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Time series vegetation aerodynamic roughness fields estimated from modis observations

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Abstract

Most land surface models used today require estimates of aerodynamic roughness length in order to characterize momentum transfer between the surface and atmosphere. The most common method of prescribing roughness is through the use of empirical look-up tables based solely on land cover class. Theoretical approaches that employ satellite-based estimates of canopy density present an attractive alternative to current look-up table approaches based on vegetation cover type that do not account for within-class variability and are oftentimes simplistic with respect to temporal variability. The current research applies Raupach's formulation of momentum aerodynamic roughness to MODIS data on a regional scale in order to estimate seasonally variable roughness and zero-plane displacement height fields using bulk land cover parameters estimated by [Jasinski, M.F., Borak, J., Crago, R., 2005. Bulk surface momentum parameters for satellite-derived vegetation fields. Agric. For. Meteorol. 133, 55–68]. Results indicate promising advances over look-up approaches with respect to characterization of vegetation roughness variability in land surface and atmospheric circulation models.

Keywords: Aerodynamic roughness; MODIS; Time series; Southern Great Plains

1. Introduction

Many contemporary model parameterizations of land–atmosphere fluxes, including momentum, sensible heat and latent heat, require knowledge of aerodynamic roughness length. Examples include Soil–Vegetation–Atmosphere Transfer (SVAT) modeling (e.g., Sellers et al., 1986, 1996), hydrological modeling (e.g., Chen et al., 1996), data assimilation for numerical weather prediction (e.g., Mitchell et al., 2004), mesoscale modeling (e.g., Grell et al., 1995), and global climate modeling (e.g., Bonan, 1998).

Typically, modelers assume that the momentum roughness is identical for all locations that fall into a particular land cover class. The assumed values may be time-invariant (Chen et al., 1996), or may have simple seasonality for differentiating between leaf-off and leaf-on conditions (Grell et al., 1995). These look-up approaches ignore the inherent temporal and spatial variability of land cover and the concomitant effects on momentum transfer.

Two fundamental momentum aerodynamic roughness variables are roughness length, z_0 and zero-plane displacement, d_0. Roughness length is the height above the surface at which the mean logarithmic wind profile

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theoretically reaches zero. The zero-plane displacement is the height above the land surface to which roughness elements (e.g., buildings, vegetation) have effectively displaced the momentum-absorbing properties of the surface. From Monin–Obukhov similarity, roughness length and zero-plane displacement are related under neutral conditions via the logarithmic wind profile equation (e.g., Brutsaert, 1982):

$$\frac{u_z}{u_*} = \frac{1}{\kappa}\ln\left(\frac{z-d_0}{z_0}\right) \quad (1)$$

where u_z is the magnitude of the horizontal wind velocity vector at height z above ground level, u_* the friction velocity and κ is von Karman's constant. Through their link with u_* in (1), z_0 and d_0 help to characterize the intensity of turbulence and the efficiency of turbulent exchanges of heat, moisture, and momentum between the land surface and the atmosphere.

Both field experimental and theoretical approaches have been developed for estimating roughness. If a specific location is of interest, the typical method is analysis of field-based measurements of wind profiles under neutral stability conditions. Most published values of z_0 and d_0 are derived in this manner. For example, Knohl et al. (2003) analyzed roughness in a deciduous forest at different foliage densities. Their results indicated that roughness length decreased from 3.3 to 2.5 m as canopy density, quantified by plant area index, increased from 1.4 to 6.4.

A second approach is to estimate roughness based on theoretical models of surface drag and physical properties of the surface elements. Raupach (1992, 1994) followed the second approach using both wind-tunnel and field data to fit his mathematical formulations for the normalized roughness length z_0/h and displacement height d_0/h, where h is the canopy height, as functions of canopy density. This theory maintained that beyond a critical canopy density, additional roughness elements actually decreased aerodynamic roughness length as flow begins to skim over the canopy. Jasinski and Crago (1999) applied Raupach's theory to a pine forest site, employing satellite-based estimates of canopy area index using a geometric approach, with good comparison to ground-based estimates. Schaudt and Dickinson (2000) also used satellite-based estimates of canopy density to generate estimates of aerodynamic roughness over coniferous forest within the BOREAS Southern Study Area, though the theoretical basis was slightly different in that they accounted for the effects of leaf area index rather than canopy area index. Comparatively less research has been conducted over other land cover types. Jasinski et al. (2005) estimated bulk parameter values for Raupach's equations for the principal, satellite-derived vegetation fields in the U.S. Southern Great Plains. That work provides the necessary parameters for the current analysis.

This research examines the seasonal and spatial variability of momentum roughness variables over the Southern U.S. Great Plains. The region has been a subject of interest in recent field campaigns such as ARM SGP, the Atmospheric Radiation Measurement campaign in the Southern Great Plains (Leese, 1997) and has been selected here for its extensive areas of relative vegetation uniformity, low topographic relief and its pronounced phenology. The intent is to compare and characterize the seasonal variability in momentum roughness of the principal vegetation types of the region.

The roughness variables are to be estimated from satellite data, specifically using the leaf area index (LAI) data product (Myneni et al., 2002) generated from data captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument orbiting aboard the Terra platform (Salomonson et al., 1989; Justice et al., 2002). The canopy density information is to be used as input to land cover-specific model equations derived from Raupach's roughness parameterization (1992) with parameters for specific land cover types from Jasinski et al. (2005).

2. Data and methods

2.1. Study area

The ARM SGP site is approximately 140,000 km^2 centered on 36.62°N, 97.50°W, covering much of northern Oklahoma and southern Kansas, USA. For the current research, the area of interest is expanded to the east of the formal SGP site to ensure sufficient data and to permit analysis at a regional scale. In total, the study area consists of two horizontally adjacent MODIS grid tiles, corresponding to an area 1200 km (latitudinally) by 2400 km (longitudinally).

The SGP site has been well characterized (e.g., Jackson et al., 1999), but as the current study area is of greater extent it merits additional description. The climate is mid-latitude continental for the majority of the area, with the growing season occurring during the Northern Hemisphere summer months.

2.2. Land cover characteristics

In order to examine the temporal and spatial variability of aerodynamic roughness variables with