Comparison of Four Different Stomatal Resistance Schemes Using FIFE Observations

DEVDUTTA S. NIYOGI AND SETHU RAMAN

Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina

(Manuscript received 11 July 1996, in final form 12 November 1996)

ABSTRACT

Stomatal resistance (R_s) calculation has a major impact on the surface energy partitioning that influences diverse boundary layer processes. Present operational limited area or mesoscale models have the Jarvis-type parameterization, whereas the microscale and the climate simulation models prefer physiological schemes for estimating R_s. The pivotal question regarding operational mesoscale models is whether an iterative physiological scheme needs to be adopted ahead of the analytical Jarvis-type formulation.

This question is addressed by comparing the ability of three physiological schemes along with a typical Jarvis-type scheme for predicting R_s using observations made during FIFE. The data used is typical of a C4-type vegetation, predominant in regions of high convective activity such as the semiarid Tropics and the southern United States grasslands. Data from three different intensive field campaigns are analyzed to account for vegetation and hydrological diversity.

It is found that the Jarvis-type approach has low variance in the outcome due to a poor feedback for the ambient changes. The physiological models, on the other hand, are found to be quite responsive to the external environment. All three physiological schemes have a similar performance qualitatively, which suggests that the vapor pressure deficit approach or the relative humidity descriptor used in the physiological schemes may not yield different results for routine meteorological applications. For the data considered, the physiological schemes had a consistently better performance compared to the Jarvis-type scheme in predicting R_s outcome. All four schemes can, however, provide a reasonable estimate of the ensemble mean of the samples considered. A significant influence of the seasonal change in the minimum R_s in the Jarvis-type scheme was also noticed, which suggests the use of nitrogen-based information for improving the performance of the Jarvis-type scheme. A possible interactive influence of soil moisture on the capabilities of the four schemes is also discussed. Overall, the physiological schemes performed better under higher moisture availability.

1. Introduction

Various planetary boundary layer (PBL) and general circulation models (GCMs) are linked with soil–vegetation–atmosphere transfer (SVAT) schemes. Some of these land surface parameterizations presently employed in PBL and GCM studies include Deardorff (1978), BATS (Dickinson et al. 1986), Avissar et al. (1985), SiB (Sellers et al. 1986), Wetzel and Chang (1988), Noilhan and Planton (1989), Acs (1994), Bosilovich and Sun (1995), Viterbo and Beljaars (1995), Pleim and Xiu (1995), and Alapaty et al. (1996a). These models have varying degrees of complexity when describing the energy partitioning at the surface—that is, at the soil and at the vegetation. In addition to these ''operational'' or ''meteorological'' schemes, physiologically intensive models for the terrestrial biosphere–atmosphere interactions also exist (see Farquhar and Sharkey 1982). Some of these include Farquhar et al. (1980), Ball et al. (1987), Meyers and Paw U (1987), Lynn and Carlson (1990), Raupach (1991), Collatz et al. (1991, 1992), Kim and Verma (1991), Baldocchi (1992, 1994), Jacobs (1994), Dougherty et al. (1994), SiB2 (Sellers et al. 1996), Cox et al. (1996), and IBIS (Foley et al. 1996). Although other approaches such as those used by Monteith (1995a,b) and Makela et al. (1996) seem to provide promising insight for understanding the SVAT strategy from observations, they are still evolving and have not been incorporated in weather or climate simulation models yet.

One of the principal differences between the ''meteorological'' and the ''physiological'' approach of the SVAT parameterization is the manner in which the stomatal response is modeled. The stomatal response, quantified as stomatal resistance (or conductance), is a measure of the difficulty (or ease) for the vegetation to transpire. Change in the transpiration alters the evapotranspirative/latent heat flux, which due to the surface energy balance constraints in the modeling perspective modifies the sensible heat flux realizations (cf. Alapaty et al. 1996a; Jarvis and McNaughton 1986; DeBruin 1983). The possible impact of the stomatal resistance changes on the coupled atmospheric processes, are quantified in Figs. 1a–c (adopted from Niyogi 1996).

Corresponding author address: Prof. Sethu Raman, Dept. of MEAS, North Carolina State University, Raleigh, NC 27695-8208.
E-mail: sethu_raman@ncsu.edu