies of the impact of anthropogenic increases in greenhouse gases were equilibrium response studies.

The first of these studies was performed with a radiative-convective model, which treats the climate system as a one-dimensional column. Results from the earliest radiative-convective model experiments (Manabe and Wetherald, 1967) illustrated two of the most fundamental aspects of the climate response to increased CO_2: tropospheric warming and stratospheric cooling. They also identified the role of water vapor feedback in amplifying the climate sensitivity. This and similar experiments also yielded sensitivities of roughly 1.5-2.5 K for the change in surface air temperature resulting from a doubling of CO_2 (Manabe, 1971; Wang et al., 1976; Augustsson and Ramanathan, 1977).

More recent equilibrium response studies have been performed with three-dimensional atmospheric general circulation models coupled with simple models of the ocean mixed layer (e. g., Manabe and Stouffer, 1979, 1980; Hansen et al., 1984; Washington and Meehl, 1984; Wilson and Mitchell, 1987; Schlesinger and Zhao, 1989). These tend to give larger values for the sensitivity to doubled CO_2, ranging from 1.9-5.2 K (Mitchell et al., 1990). The larger sensitivities can be attributed to the ability of these models to represent a wider array of feedbacks, many of which are positive, such as the snow-ice-albedo feedback. Detailed intercomparisons involving climate models from different research groups indicate that differences in their depictions of some of these feedbacks are responsible for the wide range of sensitivities (Cess et al., 1989, 1991).

Time-dependent response studies use models of the coupled atmosphere-ocean system to simulate a change in climate in response to gradually increasing greenhouse gas concentrations. Such gradual increases are similar to what is occurring in the real climate system. A number of time-dependent response studies have been performed, primarily using general circulation models of the atmosphere coupled with dynamical ocean models (e.g., Stouffer et al., 1989; Washington and Meehl, 1989, Cubasch et al., 1992). In addition to providing information about the global rate of warming that occurs in response to a given rate of increase in greenhouse gas concentrations, an important result from these studies has been the identification of important regional variations in the warming rate that are related to the mixing of heat into the deep ocean.

Because only a few modeling groups presently are capable of performing these computationally-demanding time-dependent response studies, simple models of the coupled system have been created for use in parameter studies of the time-dependent response (e. g., Hoffert et al., 1980). As part of the IPCC 1990 Scientific Assessment, one such model was tuned to mimic the behavior of three-dimensional coupled atmosphere-ocean models (Bretherton et al., 1990). This work affirmed that the equilibrium climate model sensitivity exerts a major influence on the rate of warming in response to a given rate of increase of greenhouse gases, and thus remains an important parameter in the study of anthropogenic climate change.

4. USING THE CLIMATE RECORD FOR MODEL CALIBRATION

The determination of climate sensitivity remains an important uncertainty (although certainly not the only one) in estimating the magnitude and rate of future climate change. At present, climate models yield a relatively large spread in their estimates of sensitivity.

In fact, the range of variation of climate model results may represent a lower limit to the true uncertainty, since all models could be lacking some important feedback (either positive or negative) that could move the sensitivity outside this range. The construction of more comprehensive models does not guarantee an improvement in their estimates of climate sensitivity, since many physical processes must be parameterized out of necessity, and the validation of such parameterizations presents a formidable problem.

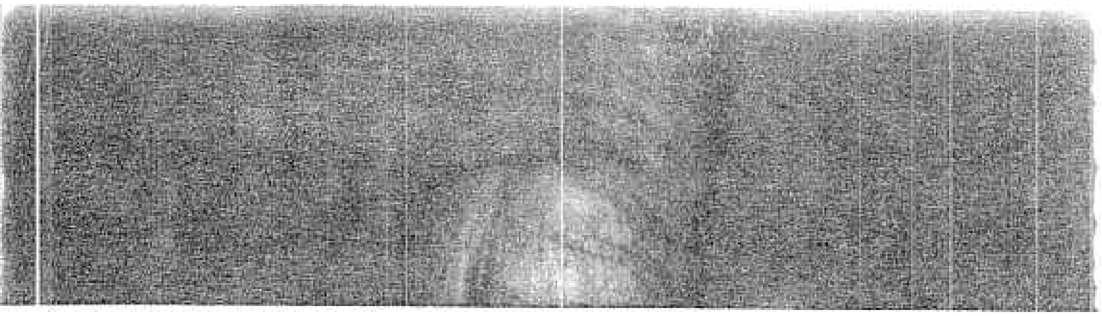
Thus it is useful to develop methods of calibrating the sensitivity of climate models against the observed climate record. Such calibration requires a knowledge of the history of climate forcing as well as adequate climatic data. Two possible avenues involve the use of the instrumental record of the past ~100 years and the use of paleoclimate data for much older periods. The former has the advantage of using direct observations of climatic parameters with relatively dense spatial coverage, while the latter allows consideration of cases in which the climate forcing was drastically different from the present.

4.1 The Instrumental Record

Systematic observations of temperature were undertaken at some locations as early as the eighteenth century. The spatial coverage of observations increased enough to allow estimates of global or hemispheric temperature by the mid- to late-nineteenth century. Several groups have constructed time series of global or hemispheric temperature extending back to that time (Jones, 1988; Hansen and Lebedeff, 1988; Vinnikov et al., 1990). While these data sets are hampered by limited spatial coverage and other uncertainties, particularly in their early decades, they contain similar low-frequency variations. Thus the data are adequate and have been used in a number of comparisons with results from time-dependent model experiments in attempts to estimate the actual climate sensitivity (Wigley and Barnett, 1990).

The second requirement, a knowledge of the history of climate forcing, is more challenging. A variety of forcing functions can be important on the time scales represented in the instrumental record (i.e., years to decades) in addition to greenhouse gas concentrations. These include stratospheric aerosols of volcanic origin, variations in solar radiation, and anthropogenic sulfate aerosols.

Large volcanic eruptions can inject sulfur dioxide gas into the stratosphere, forming sulfuric acid aerosols that can scatter incoming solar radiation, increase planetary albedo, and thus have a significant impact on the earth's radiation balance. The combination of a reduction of total solar radiation with the warming due to the thermal infrared



effects of the aerosols results in a small net cooling effect at the earth's surface, which can persist for a few years following an eruption (Mass and Portman, 1989). The inclusion of stratospheric aerosols in climate model simulations has yielded similar results (Hansen et al., 1992). Determining the history of volcanic aerosol forcing for the instrumental period is quite difficult, however. Measurements of volcanic aerosols in the stratosphere and their optical properties have only been available in recent years. Historical records provide clues to earlier eruptions, although it can be quite difficult to reconstruct the sulfur content of the erupted material and whether or not it reached the stratosphere, which is essential for it to have persisted long enough to have a climatic effect. Increased acidity in glacial ice cores has also been linked to sulfate aerosol-producing eruptions (Porter, 1986), but again there are difficulties in interpreting these proxy data.

Little is known about changes in insolation on time scales comparable to the period of instrumental records (10 to 10^3 years), since precise monitoring of solar irradiance by satellites has existed for little more than a decade. Satellite evidence indicates that irradiance varies in conjunction with the 11-year cycle of solar magnetic activity (i. e., the sunspot cycle), with a total variation of approximately 0.1 percent (Willson and Hudson, 1988). Proxies of solar magnetic activity, such as sunspot numbers, carbon-14 and beryllium-10, indicate substantial variations on time scales of decades to centuries (Stuiver and Quay, 1980; Beer et al., 1988). There has been some speculation that irradiance changes may be associated with these variations (Reid, 1991; Friis-Christensen and Lassen, 1991), but observational evidence and physical mechanisms have been lacking. However, some evidence has been offered for irradiance variations of up to 0.5 percent on these time scales based on solar modeling and the behavior of other stars similar to the sun (Lean, 1991). But at present the primary difficulty in documenting these relationships, or past changes in solar irradiance in general, is the short period of precise observations.

Anthropogenic sulfur emissions may also have potential climatic effects through two mechanisms. A direct effect is the scattering and absorption of incoming solar radiation by sulfate aerosols. An indirect effect is the potential of aerosol particles to increase cloud albedo by acting as cloud condensation nuclei. While both of these effects are extremely difficult to assess quantitatively, recent work suggests a net cooling effect at the surface with a magnitude that may be comparable to the change in greenhouse gas forcing over the period of instrumental records (Charlson et al., 1990, 1991, 1992). While estimates of the history of sulfur emissions may be available for use in chemistry/transport models to estimate the historical variations in aerosol concentrations, the large uncertainties in the magnitude of both their direct and indirect effects makes a quantitative estimate of the time variation of anthropogenic sulfate aerosol forcing quite difficult.

This suggests that efforts to calibrate climate model sensitivity using the instrumental climate record are somewhat handicapped by an inability to quantify the variations in forcing over the past century. Only if one were to assume that increases in greenhouse gas concentrations were the only changes in forcing would it be possible to do so with reasonable accuracy. In addition, the internal variability inherent to the climate system may produce variations in climate comparable in magnitude to the forced variations, further compounding the problem. Substantial variability appears to occur in the climate system even in the absence of external forcing, spanning a wide range of time scales. Much of this variability involves interactions between the atmospheric and oceanic components of the climate system. The well-known El Nino-Southern Oscillation phenomenon is an example, with climatic effects in widespread areas around the globe. More recently, models of the coupled ocean-atmosphere system have displayed variability of oceanic overturning (with accompanying atmospheric variations) on interdecadal time scales (Delworth et al., 1993). On shorter time scales, climate model experiments have demonstrated that substantial variability can occur even without changes in the ocean (Manabe and Hahn, 1981; Lau, 1981). Interactions with the land surface and internal atmospheric dynamics are likely sources of this variability (Delworth and Manabe, 1989).

It would clearly be too pessimistic to suggest that the instrumental climate record provides little useful information for calibrating the sensitivity of climate models. With proper caution, it should be possible to narrow some of the uncertainties about past climate forcing, and it may be possible to make some estimates of the magnitude of the unknown forcing. But given the contribution of internal climate variability acting as a "wild card," a case can be made for the pursuit of other, parallel approaches for calibrating climate sensitivity.

4.2 The Paleoclimate Record

Considerable amounts of paleoclimate data are available for climate modeling studies, particularly for the period of the last glacial maximum (LGM). The pioneering effort of the CLIMAP Project (1981) produced reconstructions of continental ice extent and thickness, sea ice extent, sea surface temperature (SST) and land surface albedo. Chemical analysis of ice core data has provided information about the atmospheric composition during the LGM, including the concentrations of CO_2 and other trace gases and the presence of airborne dust. In addition, past variations of the spatial and seasonal distribution of solar radiation have been calculated from the periodic variations in the earth's orbital parameters (e. g., Berger, 1978).

These paleoclimate data have been used in a number of climate model studies of past climates. Data from earlier time periods have also been used, but their relative abundance during and since the LGM have made the late Quaternary perhaps the most common subject of climate model studies. The goal of some of these studies has been to reconstruct a more complete picture of past climates, using climate models to generate information about an array of climatic variables that is physically consistent with the available paleoclimate data (e. g., Gates, 1976; Manabe and Hahn, 1977; Kutzbach and Wright, 1985). In such experiments, land ice extent and elevation, SSTs, sea ice extent, atmospheric composition and incoming solar radiation are used to force the climate models. Similar studies have attempted to objectively evaluate model performance through the use of additional paleoclimate data that were not used in forcing the models. For example, Webb et al. (1987) used temperatures and precipitation from a climate model to simulate the spatial distribution of vegetation at various times during the late Quaternary. The simulated vegetation distributions were then compared to those reconstructed from fossil pollen data in a test of model performance.

The abundance of paleoclimate data also makes the LGM a good subject for studies that evaluate climate model sensitivity. An important issue in the design of these experiments concerns how the oceans are treated in the models. This, in turn, is related to the role of the CLIMAP reconstructions of ocean surface conditions (SST and sea ice). In the experiments described above, SST and sea ice were prescribed; such experiments are relatively inexpensive to run, but require the reconstructed ocean surface data as input. This need is eliminated if SST is predicted by coupling an atmospheric GCM with some sort of ocean model. The simplest of these consider only the oceanic mixed layer and its role as a reservoir of heat on seasonal and interannual time scales. More comprehensive models are constructed by coupling an atmospheric GCM with an oceanic GCM, thereby accounting for the role of ocean circulation in influencing climate. Thus reconstructions of past SSTs can serve either as surface boundary conditions for integrations of atmosphere-only climate models, or as an independent data set against which simulated SSTs can be compared. Both of these approaches have been used in efforts to calibrate climate model sensitivity.

Hansen et al. (1984) conducted climate model experiments which utilized all available reconstructed variables for the LGM (SSTs, sea ice, land ice, land albedo, atmospheric CO_2). Climate model sensitivity was calibrated by examining the radiation balance at the top of the atmosphere. They found a negative radiation balance when the model was forced by the CLIMAP distributions of SST, sea ice, land ice and land albedo (with no change in CO_2), implying that the model would cool further if SSTs were allowed to change. A second experiment in which the boundary conditions were modified in accordance with then-recent research results (CLIMAP sea ice scaled back, reduced CO_2) yielded an even larger radiative imbalance, again indicating that the climate model would have cooled further. They suggested that this apparent overestimation of climate model sensitivity could be attributed to a number of possible causes, including an overestimate of cloud feedback in the model or a warm bias to the CLIMAP reconstructed SSTs.

A somewhat different approach was taken by Manabe and Broccoli (1985). They performed two experiments using different versions of an atmosphere-mixed layer ocean model. Each experiment consisted of two climate model integrations: one using the LGM land ice, land albedo and atmospheric CO_2, and the other a control. The two versions differed in their treatment of cloud cover. One prescribed clouds as a function of latitude and height, based on observations, but invariant over time. The other predicted cloud cover based on the simulated relative humidity at each grid point.

Manabe and Broccoli (1985) concluded that both versions of the model yielded sensitivities roughly in agreement with paleoclimatic estimates, and that it was difficult to resolve the difference between the two versions based on existing paleoclimate data. Breaking this down by latitude, there was good general agreement with paleotemperatures in the Northern Hemisphere extratropics for both versions of the model. In the Southern Hemisphere extratropics, there was reasonable agreement with the CLIMAP SST data, especially for the model with prescribed clouds. Both versions seemed to underestimate the terrestrial cooling there, although the continental data used were very limited. In addition, there was reasonable agreement between the Antarctic surface air temperature change and that reconstructed from isotopic data in the Vostok ice core (Jouzel et al., 1987), although this agreement may have been fortuitous since more recent ice sheet reconstructions suggest that the LGM Antarctic ice elevation used in the Manabe and Broccoli experiments was overestimated. In the tropics, both versions of the model indicated more cooling than the CLIMAP SSTs, while at the same time underestimating the terrestrial cooling reconstructed from pollen and mountain snowlines. The disparity between the oceanic and continental estimates of low-latitude cooling during the LGM was greater than the difference between the sensitivities of the two models.

These studies are examples of the way in which paleoclimate data can be utilized in calibrating climate model sensitivity. Obviously there are some weaknesses in this approach, the largest of which is probably the substantial uncertainty that surrounds reconstructions of past climates and forcings. For example, considerable uncertainty exists about the role of windblown dust as a source of climate forcing at the LGM. Large increases in dust are recorded in polar ice cores (e. g., De Angelis et al., 1987); if these increases are representative of a widespread increase in atmospheric dust loading, the climatic effects could have been considerable (Harvey, 1988). A recent tracer study using a climate model does not simulate a global increase in dust loading, and suggests that local or regional sources were responsible for the dust increases in polar ice cores (Joussaume, 1993). Further work will be required to resolve this issue.

But as new techniques for interpreting proxy data are developed and perfected it may be possible to improve our confidence in quantitatively reconstructing past climates and forcings. Such improvements will also be useful in future efforts to estimate climate sensitivity from paleoclimate data without the direct use of climate models (Hoffert and Covey, 1992). As the number of locations at which climate has been reconstructed increases, it may also be possible to distinguish regional variations in past climate change (for example, the presence or absence of polar amplification of warming or cooling) and compare these with variations simulated by climate models.

5. PROSPECTS FOR IMPROVED CALIBRATION OF MODEL SENSITIVITY

Despite the current limitations of paleoclimatic reconstructions, a review of previous work suggests that a quantitative assessment of a climate model's ability to simulate the LGM climate can be an important tool in evaluating model sensitivity. While it may not be possible to resolve modest differences in sensitivity, it should be possible to determine whether or not the sensitivity is in approximate agreement with that of the real climate system. In addition, previous assessments of this kind have identified important questions for further study, such as the difference between terrestrial and oceanic estimates of the tropical temperature change since the LGM. Questions such as this have implications for both climate modeling and understanding past climates.

One of the requirements for improved calibration of climate model sensitivity is the continued collection and analysis of the proxy data required for reconstructing past climates. The construction of more comprehensive data sets (combining both terrestrial and oceanic data) that describe spatial patterns of climate change for a particular time would be of particular use to climate modelers, since most of the original sources of paleoclimate data describe variations over time at a single location or a relatively small area. The efforts of the CLIMAP Project (1976, 1981) serve as a prototype for this strategy. Peterson et al. (1979) constructed one such data set, and also described different degrees of analysis for such data (borrowing terminology from the initialization of numerical weather prediction models). Another paleoclimate data set was assembled by the Cooperative Holocene Mapping Project (COHMAP Members, 1988). The creation of expanded data sets of this kind will require the integration of data of different types and from disparate sources and the expertise of a variety of paleoclimate specialists.

As further improvements in climate models occur (e. g., increased horizontal and vertical resolution, ocean dynamics, interactive vegetation), it will be useful to re-assess the calibration of their sensitivity. The simulation of a particular past time period such as the LGM can serve as a valuable benchmark, particularly since information on past climate forcing and response would be expected to become more reliable over time.

Perhaps the best way to calibrate climate model sensitivity would be to simulate ongoing changes in climate. With the current relatively rapid increase in greenhouse gas concentrations, a concomitant rapid change in climate forcing is also underway. By carefully monitoring both the changes in forcing and resulting response, the necessary information for hindcasts/forecasts by comprehensive climate models would be available. But since the history of forcing and response is replete with uncertainties at present, it is difficult to use the recent climate record for this purpose, since those uncertainties (along with the internal variability of the climate system) are of comparable magnitude to the expected climate response. Improved systems for climate monitoring (Hansen et al., 1990, Karl et al., 1993) would greatly improve our ability to use the recent climate record to calibrate climate models. But even if such systems were in place today, several more decades might be required to gather enough data. In the meantime, paleoclimate information can provide some much-needed insights into climate model performance.

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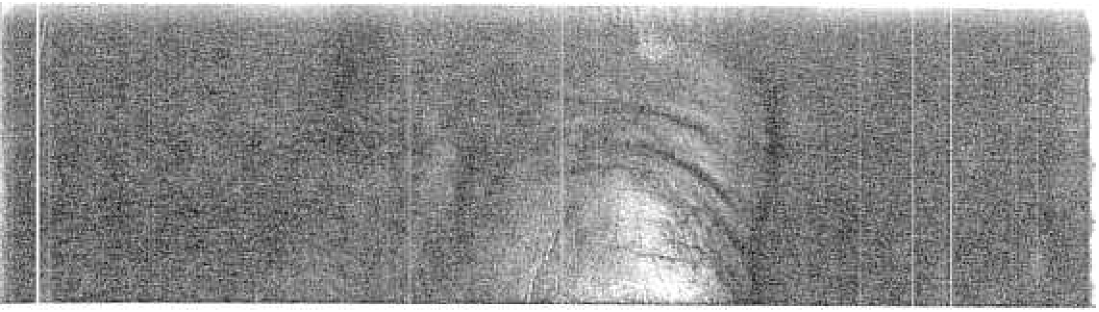

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