PINE FOREST MICROCLIMATE SIMULATION USING DIFFERENT DIFFUSIVITIES

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Abstract. Proper understanding of, e.g., evaporation from a forest requires an understanding of its microclimate. A well established, steady-state model was used to simulate microclimate and evaporation of a sparse pine forest in central Sweden. Model input included profiles of turbulent diffusivity, boundary-layer resistance, stomatal resistance, wind speed, net and global radiation and needle area density. Momentum balance, energy balance and exponentially decreasing diffusivities were used to study the sensitivity of the evaporation rates and of the temperature and humidity profiles. Model output proved to be unreliable when measured temperature and humidity at the bottom of the stand were used instead of a measured ground heat flux as the lower boundary condition. Energy balance diffusivity was usually larger than momentum balance diffusivity at the canopy top but decreased rapidly to a minimum at approximately the height where the momentum balance diffusivity had its maximum. Energy balance diffusivity commonly showed a secondary maximum below the height of the maximum needle area density. Profiles of Richardson number showed that thermal effects became important just below the canopy top. Bluff-body effects distinguished the energy balance from the momentum balance diffusivity and both were subject to shelter effects. Total evaporation was not very sensitive to the choice of diffusivity when soil heat flux was given as the lower boundary condition.

List of Notations

Where applicable, units and 'standard' values of parameters are given.

\( a(z) \quad \text{projected needle surface area density at level } z \ (m^2 \ m^{-3}) \)
\( a_0 \quad \text{regression constant in Equation (18)} \ (9.6 \ W \ m^{-2}) \)
\( a_1 \quad \text{regression constant in Equation (18)} \ (1.23) \)
\( A \quad \text{regression constant in Equation (9)} \ (6.0) \)
\( b \quad \text{regression constant in Equation (9)} \ (0.5) \)
\( B \quad \text{Bowen ratio (-)} \)
\( c_d(u) \quad \text{wind speed dependent drag coefficient of an average needle (-)} \)
\( c_p \quad \text{specific heat of air at constant pressure (1005 J kg}^{-1} \ K^{-1}) \)
\( d \quad \text{zero-plane displacement (m)} \)
\( d_n \quad \text{average diameter of a needle (0.2 cm)} \)
\( e(z) \quad \text{vapour pressure at height } z \ (Pa) \)
\( e_0 \quad \text{vapour pressure at the top of the canopy (Pa)} \)
\( e_{ai} \quad \text{vapour pressure of the } i^{th} \text{ layer (Pa)} \)
\( e_g \quad \text{vapour pressure at the lower boundary (Pa)} \)
\( g \quad \text{acceleration of gravity (9.81 m s}^{-2}) \)
\( h \quad \text{stand height (top of the most dominant trees) (20 m)} \)
\( H(z) \quad \text{sensible heat flux at level } z \ (W \ m^{-2}) \)

$H_i$ sensible heat flux at the boundary between layer $i-1$ and $i$ (W m$^{-2}$)

$k$ von Kármán's constant (0.41)

$k(z)$ stomatal conductance at height $z$ (m s$^{-1}$)

$k_0$ maximum stomatal conductance (12.3 mm s$^{-1}$)

$K(z)$ eddy diffusivity of heat and vapour at height $z$ (m$^2$ s$^{-1}$)

$K_m(z)$ eddy diffusivity of momentum at height $z$ (m$^2$ s$^{-1}$)

$K_0$ proportionality constant in Equation (4) (m)

$l$ mixing length (m)

$p_d$ shelter factor for momentum (-)

$q$ quotient between total and projected needle area (2.64)

$Q$ soil heat flux (W m$^{-2}$)

$r_a(z)$ boundary-layer resistance to transfer of heat and vapour from needles at height $z$, see Equation (14) (s m$^{-1}$)

$r_b(z)$ stomatal resistance at height $z$, see Equation (16) (s m$^{-1}$)

$R(z)$ diffusive resistance to transfer of heat and vapour in the air between two boundaries at level $z$, see Equation (13) (s m$^{-1}$)

$R_i$ diffusive resistance to transfer of heat and vapour in the air between layer $i-1$ and $i$ (s m$^{-1}$)

$R_g(z)$ global radiation flux at height $z$ (W m$^{-2}$)

$R_s(z)$ net radiation flux at height $z$ W m$^{-2}$

$T_{a}(z)$ air temperature at height $z$ ($^\circ$C)

$T_{b}$ air temperature of the $i$'th layer ($^\circ$C)

$T_{a,b}$ air temperature at the lower boundary ($^\circ$C)

$T_{n}$ needle temperature of the $i$'th layer ($^\circ$C)

$T_0$ air temperature at the top of the canopy ($^\circ$C)

$u(z)$ wind speed at height $z$, 'measured' or given by Equation (1) (m s$^{-1}$)

$V(z)$ latent heat flux at height $z$ (W m$^{-2}$)

$V_{b}$ latent heat flux at the boundary between layer $i-1$ and $i$ (W m$^{-2}$)

$VCD(z)$ vapour concentration deficit at height $z$ (g m$^{-3}$)

$x$ normalised, inverse height (-)

$z$ height above ground (m)

$z_b$ height above ground of lower boundary (2 m)

$z_0$ roughness length of the entire stand (m)

$z_{wo}$ roughness length of ground vegetation (0.02 m)

$z_r$ extinction coefficient for net radiation, see Equation (17) (0.5)

$z_{n}(u)$ regression constant in Equations (1), (2), (3), and (6) with different values for the different wind speed classes (-)

$\beta$ regression constant in Equation (15) (4.57 g m$^{-2}$)

$\beta_{n}(u)$ regression constant in Equations (1), (2), (3), and (6) with different values for the different wind speed classes (-)

$\gamma$ psychrometric 'constant' (66 Pa K$^{-1}$)

$\Gamma$ dry adiabatic lapse rate (0.98 10$^{-2}$ K m$^{-1}$)

$\partial T_a/\partial z$ air temperature gradient (K m$^{-1}$)

$\partial u/\partial z$ wind speed gradient, see Equation (3) (s$^{-1}$)

$\partial \theta/\partial z$ gradient of equivalent temperature, see Equation (12) (K m$^{-1}$)

$\delta \theta$ difference in equivalent temperature between the upper and lower boundary (K)

$\Delta H_i$ sensible heat source strength of the $i$'th layer (W m$^{-2}$)

$\Delta V_{b}$ latent heat source strength of the $i$'th layer (W m$^{-2}$)

$\Delta z$ thickness of layer (2 m)

$\theta(z)$ equivalent temperature, see Equation (12) ($^\circ$C)

$\rho$ density of dry air (1.205 kg m$^{-3}$)

$t(z)$ momentum flux at level $z$ (kg m$^{-1}$ s$^{-1}$)