Impact Assessment of Satellite-Derived Leaf Area Index Datasets Using a General Circulation Model

HYUN-SUK KANG

Department of Geography, University of California, Los Angeles, Los Angeles, California

YONGKANG XUE

Department of Geography, and Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, Los Angeles, California

G. JAMES COLLATZ

NASA Goddard Space Flight Center, Greenbelt, Maryland

(Manuscript received 9 November 2005, in final form 12 July 2006)

ABSTRACT

This study assesses the impact of two different remote sensing–derived leaf area index (RSLAI) datasets retrieved from the same source (i.e., Advanced Very High Resolution Radiometer measurements) on a general circulation model's (GCM) seasonal climate simulations as well as the mechanisms that lead to the improvement in simulations over several regions. Based on the analysis of these two RSLAI datasets for 17 yr from 1982 to 1998, their spatial distribution patterns and characteristics are discussed. Despite some disagreements in the RSLAI magnitudes and the temporal variability between these two datasets over some areas, their effects on the simulation of near-surface climate and the regions with significant impact are generally similar to each other. Major disagreements in the simulated climate appear in a few limited regions.

The GCM experiment using the RSLAI and other satellite-derived land surface products showed substantial improvements in the near-surface climate in the East Asian and West African summer monsoon areas and boreal forests of North America compared to the control experiment that used LAI extrapolated from limited ground surveys. For the East Asia and northwest U.S. regions, the major role of RSLAI changes is in partitioning the net radiative energy into latent and sensible heat fluxes, which results in discernable warming and decrease of precipitation due to the smaller RSLAI values compared to the control. Meanwhile, for the West African semiarid regions, where the LAI difference between RSLAI and control experiments is negligible, the decrease in surface albedo caused by the high vegetation cover fraction in the satellite-derived dataset plays an important role in altering local circulation that produces a positive feedback in land/atmosphere interaction.

1. Introduction

During the last 3 decades, the role of land surface processes in controlling exchanges of energy, mass, and momentum between the land surface and atmosphere has been investigated by numerous studies through field measurements as well as numerical experiments (e.g., Sellers et al. 1988; Dickinson and Henderson-Sellers 1988; Xue and Shukla 1993; Betts et al. 1996; Xue et al. 2004, 2006; among many others). These studies generally show that interactions between the atmosphere and terrestrial ecosystem play a significant role in climate variations that is as important as atmospheric dynamics and composition, ocean circulation, and solar orbit perturbations (Pielke et al. 1998). In most biophysical land surface models, the leaf area index (LAI), defined as the one-sided green leaf area per unit ground area, is an important indicator of vegetation state because it affects the radiative transfer process within the canopy and evapotranspiration from the surface and consequently modulates near-surface climate and atmospheric circulations.

In this context, more than 2 decades of the Advanced

Corresponding author address: Yongkang Xue, 1255 Bunche Hall, Department of Geography, University of California, Los Angeles, P.O. Box 951524, Los Angeles, CA 90095-1524.
E-mail: yxue@geog.ucla.edu

DOI: 10.1175/JCLI4054.1

Very High Resolution Radiometer (AVHRR) measurements have provided valuable information on vegetation properties such as Normalized Difference of Vegetation Index (NDVI), LAI derived from NDVI, and their long-term and interannual variations in association with climate variability (e.g., Myneni et al. 1998; Los et al. 2000). In spite of several factors that may cause uncertainties in the retrieved vegetation properties (e.g., intersensor discontinuity, orbital drift, volcanic aerosols, clouds, and water vapor, etc.), it has been proposed that effects of climate change have been apparent in vegetation's phenology since the early 1980s, especially in mid- and high latitudes of the Northern Hemisphere. For example, Slayback et al. (2003) have found that significant long-term trends in NDVI can be identified among several datasets that differ in their approaches to correct for sensor calibration, orbital characteristics, and aerosols. Meanwhile, they also suggested that independent validation by comparison with other measurements is needed to help in identifying uncertainties in datasets.

Despite some qualitative agreement in terms of long-term trend and interannual variation of vegetation activity, there exist significant discrepancies in remote sensing–derived LAI (RSLAI) among datasets because of their different retrieval algorithms and atmospheric corrections even though measurements are from the same source. There have been a number of analytical studies to estimate uncertainties in the RSLAI and/or NDVI fields by conducting extensive error analysis (e.g., Los et al. 2000; Buermann et al. 2002) and by evaluating consistency between RSLAI and near-surface climatic variables such as sea surface temperature (SST), precipitation, and surface air temperature (e.g., Myneni et al. 1996; Los et al. 2000; Buermann et al. 2002; Lotsch et al. 2003). In addition, efforts have been made to evaluate the quality of RSLAI values by direct comparison with field measurements (e.g., Los et al. 2000; Buermann et al. 2002). This type of comparison, however, has usually been compromised to some degree because of the difference in spatial measurement scales.

To investigate the quality of global RSLAI datasets and the implications of their use in climate models, a number of numerical experiments have been conducted by using RSLAI estimates as a surface boundary condition of GCMs (e.g., Bounoua et al. 2000; Oleson and Bonan 2000; Buermann et al. 2001; Guillevic et al. 2002; van den Hurk et al. 2003; Tian et al. 2004a,b; Lawrence and Slingo 2004a,b). All of these studies stressed the importance of the accurate designation of land surface parameters in a climate model for improvements of simulations. Up until now, these studies have focused on impacts of RSLAI on the simulated climate in terms of the overall difference pattern at global scale and/or some areas associated with the same vegetation types, as well as the annual cycle of continental and/or global averages (Buermann et al. 2001; Lawrence and Slingo 2004a; Tian et al. 2004b). Another issue in RSLAI application is to estimate the impacts of uncertainties in RSLAI data in climate simulations. There have been several sensitivity experiments regarding this issue that investigate impacts of the potential uncertainties in the LAI dataset and its seasonality (Chase et al. 1996; van den Hurk et al. 2003), the surface vegetation fraction (Oleson and Bonan 2000; Bounoua et al. 2000), and the interannual variability of vegetation (Buermann et al. 2001; Guillevic et al. 2002). These studies used a single RSLAI dataset and assumed somewhat extreme potential changes in surface vegetation to design their experiments. However, the response of the models to uncertainties associated with the currently existing RSLAI has not been addressed.

The purposes of this study are to investigate 1) the impact of two widely used RSLAI datasets retrieved from the same source (i.e., AVHRR measurements) on a GCM's seasonal climate simulation and 2) the mechanisms that lead to improvements in regional simulations from using RSLAI fields instead of prescribed values derived from ground surveys, which are generally extrapolated spatially according to vegetation-cover type. We believe these issues, which have not been addressed in previous studies, should be among the major issues in the forthcoming research on RSLAI data applications. The selected regions for regional analysis are East Asian, North American, and West African summer monsoon areas as well as boreal forests in North America, which have been identified as the regions sensitive to vegetation biophysical processes (VBPs; Xue et al. 2004).

In this paper, section 2 describes the two RSLAI datasets used in this study. General patterns of seasonal mean RSLAI values for boreal spring and summer are also briefly explained in this section. GCM description and experimental design are presented in section 3. Section 4 discusses the results of GCM simulations, highlighting the impacts of uncertainties in RSLAI datasets and the mechanisms leading to improvements in the seasonal climate simulation over several regions by using RSLAI. Finally, concluding remarks are given in section 5.