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Seasonal variation of surface fluxes and scalar roughness of suburban land covers

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Abstract

Flux observations above five different land covers over a year allowed evaluation and comparison of seasonal change of fluxes and roughness parameters. The selected land covers consist of a pine forest, a paddy field, short grass, tall grass and a building roof top which are typical surfaces one can find in a suburban area in a temperate humid region. It was found that the available energy was the largest through the year for the forest because of its small albedo and low surface temperature. The grass fields and the paddy field received a similarly large energy input, but only during midsummer. The ratio of the latent heat to the available energy fluxes was found to be the largest above the grassy surfaces during the growing season while above the forest it was the smallest. This reversed itself during the winter season when the pine trees still transpirated water while the grassy vegetation went into dormancy. Over the building, the lack of evaporation caused very large sensible heat fluxes during daytime, which often continued to be positive albeit smaller even after sunset. The momentum roughness length and the scalar roughness for sensible heat of the vegetated surfaces showed good correlation with vegetation growth, in general. However, the relation between the scalar roughness and vegetation growth was found to vary among the different sites. A comparison by means of model simulations has shown that this difference was probably caused not only by the difference of the LAI range of each site, but also by the difference of the roughness of the underlying soil surfaces. As expected, the apparent scalar roughness for latent heat depended not only on vegetation growth, but also on soil water availability.

Keywords: Surface energy flux; Roughness length; Scalar roughness; Suburban land use

1. Introduction

The exchange processes of mass, momentum and energy between land surfaces and the atmosphere are among the major factors influencing the climate and hydrology of a region. For example, urbanization has replaced vegetated surfaces with houses, buildings or asphalt surfaces, and such surfaces usually do not allow evaporation to take place and tend to store heat within the urban environment during daytime and release it at night. As a result, the urban climate with higher temperature and lower humidity is now quite common. Similarly, deforestation of a watershed tends to increase evaporatio‘n, and as a result, river discharges from the watershed

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Abbreviations: BR, Bowen ratio and energy balance method; EB, energy budget; EC, eddy covariance methods; FOV, field of view; HFP, heat flux plate; IRT, infrared thermometer; LAI, leaf area index; MRI, Meteorological Research Institute; NR, net radiometer; PRT, platinum resistance thermometer; RB, radiation budget; REBS, Radiation and Energy Balance Systems; RMSE, root mean square error; SAT, sonic anemometer–thermometer; TERC, Terrestrial Environment Research Center of the University of Tsukuba; TDR, time domain reflectmetry

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Nomenclature

A	available energy (W m^{-2})
A^+	model parameter in Eqs. (11) and (12)
b	surface moisture availability
c_d	leaf transfer coefficient for momentum
c_h	leaf transfer coefficient for heat
c_p	specific heat of air at constant pressure (J kg^{-1} K^{-1})
C_e	bulk transfer coefficient for water vapor (Dalton number)
C_e^*	apparent Dalton number
C_X^0	model parameter in Eq. (12)
C_X^∞	model parameter in Eq. (12)
d	displacement height (m)
E	evaporation flux (kg m^{-2} s^{-1})
EF	evaporative fraction
F_x	ratio of c_h to c_d ($F_x = c_\mathrm{h}/c_\mathrm{d}$)
h	vegetation height (m)
H	sensible heat flux (W m^{-2})
G	ground heat flux (W m^{-2})
k	von Kármán's constant
kB^{-1}	logarithmic ratio of two roughness lengths ($kB^{-1} = \ln(z_{0\mathrm{m}}/z_{0\mathrm{h}})$)
L	Obukhov length (m)
L_A	leaf area index (area of foliage per unit area of ground underneath) (m^2 m^{-2})
P	precipitation (mm)
P_1	model parameter in Eq. (12)
P_2	model parameter in Eq. (12)
P_3	model parameter in Eq. (12)
P_4	model parameter in Eq. (12)
q	specific humidity of air (kg kg^{-1})
q_s	specific humidity at surface (kg kg^{-1})
$q_*(T_\mathrm{s})$	saturated specific humidity at surface temperature T_s (kg kg^{-1})
R_ld	downward long-wave radiation (W m^{-2})
R_lu	upward long-wave radiation (W m^{-2})
R_n	net radiation (W m^{-2})
R_sd	downward short-wave radiation (W m^{-2})
R_su	upward short-wave radiation (W m^{-2})
T_a	air temperature (K, °C)
T_s	surface temperature (K)
T_sm	output of infrared thermometer (IRT) (K)
u	wind speed (m s^{-1})
u_*	friction velocity (m s^{-1})
w	volumetric soil water content
z	height of measurement (m)
z_0	roughness length (m)
$z_{0\mathrm{h}}$	roughness length for sensible heat (m)
$z_{0\mathrm{m}}$	roughness length for momentum (m)
$z_{0\mathrm{s}}$	roughness length of substrate soil surface for momentum (m)
$z_{0\mathrm{v}}$	roughness length for water vapor (m)
$z_{0\mathrm{v}*}$	apparent roughness length for water vapor (m)
z_{0+}	roughness Reynolds number (m)
$z_{0\mathrm{h}+}$	roughness length for heat for the case of $F_x = 0$ (m)
z_hs	roughness length of substrate soil surface for heat (m)

Greek letters

Ψ_h	stability correction function for heat
Ψ_m	stability correction function for momentum
Ψ_v	stability correction function for water vapor
α	surface albedo
ε	longwave emissivity
λ	latent heat of vaporization of water (J kg^{-2})
λE	latent heat flux (W m^{-2})
ν	kinematic viscosity (m^2 s^{-1})
θ	air potential temperature (K)
θ_s	surface potential temperature (K)
ρ	density of air (kg m^{-3})
σ	Stefan–Boltzmann constant (W m^{-2} K^{-4})
$\partial S/\partial t$	rate of change of energy storage in the layer between ground surface and measurement height (W m^{-2})

are often found to have decreased (e.g., Bosch and Hewlett, 1982). As such, there is a need to understand the exchange processes between the atmosphere and underlying surfaces. Although much progress has been made, many problems remain. One of them is the lack of information on seasonal variations. Most of the observations and studies concentrated on the summer time (e.g., Sellers et al., 1992; Hiyama et al., 1995; Halldin et al., 1999) and only recently has the need been recognised for observations that cover the whole annual cycle. Also, only recently, have long-term measurements become possible through the advent of new measurement technology (e.g., Sellers et al., 1995; Toda et al., 2002). In addition to a general lack of information on the seasonal changes of surface fluxes, even less is known on the seasonal changes of the surface roughness parameters. Many textbooks list values of these parameters, but they usually do not give any information on their annual variation, and one can only speculate that these values are