SIMULATED AND OBSERVED PRE-INDUSTRIAL TO MODERN VEGETATION AND CLIMATE CHANGES

M. Notaro, Z. Liu, R. Gallimore, S. J. Vavrus, J. E. Kutzbach
Center for Climatic Research, University of Wisconsin-Madison, Madison, Wisconsin

I. C. Prentice
Department of Earth Sciences, University of Bristol, United Kingdom

R. L. Jacob
Argonne National Laboratory, Chicago, Illinois

1. INTRODUCTION

Rising concentrations of atmospheric carbon dioxide during the 20th century have likely contributed towards changes in both climate and vegetation. The global mean surface air temperature has risen by an estimated 0.4-0.8°C since the late 19th century, with the greatest warming over the northern mid-high latitudes (Hansen et al., 1999; Houghton et al., 2001). Consistent with the high latitude warming of the 20th century has been a poleward expansion of the northern boreal forest (D'Arrigo et al., 1987). A greening trend in the boreal zone was identified in satellite data by Myneni et al. (1997) and further investigated by Zhou et al. (2001) and Lucht et al. (2002). This study focuses on the pre-industrial to modern period and investigates the radiative and physiological impacts of the increase in CO_2 on climate and vegetation.

2. METHODOLOGY

The model used in this study is the fully coupled global atmosphere-ocean-land model FOAM-LPJ (Gallimore et al., 2004; Notaro et al., 2004), run without flux adjustment. The FOAM1.5 atmosphere-ocean model (Jacob, 1997) was coupled to LPJ dynamic vegetation model (Sitch, 2000). The three main transient simulations performed for this study were RP (radiative+physiological), R (radiative), and P (physiological), all 100 years in length and forced by rising levels of CO_2.

Corresponding author address: Michael Notaro, 1225 West Dayton Street, Madison, WI 53711; mnotaro@wisc.edu.

3. RESULTS

FOAM-LPJ reproduced broad aspects of the natural (excluding land-use) biome distribution as well as seasonal shifts in vegetation, despite overprediction of forest in many areas and an excessive simulated area of polar desert. Simulations with rising CO_2 produced a general global warming of 1°C, strongest at the high latitudes. The overall warming was dominated by the radiative effect of rising CO_2, although the physiological effect contributed some additional regional warming over central and eastern Asia, northern Europe, and the United States (Fig. 1). The RP simulation also showed a 3% rise in global land surface precipitation as the hydrological cycle intensified.

The model simulated a global greening trend, which included a poleward expansion of the Eurasian and North American boreal forest and an expansion of tundra into the northern polar desert (Fig. 2). The simulations suggest that, during the pre-industrial to modern time, the increase in global total tree cover and vegetation was primarily due to the physiological effect on plant growth, with positive trends noted even within the first couple of decades of run P. The radiative effect supported boreal expansion by extending the growing season and melting snow cover at high latitudes. The physiological effect accelerated the northern high latitude expansion by enhancing forest growth in ecological transition regions, where both trees and grass co-exist, through CO_2 fertilization.

4. REFERENCES

D'Arrigo, R., G. C. Jacoby, and I. Y. Fung, 1987: Boreal forests and atmosphere-biosphere exchange of carbon dioxide. *Nature*, **329**, 321-323.

Gallimore, R., R. L. Jacob, and J. E. Kutzbach, 2004, submitted: Coupled atmosphere-ocean-vegetation simulations for modern and mid-Holocene climates: Role of extratropical vegetation cover feedbacks. *Climate Dyn.*.

Goldewijk, K. K., 2001: Estimating global land use change over the past 300 years: the HYDE database. *Global Biogeochemical Cycles*, **15(2)**: 417-434.

Goldewijk, C. G. M. K., and J. J. Battjes, 1997: A hundred year (1890-1990) database for integrated environmental assessments (HYDE, version 1.1). RIVM Report no. 422514002. 110 pp.

Hansen, J. E., R. Ruedy, J. Glascoe, and M. Sato, 1999: GISS analysis of surface temperature change. *J. Geophys. Res.*, **104**, 30 997-31 022.

Houghton, J. T., Y. Ding, D. Griggs, M. Noguer, P. van der Linden, X. Dai, K. Maskell, and C. Johnson Eds.,. , 2001: *Climate Change 2001: The Scientific Basis*. Cambridge University Press, 881 pp.

Jacob, R. L., 1997: Low frequency variability in a simulated atmosphere ocean system. Ph.D. Thesis, University of Wisconsin, Madison, 1997.

Lucht, W., I. C. Prentice, R. B. Myneni, S. Sitch, P. Friedlingstein, W. Cramer, P. Bousquet, W. Buermann, and B. Smith, 2002: Climatic control of the high-latitude vegetation greening trend and Pinatubo effect. *Science*, **296**, 1687-1689.

Myneni, R. B., C. D. Keeling, C. J. Tucker, G. Asrar, and R. R. Nemani, 1997: Increased plant growth in the northern high latitudes from 1981-1991. *Nature*, **386**, 698-701.

Notaro, M., Z. Liu, R. Gallimore, S. J. Vavrus, J. E. Kutzbach, I. C. Prentice, and R. L. Jacob, 2004, submitted: Simulated and observed pre-industrial to modern vegetation and climate changes. *J. Climate*.

Sitch, S., 2000: The role of vegetation dynamics in the control of atmospheric CO_2 content. Ph.D. dissertation, Lund University, Lund, 213 pp.

Zhou, L., C. J. Tucker, R. K. Kaufmann, D. Slayback, N. V. Shabanov, and R. B. Myneni, 2001: Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *J. Geophys. Res.*, **106**, 20 069-20 083.

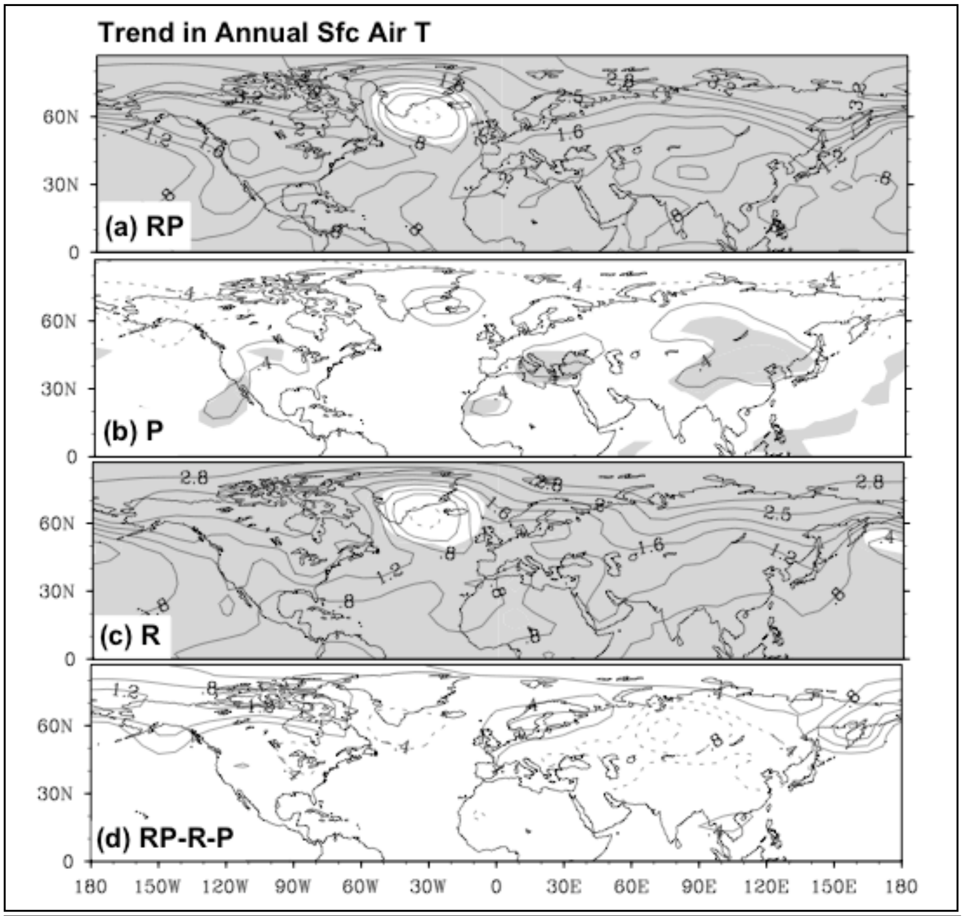

Fig.1 Trend in annual surface air temperature (°C century^{-1}) over 100 years for the (a) RP, (b) P, and (c) R runs over the northern mid- and high-latitudes. The difference in trends (RP-R-P) is shown in (d). Shading in (a)-(c) represent statistically significant trends with P<0.05.

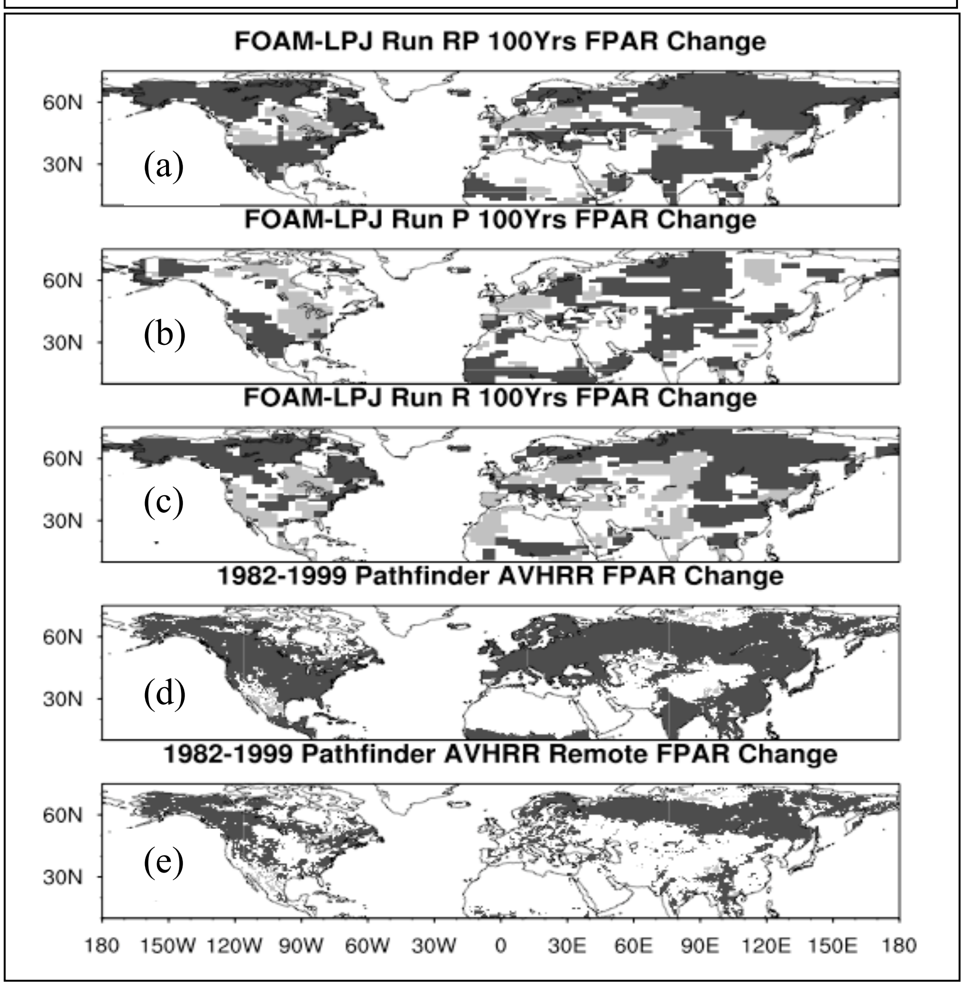

Fig. 2 Change in annual-average FPAR (fraction of photosynthetically active radiation) over 100 years from (a) RP run member 1, (b) P run, and (c) R run. Increases ≥0.1 are in dark shading and decreases ≤-0.1 are in light shading. The change in annual-average FPAR during 1982-1999 based on Pathfinder AVHRR data (Myneni et al., 1997) is shown in (d). The change shown in (e) is the same as in (d) except regions that were anthropogenically-altered by croplands and pastures are masked out, based on 1990 HYDE data (Goldewijk, 2000; Goldewijk and Battjes, 1997).