Available online at www.sciencedirect.com
ScienceDirect
Global and Planetary Change 54 (2006) 94 – 108
GLOBAL AND PLANETARY CHANGE
www.elsevier.com/locate/gloplacha

Soil moisture regulates the biological response of elevated atmospheric CO_2 concentrations in a coupled atmosphere biosphere model

Dev Niyogi [a,*], Yongkang Xue [b]

[a] *Departments of Agronomy and Earth and Atmospheric Sciences, Purdue University, United States*
[b] *Departments of Geography and Atmospheric and Oceanic Sciences, University of California at Los Angeles, United States*

Received 16 March 2005; received in revised form 5 February 2006; accepted 5 February 2006
Available online 23 June 2006

Abstract

Terrestrial biosphere models/land surface models are routinely used to study the effects of CO_2 doubling and climate change. The objective of this study is to show that the biological response associated with CO_2 doubling is important, and that the effects intrinsically depend on the soil moisture state. Therefore, using a coupled biosphere–atmosphere model, we tested the hypothesis that the biological effects of CO_2 changes in biosphere models are significantly coupled to the hydrological feedback via soil moisture availability in a terrestrial biosphere/land surface model. The results from a 15-day simulation of a photosynthesis-based land surface model, dynamically coupled to an atmospheric boundary layer and surface energy balance scheme, were analyzed to test the hypothesis. The objective was to analyze the biological effects of CO_2 doubling under high as well as limiting soil moisture conditions for prescribed changes to the vegetation/land use type. The approach was to analyze the results from a coupled land surface-atmosphere model obtained by changing the biome type for each run. Sensitivity for all of the nine global vegetation type changes, as defined through the Simple Biosphere Model ver. 2 (SiB2) land cover classification, were analyzed for evapotranspiration and net carbon assimilation. The results indicated that: (i) the soil moisture (and its interaction with CO_2) has a direct (first-order) effect on the biological effects of CO_2 changes and the terrestrial ecosystem response; (ii) the biological impacts associated with CO_2 changes in a biospheric model should be interpreted in consideration of the soil moisture status; and droughts or high soil moisture availability can enhance or completely balance or even reverse the effects associated with CO_2 changes; (iii) for each vegetation type, the model results indicated a different response to soil moisture and CO_2 changes; and resolving the direct and indirect effects explicitly, both C3 and C4 vegetation, appeared to be significantly affected by the biological effects of CO_2 changes, and (iv) the explicit coupling between soil moisture/hydrological state and the CO_2 changes need to be explicitly considered in projecting climate change impacts. The study results also indicated that feedback pathways can be efficiently determined by dissociating the direct and the interactive effects of CO_2 impacts.

Keywords: Land–atmosphere interaction; CO_2 doubling; Soil moisture; Climate change; Net primary productivity

1. Introduction

Though a consensus exists that atmospheric CO_2 levels have been rising since the pre-industrial revolution, the effects of these changes are still under investigation. For example, Diffenbaugh et al. (2005) used a coupled

* Corresponding author.
E-mail address: climate@purdue.edu (D. Niyogi).

0921-8181/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2006.02.016