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SENSITIVITY OF CLIMATE MODELS: COMPARISON OF SIMULATED AND OBSERVED PATTERNS FOR PAST CLIMATES

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PROGRESS REPORT
1992
SENSITIVITY OF CLIMATE MODELS: COMPARISON OF SIMULATED
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SECTION I. INTRODUCTION

Predicting the potential climatic effects of increased concentrations of atmospheric carbon dioxide requires the continuing development of climate models. Confidence in the predictions will be much enhanced once the models are thoroughly tested in terms of their ability to simulate climates that differ significantly from today's climate. As one index of the magnitude of past climate change, the global mean temperature increase during the past 18,000 years is similar to that predicted for carbon dioxide doubling. Simulating the climatic changes of the past 18,000 years, as well as the warmer-than-present climate of 6000 years ago and the climate of the last interglacial, around 126,000 years ago, provides an excellent opportunity to test the models that are being used in global climate change research (Webb and Wigley, 1985).

During the past several years, we have used paleoclimatic data to test the accuracy of the NCAR CCM0 (National Center for Atmospheric Research, Community Climate Model, Version 0), after changing its boundary conditions to those appropriate for past climates (Kutzbach and Guetter, 1986; Webb et al., 1987; Prell and Kutzbach, 1987; COHMAP, 1988; Prell and Kutzbach, in press). We have assembled regional and near-global paleoclimatic data sets of pollen, lake level, and marine plankton data (COHMAP, 1988) and calibrated many of the data in terms of climatic variables (Webb et al., 1992a). We have also developed methods that permit direct quantitative comparisons between the data and model results (Webb et al., 1987; 1992a). Our comparisons have shown both some of the strengths and weaknesses of the model.

Our research has shown that comparing the model results with the data is an evolutionary process, because the models, the data, and the methods for comparison are continually being improved. During 1992, we

have completed new modeling experiments, further analyzed previous model experiments, compiled new paleodata, made new comparisons between data and model results, and participated in workshops on paleoclimatic modeling.

Section II. GENERAL RESEARCH ACCOMPLISHMENTS DURING 1992

The COHMAP book is going through final editing stage and should be published in late '92 or early '93. This past year, we completed a wide variety of sensitivity experiments that evaluated the CCM1 response to changes in CO₂, ice sheet size and location, solar radiation and mountain orography. These studies have quantified several aspects of the model response and, in one case, have been combined to estimate the pattern of monsoon evolution and variability over the past 15 million years.

SECTION III. MODEL EXPERIMENTS

Tuning of CCM1

During the past year we found that the version of CCM1 running on the NCAR CRAY YMP and using slightly revised computational routines has a significantly colder climatology than the same model running on the XMP. Oglesby (Purdue) and Kutzbach and Gallimore (Wisconsin) have analyzed these differences and concluded that it was necessary to retune the model's snow cover and sea ice albedos to obtain a reasonable climatology. This entire process took several months--first, we had to carefully diagnose the features of the altered climatology (colder polar regions), then carefully examine the code, then make new runs with altered snow and sea ice albedos. We now have a tuned version of CCM1 with a good snow cover and sea-ice climatology (and with realistic albedos).

New models: CCM2/Genesis Model

NCAR will release the CCM2 in October 92. We will be able to use this model, which operates at T42 or $2.8^\circ \times 2.8^\circ$ resolution, as soon as an appropriate land surface process package is added.

Gallimore, Guetter, and Behling traveled to NCAR to learn how to run the new Genesis model of Thompson and Pollard. This model has greatly improved land surface process, sea ice, and convective parameterizations.

Model/model comparisons

Our comparison of model simulations for 6Ka with two different GCMs, the NCAR CCM1 and the UKMO, continues.

The NATO Workshop of May 91 adopted a strategy for model/model comparisons essentially as proposed by our group. Kutzbach is a member of the international advisory board for model/model comparisons.

Generic precession/tilt experiments

Kutzbach and Gallimore are completing two manuscripts describing the results of simulations with idealized changes of axial tilt and time of perihelion in order to isolate the unique climatic responses to these two kinds of insolation forcing (Gallimore & Kutzbach, 1992; Kutzbach and Gallimore, 1992). The model used for the experiments is the UW LRM with interactive mixed-layer ocean.

Vavrus (UW grad student) modified this model to incorporate sea-ice lead parameterizations and repeated the above-mentioned generic precession/tilt experiments to estimate more accurately the high-latitude response of climate to insolation changes. His M.S. thesis and a journal paper will be completed by December 1992.

Vegetation/soil nutrient model

Foley (UW grad student) is working with Colin Prentice to develop a global vegetation model that can be asynchronously coupled to the CCM. This vegetation model should aid in testing model sensitivity to land surface changes and in comparing simulated past climates to observations. Foley passed his prelims for the PhD in Spring 92 and expects to complete his thesis in summer 93. Prentice has used our 6Ka results with CCM1 to estimate the vegetation of 6Ka. Webb will coordinate with Prentice to develop a publication based upon these results.

Sensitivity of Indian Monsoon to SST

Oglesby and Clemens (Brown) have completed a study investigating the effects of prescribed versus computed SST on simulation of the Asian monsoon, finding that only with computed SST were fully consistent results obtained. A paper reporting on this study has been accepted for publication by *Paleoceanography* (Clemens and Oglesby, 1992).

Sensitivity of Northern Hemisphere Glaciation to Changes in CO₂

Verbitsky (Yale) and Oglesby have completed a preliminary study of the sensitivity of northern hemisphere ice sheets to changes in atmospheric CO₂. The study involved using CCM1 to obtain net snow mass balances which were then input into a dynamic ice sheet model which computed the subsequent ice sheet height and extent. A paper reporting on these results recently appeared in *JGR* (Verbitsky and Oglesby 1992).

Paleoclimatic Implications of Changing CO₂

Oglesby and Saltzman (Yale) extended their study of CCM1 sensitivity to atmospheric CO₂ changes by investigating paleoclimatic implications of CO₂ for past climates both colder and warmer than at present. Emphasized was the Last Glacial Maximum. A paper reporting on

these results has been submitted to Journal of Climate (Oglesby and Saltzman, 1992).

Improved Snow Hydrology in CCM1

Marshall (Colorado State Univ.) and Oglesby have completed the first phase of a study implementing a new, physically-based snow hydrology (Marshall 1989) into CCM1. Motivation for this work was provided by our previous modeling work which clearly showed deficiencies in the previous snow hydrology. Results of this study were presented at the Second International Conference on Modelling of Global Climate Change and Variability in Hamburg, Germany, Sept. 1992. A paper is in the final stages of preparation for submission to a special issue of Climate Dynamics (Marshall and Oglesby, 1992).

SECTION IV. OCEAN DATA AND COMPARISONS WITH MODEL RESULTS

During 1992, we have made progress toward ocean data-model comparison in the following areas:

Marine calibration data set

As part of our effort to upgrade the planktonic foraminifera data that is used to make SST estimates, we had a successful sampling trip to Scripps Institution of Oceanography where we obtained an extensive set (about 170 samples) of modern Pacific Ocean coretop samples for our global data base. These data will help fill in the gaps in our Pacific data base. At the International Conference on Paleoceanography in Kiel, W. Prell will be attending a workshop on pelagic biogeography and meeting with Laurent Labeyrie (Gif) to arrange acquisition of French samples from the Southern Ocean and the Northwest Pacific. These data will make a significant addition to our existing global data for modern sediments.

We have continued to evaluate both our calibration data and quantitative techniques for making SST estimates. Work by graduate student Min-Te Chen on "Comparison and Evaluation of Faunal Sea-Surface Temperature Estimates in Tropical Pacific Ocean" is coauthored by W. Prell and J. Imbrie and will be submitted for publication soon. An additional manuscript, "Thermocline Interpretation of Planktonic Foraminifer Faunal Data With Application to Late Quaternary Tropical Indo-Pacific Records" is in review by W. Prell and will be submitted for publication this fall.

Evaluation of overlapping paleotemperature estimates from multiple fossil groups has lagged because Prell and Pisias have been unable to coordinate the foraminifera and radiolarian data sets. This is a high priority for next year. The data from the eastern equatorial Pacific are now available for this evaluation and will help fill a gap in the Pacific coverage.

Past sea surface temperature (SST) variations

We continue to identify new LGM levels in the literature and by processing new cores in our laboratory. A new PhD candidate, Vicky McKenna is working on a transect of cores in the western Indian Ocean to evaluate the spatial and temporal (over the past 400 Ky) extent of the warm SST anomalies observed in the CLIMAP (1981) reconstruction of the Last Glacial Maximum. Initial sampling is complete and processing of the samples is underway.

We also continue to work with the Paleoclimate Modeling Intercomparison Project (PMIP) to generate a revised set of SST estimates for the LGM. This activity is a followup to the workshop on Late Quaternary Paleoclimate Boundary Conditions (held at Lamont-Doherty Geological Observatory last November).

Structure of the LGM Indian Ocean.

Our reconstruction of two-dimensional $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ transects (depth versus latitude) for the LGM is complete and being finalized for publication. These data allow us to examine the patterns of water masses and infer circulation. We have added new samples and reanalyzed some previous data and the manuscript "Intermediate and Deep Water Circulation in the Indian Ocean during the Last Glacial Maximum" by Jiajie Chen and Warren L. Prell is in final review before submittal to *Paleoceanography*. Our results confirm the existence of a deep thermocline near 2000 m but suggest that it may be limited to the northern Indian Ocean along with the highly negative $\delta^{13}\text{C}$ (nutrient rich) deep waters. We also find considerable heterogeneity in the deep waters between the northeastern and northwestern basins of the Indian Ocean suggesting a complex ventilation during the LGM. These results should provide some constraints on the ocean GCM simulations for the LGM.

Model-data comparisons.

Prell and Kutzbach (in press) and Prell et al. (in press) have completed a study that estimates the sensitivity of the monsoon (simulated by the NCAR CCM0,1) to four forcing factors (orbital induced radiation changes, glacial boundary conditions, elevation changes in Tibet, and enhanced CO_2), combines the sensitivities to construct time series of monsoon strength, and compares the time series to paleo data. This study indicates that major elevation changes have the largest effect on the monsoon and that monsoons as strong as modern cannot exist unless the elevations are at least half of the modern elevation. Radiation induced variability is almost as large as the elevation induced variability but is a relatively short periods (Milankovitch periods) compared to the uplift trends. The inferred extent of glacial boundary conditions and CO_2 changes have much less effect on the monsoon system. The comparison of marine and terrestrial paleodata (Prell et al., in press) shows the onset of monsoon induced upwelling and precipitation changes at about 7 to 8 My

ago and is consistent with models that propose rapid uplift of Tibet at that time.

SECTION V. TERRESTRIAL DATA AND COMPARISONS WITH MODEL RESULTS

During 1992, research activities with terrestrial data sets have focused on comparing pollen-generated paleoclimatic estimates with climate model results, preparing an article that describes the comparison of the new CCM1 simulation for 6 ka with terrestrial data, writing and publishing several articles and book chapters describing these and other results, continued development of the pollen data base at Brown and its transfer to NOAA's National Geophysical Data Center, and work on preparing a global vegetation map for 18 ka for use in the PMIP (Paleoclimate Modeling Intercomparison Project) experiments.

Several articles mark this year's progress. They include maps of temperature and precipitation estimates for eastern North America for each 3000-year interval from 18,000 years ago to present (Prentice et al., 1991, Webb et al., 1992), maps of pollen assemblages without modern analogs indicative of times and places where past climates are not analogous to any modern climates and thus key areas for testing how analogous the model simulations are (Overpeck et al., 1992; Webb et al., 1993), estimates of moisture balance from pollen data in the northeastern United States that are compared to lake level data and to model simulations (Webb et al., in prep.), a chapter co-authored with Andre Velichko contrasting the maps of estimated temperatures for 6 ka produced by Russian and U.S. scientists. (Webb, 1992), and a chapter evaluating possible biospheric feedbacks to increased carbon dioxide concentrations (Post et al., 1992), and two review articles describing the key results from the data/model comparisons for 18 ka to present and showing how these results relate to global change research in terrestrial ecosystems and in the geological record (Webb and Bartlein, 1992, Webb, 1993).

We have continued to update and increase the coverage in the pollen data base at Brown. We have also transferred data to the North American Pollen Data Base being developed for the Paleoclimate Data Center at NOAA's NGDC (National Geophysical Data Center) in Boulder. Eric Grimm at the Illinois State Museum is the curator in charge of the data base and will manage the archiving of the data and will provide the raw pollen data to outside users. This transfer of the data frees up the work at Brown to focus on developing research data bases that can be used for paleoclimatic estimation and for checking the simulations of past climates by GCM's.

A key research effort has been to prepare a global vegetation map for 18 ka. This research is tightly coordinated with PMIP and the need for vegetation data to specify the boundary conditions in some of the model simulations of 18 ka. In November, 1991, we attended a meeting at Lamont to initiate this work. The mapping effort at Brown has focused on North America and the Middle East. We are coordinating our research with R. S. Webb and J.T. Overpeck at NOAA, P. J. Bartlein at the University of Oregon, and I.C. Prentice at Lund University, and data for vegetation mapping are coming from Brian Huntley for Europe, R.S. Thompson for the western United States, P. Anderson for Alaska and eastern Siberia, K. Liu for China, R. Bonnefille and others for Africa, and J. Dodson for Australia. An initial version of the map is being presented at the International Palynological Congress in Aix, France in September, 1992.

SECTION VI. EQUILIBRIUM SENSITIVITY COEFFICIENTS

We have improved our methods for evaluating the significance of equilibrium sensitivity coefficients that have been used to quantify the model response to orbital insolation changes. This study used the CCM0 COHMAP simulations at 0 Ka, 3 Ka, 6 Ka, 115 Ka, and 126 Ka and expands the previous work of Prell and Kutzbach (1987). In addition to mapping the sensitivity coefficients, our new study now uses a version of t-test to combine the jackknife uncertainty and misfit to quantitatively identify the areas with significant sensitivity. After a complete revision, the manuscript (A Systematic Study of GCM Sensitivity to Changes in Solar

Radiation by R. J. Oglesby, H. Shao, T. Webb III, W. L. Prell, J. Kutzbach and B. Felzer) is ready to be submitted for publication.

We (Prell and Kutzbach) have also calculated the sensitivity of monsoonal climate variables to changes in orography (mountains and plateaus) for comparison to other climate forcings, such as changes in Milankovitch insolation, the extent of glacial boundary conditions and CO₂ (also see Section IV). This study (Prell and Kutzbach, in press) documents that the monsoon's sensitivity to major elevation change is on the same order as it's sensitivity to orbital insolation changes.(Milankovitch periods). These sensitivity coefficients lay the foundation for comparing paleoclimatic records with model estimates of monsoonal history (Prell et al., in press).

To evaluate the influence of large continental ice sheets on late Quaternary paleoclimates, Ben Felzer, a graduate student at Brown, has completed a series of experiments (with CCM1) to establish the sensitivity to ice sheet area and height. Preliminary results suggest large responses over and adjacent to the ice sheets, but relatively little response elsewhere. Unlike for insolation or CO₂, the sensitivity of such quantities as surface pressure and temperature cannot be uniformly categorized as linear or non-linear, instead the nature of the response must be determined on a region-by-region basis.

Finally, computation of sensitivity coefficients for the solar constant study is currently underway. Preliminary results were presented by R. Oglesby at the Second International Conference on Modelling of Global Change and Variability (Hamburg, 1992). The study suggests a response seasonally similar to that of orbital insolation changes, being fairly large and linear for surface temperature over continental interiors.

SECTION VII. WORKSHOPS

The PI's met in Madison in Fall, 1992 and plan another meeting for fall or winter, 1993. Winkler (UW - Madison) has received funding from NOAA to develop and update a global lake-level data set for data/model comparisons. A meeting of collaborators in this project will occur within

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