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Utilizing satellite imagery and GLOBE student data to model soil dynamics

Jessica Robin[a,b,*], Elissa Levine[b], Susan Riha[c]

[a] University of Maryland, College Park, MD 20742, USA
[b] Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA
[c] Cornell University, Ithaca, NY 14853, USA

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Abstract

General Purpose Atmosphere Plant Soil Simulator (GAPS), a menu-driven soil-vegetation-atmosphere transfer (SVAT) model, was used to simulate soil water dynamics from 1998 through 2001 for Greenville, PA, USA. GLOBE student data collected by students from Reynolds Junior and Senior High School, coupled with normalized difference vegetation index (NDVI) data derived from SPOT4 vegetation imagery, were used to parameterize and validate the model. Data from the National Weather Service Cooperative (NWSC) was used to evaluate the GLOBE dataset. Overall, there was a high index of agreement ($d > 0.80$) between field measurements and simulated soil water values from both datasets (GLOBE and NWSC). Simulations using the GLOBE climate data outperformed the NWSC data for the 1999, 2000, and 2001 growing seasons. In addition, the GLOBE simulations showed that NDVI could be utilized to predict transpiration periods (QI, QII, and QIII) for northern latitudes >35° with a distinct winter period. In phenological terms, QI reflects the onset of the growing season when vegetation is greening up (NDVI < 0.60) and transpiration is beginning (<2 mm/day) and QII reflects the end of the growing seasons when vegetation is greening down and transpiration is decreasing. QIII reflects the height of the growing season when transpiration rates average between 2 and 5 mm per day and NDVI is at its maximum (>0.60). Results of this study demonstrate that GLOBE student data, coupled with remotely sensed data, can provide an important source of input and validation information for capacitance SVAT models such as GAPS.
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Keywords: SVAT; Model; Soil moisture; Transpiration; NDVI

1. Introduction

As the Earth's climate changes, scientists are seeing changes in the phenology of global vegetation using satellite imagery (Myneni et al., 1997, 1998; Tucker et al., 2001; Zhou et al., 2001). In biomes where climate changes seasonally, soil moisture and temperature also show seasonal patterns, which correspond with above ground climate (Levine and Knox, 1994). Thus, the variability in the length of the growing season may be due to the number of days that moisture and heat in the soil are available for plant growth. Soil moisture and temperature are dynamic in that they change rapidly depending on the climate, topography, land cover and soil properties that are present. They play a major role in the type, amount, and timing of vegetative growth as well as in the hydrologic cycle by affecting the rate of evapotranspiration (ET), drainage, and surface run-off. These processes are difficult to measure directly, but are nonetheless important for understanding water and energy fluxes. Furthermore, evapotranspiration and soil moisture are recognized as the central physical process and variable for predicting these fluxes (Milly, 1992; Mintz and Walker, 1993; Felzer and Heard, 1999).

Soil-vegetation-atmosphere transfer (SVAT) models have become an important tool for simulating these processes and furthering our understanding of water and energy dynamics (McIntyre et al., 1996; Olioso et al., 1996; Koster and Milly, 1997). For accuracy and reliability, detailed measurements obtained over a wide spatial scale at regular temporal intervals are required to drive and validate these models. However, these types of data are often difficult to obtain, or when available, insufficient in the time domain (e.g. daily net radiation measurements may be required but are unavailable for cloudy days). Ideally, simulation models should make use of the minimum number of regularly available field measurements to remain accurate enough to capture ecosystem dynamics effectively.

While many consider Penman–Monteith (1948 and 1964) the most accurate method for estimating ET, it also requires the most detailed measurements (Jensen et al., 1990; Choudhury, 1997). Furthermore,

* Corresponding author. Tel.: +1 301 614 6636; fax: +1 301 614 6695.
E-mail address: jrobin@ltpmail.gsfc.nasa.gov (J. Robin).

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net radiation, the most essential parameter for the Penman–Monteith algorithm, is not available for many parts of the world. For example, FLUXNET, a global network of micrometeorological tower sites, lacks sufficient radiation measurements to spatially capture surface energy fluxes. With this lack of field measurements, remote sensing observations coupled with surface flux models have been used to calculate ET (Gillies et al., 1997; Olioso et al., 1999; French et al., 2000). The problem with these methods is that they often rely on observations at a coarser resolution than the land surface features that influence the surface energy fluxes (French et al., 2003). Given the difficulties in capturing surface energy fluxes across spatial domains, empirical methods for calculating ET, such as Thornthwaite (1948) and Linacre (1977), still retain much appeal (Mintz and Walker, 1993). Both of these methods rely on mean surface air temperature, day length, and elevation to estimate potential evapotranspiration. The Linacre method approximates the Penman equation and has shown closer estimations to actual ET measurements and Penman calculated ET values (Linacre, 1977).

In this study, student environmental data from the GLOBE Program, and remotely sensed NDVI data were used to determine whether these measurements were sufficient to initialize, drive, and provide accurate results for simulating water and energy fluxes with the General Purpose Atmosphere Plant Soil Simulator (GAPS). GAPS, a SVAT model developed by Riha et al. (2003), is a menu-driven capacitance model, with multiple soil layers, that simulates soil, plant, and atmospheric processes (e.g. evapotranspiration, soil water flow, plant water uptake) using a choice of algorithms and robust graphical display of output. The graphic display output of GAPS, both during and upon completion of a simulation run, provides a dynamic visualization of a particular process. GAPS can display a dynamic view of up to 4, out of a possible 40, aspects of the plant–soil–atmosphere system as it is being simulated. The software can run on any personal computer that uses Windows95 or higher operating systems. GAPS has been utilized in a variety of studies (e.g. Buttler and Riha, 1987; Buttler and Riha, 1992; Melkonian et al., 1998; McDonald and Riha, 1999; Rossiter and Riha, 1999). The input parameters and degree of detail required to run a simulation in GAPS depend on the model algorithms selected by the user. This attribute makes this model a good choice for GLOBE data. General to more complex simulations can be performed based on the available data for a particular site.

Data collected by GLOBE students from Reynolds Junior and Senior High School in Pennsylvania, USA, were used to parameterize and validate the model. The GLOBE Program is an international partnership network of K-12 students, teachers, and scientists working together to study and understand the global environment. It is a cooperative effort, led by University Corporation of Atmospheric Research (UCAR) and Colorado State University, and funded in the United States by a federal interagency program including, NASA, NSF, and U.S. State Department. Internationally, GLOBE is a partnership between the United States and over 100 countries. GLOBE is designed as both an education and research Earth Science program. Teachers are trained in the GLOBE protocols and use the educational materials to help students improve their science and math skills (Becker et al., 1997; Haskett et al., 2000; Levine, 1998; Brooks and Mims, 2001; Aquino and Levine, 2003). By participating in the program, teachers and students also contribute data for scientific research (Fried, 1997; Kramer, 1998; Mims, 1999; Clemmons, 2000; Congalton and Russell, 2002). Currently, over 28,000 teachers have been trained in the program, and over 12 million data measurements have been reported by students worldwide. GLOBE students make observations and measurements on the soils, hydrology, land cover, phenology, and atmosphere at or near their schools. Utilizing GPS receivers, students determine the latitude and longitude of their sites and conduct a series of protocols established by scientists in the various disciplines. Students report their data through the Internet to the GLOBE data archive, where scientists can access these data for research purposes.

5. Conclusion

The data collected by GLOBE students from Reynolds Junior and Senior High School were highly correlated with SPOT4 vegetation data for the study site. The GAPS model, parameterized with the student measurements, successfully predicted soil water dynamics for 1998 through 2001. The model's maximum temperature stipulation for transpiration was accurate for the site as shown by: (1) the strong index of agreement and correlation between the simulated and measured soil water values with both the GLOBE and NWSC datasets; (2) the strong correlation between the students' temperature measurements and the NDVI values; and (3) the correspondence between NDVI values and simulated transpiration rates during the growing season. Furthermore, the students' weather dataset outperformed the National Weather Service Cooperative dataset.

This study illustrates that NDVI could be utilized to predict transpiration periods for northern latitudes >35° that have distinct winter periods. Furthermore, GLOBE student measurements, coupled with NDVI data, can provide an important source of input and validation information for capacitance SVAT models such as GAPS. GLOBE through its extensive worldwide network provides a valuable resource for data that is currently underutilized for these types of models. In addition, data from GLOBE schools provides the opportunity to compare ecosystem function across a wide variety of biomes.