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

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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 21,000 (calendar) years is similar to that predicted for carbon dioxide doubling. Simulating the climatic changes of the past 21,000 years, as well as the warmer-than-present climate of 6000 years ago and the climate of the last interglacial, around 125,000 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, 1992). We have assembled regional and near-global paleoclimatic data sets of pollen, lake level, and marine plankton data (Prell, 1985; COHMAP, 1988) and calibrated many of the data in terms of climatic variables (Prell, 1985; Webb et al., 1993a). We have also developed methods that permit direct quantitative comparisons between the data and model results (Webb et al., 1987; 1993a). 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. From 1991 to 1993, we have completed new modeling experiments, further analyzed previous model experiments, updated existing sets of paleoclimatic data, 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 *Global Climates Since the Last Glacial Maximum* (Wright et al., 1993) describing the climate-model simulations, regional and global data sets, and the comparisons between the data and model results is due for release in August, 1993. We also completed a wide variety of sensitivity experiments that evaluated the NCAR CCM1 response to changes in CO_2, ice sheet size and location, solar radiation and mountain orography (Kutzbach et al., 1989; Clemens and Oglesby, 1992; Verbitsky and Oglesby 1992; Oglesby and Saltzman, 1992; Prell and Kutzbach, 1992). 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 (Prell and Kutzbach, 1992; Prell et al., 1992). We also published a key test of the NCAR CCM0 results for 9000 (^{14}C) yr BP (Before Present) in the northeastern United State (R. Webb et al., 1993) and a major review article showing how the data and modeling studies for the climates of the last 21,000 (cal.) years help us to understand the changes over the past 175,000 and 3 million years. We have also made comparisons with ocean model simulations of upwelling in the modern and 9000 (radiocarbon) yr BP Arabian Sea (Luther et al., 1990; Prell et al., 1990), with pollen and isotopic-based SSTs off southeast Africa (van Campo, et al., 1990), and with monsoon wind intensity (Clemens and Prell, 1991).

SECTION III. COHMAP Book

Global Climates Since the Last Glacial Maximum (Wright et al., 1993), describes the results of general circulation model experiments made with the NCAR Community Climate Model (CCM 0) for July and January conditions at 18,000, 15,000, 12,000, 9,000, 6,000 and 3,000 (radiocarbon) yr BP. This book presents the simulated and observed paleoclimates studied by COHMAP (Cooperative Holocene Mapping Project) in much more detail than a previous journal article (COHMAP, 1988). The book includes chapters on concepts (Kutzbach and Webb, 1993), boundary conditions (Kutzbach and Ruddiman, 1993) paleoclimate simulations (Kutzbach *et al.*, 1993), data/model comparisons for all the continents, an overall synthesis (Webb *et al.*, 1993b) and a plan for future experiments (Kutzbach *et al.*, 1993). Overviews of paleoclimate modeling studies are also published in several other books (Kutzbach and Webb, 1991; Kutzbach, 1992a; and Kutzbach, 1992b).

SECTION IV. MODEL EXPERIMENTS

The Past 21,000 Years

Kutzbach and Gallimore (UW) and Oglesby (Purdue) have tuned a version of CCM1 to have a better snow cover and sea-ice climatology, and more realistic snow and sea-ice albedos, than the frozen version of CCM1. This version of CCM1 is being used in our new series of COHMAP baseline experiments. We've completed a simulation for 6000 yr BP with this model. We are now coding the new ice sheet area/height data for the simulation for 21,000 (cal.) yr BP and developing the prescribed SST and sea-ice boundary conditions for 16,000, 14,000, and 11,000 (cal.) yr BP.

Coe (1993) partitioned the control run for NCAR CCM0 into the major sub-continental drainage basins and then processed the simulated runoff to obtain estimates of river discharge into the major ocean basins. The simulated discharge agreed fairly closely with observations. He also calculated these discharges for model runs for the last glacial maximum and for 6000 yr BP.

Interactive Soil Parameterization

When we added an interactive soil moisture parameterization to the model, we found a significant positive feedback that improved the agreement between simulation and observations: the northern tropics became even wetter and the northern mid-latitudes even drier at 9,000 (^{14}C) yr BP than in our earlier experiments with prescribed soil moisture (Gallimore and Kutzbach, 1989). We have also completed a seasonal cycle simulations of the climate of 6,000 yr BP using the version of CCM1 with interactive soil moisture and snow parameterizations that is coupled to mixed-layer ocean. We found a similar enhancement of the climatic response compared to our earlier studies with CCM0 and the simulation of lower-then-present moisture balance at 6000 yr BP for central North America were similar to the data there. The results from CCM0 in central North America did not match the data. So CCM1 with its interactive soil moisture parameterization produced a more realistic set of results for this region for 6000 yr BP.

Model Improvements for Snow Hydrology

Of paramount importance to the study of glaciation and crucial to any study of long-term climate is the ability to accurately and precisely model the seasonal cycle of snow cover. This computation is, however, very crudely done in most current GCMs, including CCM1. As a step towards correcting this deficiency, we have incorporated the physically-based snow hydrology of Marshall (1989) into CCM1 (Marshall and Oglesby, 1993). This new parameterization includes the effects of snow age, grain size, and fractional snow cover on the albedo of a snow-covered surface. They found that the seasonal cycle of snow cover in a present-day control was improved with use of the new snow hydrology; in particular the spring-time melt was simulated much more realistically. Because of its more physically-realistic formulation, use of the new snow hydrology should also improve the predictive capability of the model when applied to questions of past climates or possible future climatic change. As a test of this selected Antarctic simulations of Prentice et al. (1993) and northern hemisphere simulations of Verbitsky and Oglesby (1992) were repeated. Little impact was seen on the basic results for Antarctica but a profound difference was seen in the results for the Northern Hemisphere. In this latter case, use of the new snow hydrology does not change the overall functional rate of ice volume decrease with increasing CO_2, but the resultant ice sheets in every case are much larger and, for low values of CO_2, may approach the total volume of ice at the Last Glacial Maximum.

Model Experiments with GENESIS-version of CCM1

We have run a series of experiments with the GENESIS model. First, we ran an experiment for 6000 yr BP and found results similar to those with CCM1 (Foley, 1993). Second, we used an expanded version of the vegetation model of Prentice (see Foley, 1993) to assess the sensitivity of the 6000 yr BP climate to prescribed expansion of high latitude forests and subtropical grasslands (Foley, 1993). We found a very significant high latitude warming. This result suggests the operation of a significant positive feedback involving climate-biosphere processes. The orbital conditions at 6000 yr BP promote high-latitude warming of 2-3°C and the associated expansion of northern forests promotes an additional warming of 2-3°C. We will now compare the results with observations and also make plans for an experiment with truly interactive vegetation (i.e., where the vegetation-climate feedbacks are internalized in the model).

Sensitivity to Orbital Changes - The past 150,000 Years

To study the effects of extremes of orbital forcing, we simulated the climate using orbital conditions of large eccentricity, 0.04, with perihelion in either northern summer or northern winter and with axial tilt of either 25° or 22° (Gallimore and Kutzbach, 1993; Kutzbach, Prell and Imbrie, in prep). The orbital configuration with large eccentricity, perihelion in northern summer, and 25° tilt resembles orbital conditions at the previous interglacial, about 125,000 yr BP. These simulations showed strong sensitivity of sea-ice and snow cover to orbital changes (MacCracken and Kutzbach, 1991; Vavrus, 1992) and were used by geologists and paleoecologists to study the previous interglacial in high latitudes (Harrison *et al.*, 1991; Kutzbach *et al.*, 1991) and by the SPECMAP group to help interpret the role of orbital changes in glacial/interglacial fluctuations as recorded in marine sediment cores (Imbrie *et al.*, 1992). We are working with Prentice and Foley to simulate the vegetation changes that could be associated with orbital extremes.

Vavrus (UW grad student) incorporated parameterizations for sea-ice leads in the NCAR CCM and repeated the above-mentioned generic precession/tilt experiments to estimate more accurately the high-latitude response of climate to insolation changes. The presence of leads resulted in a slightly reduced sensitivity to insolation changes, compared to the sensitivity with the standard sea-ice parameterization. His M.S. Thesis was completed in 1992 (Vavrus, 1992), and he is preparing a journal article.

The Past 10 to 20 Million Years

Two of us (Kutzbach and Prell) have collaborated with Bill Ruddiman (Virginia) to study the possible effect of increases in the height of mountains and plateaus on tropical monsoons and mid-latitude and polar climates over the past 10-20 million years. The Tibetan Plateau may have doubled in elevation within the past 10 million years and comparable elevation changes in the Colorado Plateau/Rockies may have occurred over a somewhat longer period (Ruddiman *et al.*, 1989). We completed a set of model experiments with NCAR CCM 0 for "no mountain", "half mountain", and "full mountain" (modern) conditions (Kutzbach *et al.*, 1989; Ruddiman and Kutzbach, 1989; Ruddiman and Kutzbach, 1990; Ruddiman and Kutzbach, 1991). With uplift, the climate of South and East Asia becomes wetter, the climate of Central Asia and the Middle East becomes drier, and the climate of Eastern Asia and Eastern North America becomes colder. These results with CCM 0 compare favorably with some of the patterns of geologic observations, but the simulated changes are of smaller magnitude than the observed changes.

We repeated these mountain uplift experiments with a version of the NCAR CCM 1 that included a full seasonal cycle, a 50m-mixed-layer ocean, and parameterizations for sea-ice, snow cover and soil moisture (Prell and Kutzbach, 1992; Kutzbach *et al.*, 1993). The new results show the same patterns of change that we found with CCM 0; however the magnitude of the changes is considerably larger owing to feedback effects of soil moisture and snow cover.

Based upon various paleoclimatic sensitivity experiments, we described a hypothetical evolution of the Indian monsoon over the past 10-20 million years as a function of the possible effects of uplift, CO_2 changes, and orbital changes on the climate of Southern Asia (Prell and Kutzbach, 1992). The simulations were then compared to observations.

Based upon evidence that atmospheric CO_2 concentration may have been at least two times present around 20 million years ago, we've repeated these experiments using combinations of lowered elevation and raised CO_2 (Ruddiman, Prell, Kutzbach, Prentice, in prep). These simulations are in better agreement with observations than our previous simulations for lowered elevations alone. We are also exploring the possibility that mountain uplift has increased weathering actions and thereby contributed to CO_2 drawdown over the past twenty million years.

Sensitivity to Ice Sheets

As a major portion of his Ph.D. research at Brown, Ben Felzer has been performing a study that systematically varies ice sheet size and height over North America and Eurasia. To date, he has completed a series of perpetual season (January and July) simulations with CCM1 in which he set the area of the 21,000 (cal.) yr BP ice sheet (last glacial maximum) as '1', then varied this from 0.5 to 1.7 (i.e., an ice sheet with half the area to one with 1.7 times the area). He varied the height from 0 (background topography) systematically to almost 3 km. The first step was to attempt to perform a formal sensitivity analysis similar to what had been done by Felzer et al. (in prep.) for orbital insolation changes (and Oglesby and Saltzman, 1992, for CO_2 changes). This did not prove as meaningful as in these other studies as the analysis showed large changes over and immediately adjacent to the ice sheets but surprisingly little change more than a few grid squares away from the ice sheets. These simulations did not, however, have an interactive surface hydrology or computed SST, either of which could serve to amplify the "far-field" response to the ice sheets. In particular, analysis of the fluxes of sensible and latent heat over the Atlantic Ocean immediately off the coast of North America revealed large effects that could impact not only SST's but also aspects of ocean circulation as well. Additional model experiments were run with seasonal simulations and interactive hydrology for extremes in ice sheet height. These runs also revealed few significant changes far from the ice sheets (Hyman and Felzer, in prep). Experiments with CCM1 with a 'slab ocean' are now being run.

Sensitivity to SST Anomalies

Clemens and Oglesby (1992) completed a modeling experiments aimed at a better understanding monsoon processes and how to model these processes. They found that only when SST's were computed did CCM1 simulate the right sequence of physical events and processes that couple the pressure anomalies over the Asian interior with circulation changes in the southern hemisphere Indian Ocean. When SST's were prescribed, the end result over Asia was reasonably well-simulated, but the sequence of events was no longer well-simulated, suggesting an inability to properly predict changes in the monsoon under past or altered conditions. They were able to use a previously made computed-SST control for that portion of the study, but had to make a series of prescribed-SST runs in which they imposed anomalies over Indian Ocean SST's.

As a portion of her Ph.D. research, Vicki McKenna, a graduate student at Brown, has made model simulations aimed at investigating the impacts of SST anomalies off the Atlantic and Indian Ocean coasts of Africa. Based on CLIMAP SST reconstructions for the last glacial maximum (ca. 21,000 (cal.) yr BP), she imposed warm SST anomalies of up to 3°C over portions of the South Atlantic. In this initial phase, she has for simplicity used perpetual season forcing. A total of four experiments have been made to date. Analysis and interpretation of the results is continuing.

Sensitivity to Orbital Variations

'Milankovitch' orbital insolation parameters. Felzer et al. (1993) used the previous CCM0 simulations of Kutzbach at 0, 3000, 6000, 115,000 and 125,000 yr BP to compute formal linear sensitivity coefficients that on a grid point by grid point basis related the response of important model variables (such as surface temperature and pressure) to the changes in forcing. As measures of the uncertainty, they also computed the linear least squares misfit, a jackknife standard deviation, and the variability in a lengthy model control. The patterns of the sensitivity coefficients, which were normalized via a t-test, showed the regions of high and low sensitivity. Prell and Kutzbach (in prep) have also examined the interaction of orbital insolation extremes and orographic boundary conditions on the monsoon precipitation and runoff from Asia.

Climate sensitivity to solar constant changes. Oglesby performed a series of experiments systematically varying the solar constant (1370 Wm^{-2} in the present-day control) by -10%, -5%, -2%, 0%, +2%, +5% , and +10%. He then performed a linear sensitivity analysis comparable to what was done for the orbital insolation simulations described in 1) above. For simplicity, each solar constant value was run for perpetual January and July. These results, which are in the final stages of being written up for a journal paper, can also be compared to a recent study by Marshall, Oglesby, and Saltzman (submitted) in which a similar set of experiments was made, only using the seasonal-cycle computed-SST-mode of CCM1.

The nature of the forcing to changes in (short wave) solar luminosity is very different than that due to changes in CO_2 (long wave). Changes in solar luminosity are also of importance in studies of paleoclimate because this quantity has increased by about 30% since the inception of the solar system over 4 billion years ago. Marshall et al. (submitted) report the basic results for surface temperature for simulations with variations in the solar luminosity of -5%, -2%, 0%, +2%, and +5% relative to the present-day control values of 1370 Wm^{-2}. Note that the 0% and 330 ppm 'controls' are equivalent, and that Marshall et al. (submitted) is analogous to that of Oglesby and Saltzman (1990) regarding CO_2. Marshall et al. (submitted) find a strongly linear sensitivity in surface temperature over land but a less-well defined linear sensitivity over ocean; indeed over ocean a log fit is a good (or as poor) as the linear fit.

CCM1 Sensitivity to CO_2

Some of the most basic results of Oglesby and Saltzman (1990) were presented at the 1990 CCM Workshop, and described in the 1990 Progress Report. Simulations were made with the following CO_2 values: 100, 200, 330, 460, 660, and 1000 ppm, with all simulations integrated for at least 15 seasonal cycles. A clearly nonlinear, logarithmic-like response in surface temperature was seen, with greater sensitivity for lower-values of CO2 than for higher values. Oglesby and Saltzman (1992) presented a formal sensitivity analysis for key climatic quantities, computing logarithmic sensitivity coefficients at every model grid point, and three measures of the uncertainty of these coefficients, the jackknife standard deviation, the least squares (log) misfit, and the ensemble standard deviation for the 20-year 330 ppm control. Variables were grouped into those that had a relatively large sensitivity to CO_2 changes (surface temperature, sea ice, and atmospheric specific humidity) and precipitation).

More recently, we have made a simulation with a preindustrial (circa 1800 AD) atmospheric CO_2 level of 265 ppm. In Marshall et al. (in prep.) we compare these results with the 'present-day' (circa 1975) 330 ppm control, assessing both the overall model sensitivity above inherent model variability. We then compared these results to observed temperature variations from the 1850's until the 1980's finding some correspondence both in magnitude and spatial patterns of change. For both model results and observations, the changes in climatic variables are more detectable in winter than in summer, despite the former being the time of greater variability.

Patterns of Forcing

Oglesby et al. (in prep.) compared the model sensitivity to changes in solar luminosity with the model sensitivity due to CO2 changes. Similarities or disparities could suggest the relative roles of the direct response to the forcing versus modulation by feedbacks. Oglesby et al. (in prep.) report on the computation of linear sensitivity coefficients for solar luminosity simulations (as well as the same three measures of uncertainty as for CO2) and then compare these results to those of Oglesby and Saltzman (1992). They found a marked similarity in the geographic patterns of sensitivity between solar luminosity and CO2; this, combined with the fact that the largest sensitivity to solar luminosity occurs in the high latitudes in winter, precisely when the forcing is smallest, suggest the importance of feedbacks, and that regions are either 'climatically-sensitive' or 'climatically-insensitive'. This also has implications for the use of past warm earth climates as analogs for possible future climatic changes and perhaps more importantly as important tools for model validation.

SECTION V. OCEAN DATA AND COMPARISONS WITH MODEL RESULTS

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

Marine calibration data set

We have made significant progress in upgrading the surface sediment planktonic foraminifera data base that is used to make sea surface temperature (SST) estimates for past oceans. Under DOE and NSF/NOAA funding, we have obtained about 170 new coretop samples from the Pacific Ocean (Scripps Institution of Oceanography) and have added several hundred samples to the Indian and Atlantic Oceans. These data give us about 1750 surface sediments that are curated here at Brown University and will be the basis for our new SST equations. We are still trying to acquire French samples from the Southern Ocean and the Northwest Pacific and better coverage of marginal seas.

We have used data from the Global Ocean Surface Temperature Atlas (GOSTA) (Bottomly et al., 1990) as our new data base for calibration of SST. Among the available climatologies for modern SST, the GOSTA data are a 30 year (1950-1981) mean monthly climatology, are the most continuous and are available at 1° latitude-longitude resolution. We plan to use this GOSTA climatology to recalibrate our paleo-SST estimates and to compare with model computed SSTs..

The integration of the planktonic foraminifera and radiolarian data sets and comparison of their respective paleotemperature estimates is currently being pursued by Prell, who will spend the next year in residence at Oregon State University - School of Oceanography and will be working directly with N. Pisias, who developed the radiolarian data. Integration of these data is a high priority for this year.

Past sea surface temperature (SST) variations

During the past year, we have continued to evaluate and test both our calibration data (see above) and quantitative techniques for making SST estimates. We have modified our Modern Analogue Technique (MAT) to accept variable cutoff values in terms of number of analogues or the value of dissimilarity coefficients and have incorporated the GOSTA data as the new calibration. We are in the process of testing the new SST estimates based on these monthly (calendar rather than warm-cold) data. Graduate student Min-Te Chen's thesis chapter (co-authored by W. Prell and J. Imbrie) "An Intercomparison and Reexamination of Faunal Methods for Estimating Quaternary Sea-Surface Temperatures" has been completely revised and should be submitted for publication in the Fall. The difficulty of estimating SST in the tropical Pacific has led Chen to examine the role of the thermocline in controlling the distribution of Planktonic foraminifera and SST and has evolved to another thesis chapter, entitled "Thermocline Interpretation of Planktonic Foraminifera Faunal Data With Application to Late Quaternary Tropical Indo-Pacific Records." This effort has been revised to take advantage of our new Pacific calibration data and will be submitted as part of Min-Te Chen's Ph.D. thesis this fall. Another effort to understand SST variation in the equatorial Pacific by graduate student V. McKenna has led to submittal of a manuscript "The Foraminiferal Record at ODP Site 847: Paleoceanographic Response to Late Pleistocene Climate Variability". This study provides additional LGM (last glacial maximum) levels and climatic time series for comparison to model simulations.

We continue to expand the data base of LGM SST estimates for improving the CLIMAP (1981) reconstruction of the Last Glacial Maximum and for comparison with the PMIP modeling results. We have added about 50 new LGM samples in the Indian Ocean are corresponding with our colleagues to add samples that we have identified from the literature in the Atlantic and Pacific Oceans and in the marginal seas The acquisition of these additional LGM samples is slow and will continue for several years, we plan to have an updated map of SST at the LGM by the end of this grant. This work is being coordinated with the Paleoclimate Modeling Intercomparison Project (PMIP) to generate a revised set of LGM SST estimates for comparison with the model computed SSTs for the LGM experiment.

Structure of the LGM Indian Ocean.

During the past year we have revised our reconstruction of two-dimensional $\delta^{18}O$ and $\delta^{13}C$ transects (depth versus latitude) for the LGM to take account of a new calibration of the isotopic data and add some additional samples. This work is a major chapter ("Intermediate and Deep Water Circulation in the Indian Ocean during the Last Glacial Maximum") in Jiajie Chen's Ph.D. thesis, which he will defend in the Fall term of 1993. This study confirms the existence of a deep thermocline near 2000 m but suggests that it may be limited to the northern Indian Ocean along with the highly negative $d^{13}C$ (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 (1992) and Prell et al. (1992) 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). They combined the model sensitivities with the temporal variations in the forcing factors to estimate time series of monsoon strength (see also Prell and Kutzbach, 1987). The model simulated paleoclimatic time series were then compared to sedimentologic, biotic, and isotopic records of monsoon variability over the past 150,000 to 15 million years ago. These studies indicate that development of the high elevations associated with the Himalaya-Tibet produced the largest increase in monsoon intensity and that elevations of at least half of the modern plateau are required to produce monsoons as strong as currently observed. Changes in solar radiation produce almost as large a monsoon response as the elevation changes but these Milankovitch scale changes occur on relatively short time scales (10^3 to 10^5 years) compared to the mountain building time scales. Changes in the extent of glacial boundary conditions and CO_2 appear to have much smaller effects on the monsoon intensity. The comparison of marine and terrestrial paleoclimatic data (Prell et al., 1992; Prell and Kutzbach, 1992) shows the onset of monsoon wind induced upwelling and monsoon precipitation changes at about 7 to 8 million years ago are consistent with models that propose rapid uplift of Tibet at that time.

As part of out DOE effort, we have published a more detailed analysis of the variability of monsoon-related winds and ocean responses over the past 400,000 years ago (Clemens and Prell, 1991; Clemens et al., 1991) and compared it to the forcing mechanisms suggested by our studies with the CCM. We have also published comparisons with ocean model simulations of upwelling in the Arabian Sea (Luther et al., 1990; Prell et al., 1990), with pollen and isotopic-based SSTs off southeast Africa (van Campo, et al., 1990).

As part of our efforts to identify marine data sets appropriate for comparison with model simulations, W. Prell helped organize a workshop and served as co-editor for the publication, Evolution of upwelling systems since the Early Miocene (Summerhayes, C.P., Prell, W.L., and K.C. Emeis (eds.), 1992), which was Special Publication No. 64 of the Geological Society of London.

SECTION VI. TERRESTRIAL DATA AND COMPARISONS WITH MODEL RESULTS

During the past 3 years, research activities with terrestrial data sets have focused on comparing pollen-generated paleoclimatic estimates with climate model results (Webb et al., 1993a,b; R. Webb et al., 1993), continued development of the global terrestrial paleoclimatic data base at Brown, and work on preparing a paleovegetation maps for eastern North America for 6000 and 18,000 (radiocarbon) yr BP for use in checking the PMIP (Paleoclimate Modeling Intercomparison Project) experiments. We plan to expand the paleovegetation mapping to a global scale once we have tested the methods on eastern North America

Several articles mark the research progress. They include maps of temperature, and precipitation estimates for eastern North America for each 3000-year interval from 18,000 (radiocarbon) years ago to present (Webb et al., 1993a), 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., 1993a), estimates of moisture balance from pollen data in the northeastern United States that are compared to lake level data and to model simulations (R, Webb et al., 1993), a Dahlem Conference report on the use of paleoclimatic data as analogs for understanding future global changes, and a review article describing the key results from the data/model comparisons for 18,000 (radiocarbon) yr BP to present and showing how these results relate to global change research in terrestrial ecosystems and in the geological record (Webb and Bartlein, 1992).

We have continued to update and increase the coverage in the pollen data base at Brown. We have also transferred data from the North American Pollen Data Base being developed for the Paleoclimate Data Center at NOAA's NGDC

(National Geophysical Data Center) in Boulder, and now have the data base available at Brown on personal computers. Previously, it was only available on the IBM Mainframe, and its use there was becoming cumbersome. We can now update our database as new data become available at NGDC.

A key research effort has been to prepare a paleovegetation maps for 6000 and 18,000 (radiocarbon) yr BP for eastern North America (Solomon et al., 1993). We are comparing the maps with simulations from a global vegetation model developed by Prentice et al. (1992), which was applied to GCM simulations for 6000 and 18,000 (radiocarbon) yr BP. This is a prototype study for one that we plan to extend to a global paleovegetation database for testing GCM results globally. This research is coordinated with PMIP and the need to validate the planned global model simulations. This research follows up on the earlier simulation of paleovegetation maps from model output by Guetter and Kutzbach (1990).

SECTION VII. WORKSHOPS

The PI's met in Madison in January, 1993 and discussed the research progress. I.C. Prentice and S. Harrison attended the meeting and we discussed coordination of global change research on past climates and vegetation modeling with them. Winkler (UW-Madison) with NOAA funding is developing and updating the global lake-level data set of Perrott et al. (1989) for data/model comparisons. A meeting of collaborators in this project was held in August, 1993 in Madison, WI.

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