FACTORS AFFECTING THE CANOPY RESISTANCE
OF A DOUGLAS-FIR FOREST

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Abstract. The physiological nature of canopy resistance was studied by comparing the stomatal and canopy resistance of a 10-m high Douglas-fir forest. Stomatal resistance of the needles was measured using porometry, while the canopy resistance was calculated using energy balance/Bowen ratio measurements of evapotranspiration. A typical steady increase in the forest canopy resistance during daytime hours, even at high soil water potentials, was observed. A similar trend in the stomatal resistance indicated that increasing canopy resistance during the daytime was caused by gradually closing stomata. During a dry period when soil water potentials declined from 0 to \(-10.5\) bars, the mean daytime value of canopy resistance increased in proportion to the mean daytime value of the stomatal resistance. Values of canopy resistance calculated from stomatal resistance and leaf area index measurements agreed well with those calculated from energy balance measurements. The dependences of stomatal resistance on light, vapour pressure deficit, twig and soil water potentials are summarized.

List of Symbols

\begin{align*}
A & \quad \text{available energy for evapotranspiration:} \ (R_n - G - M) (W \ m^{-2}) \\
E & \quad \text{evapotranspiration rate} \ (kg \ m^{-2} \ s^{-1}) \\
G & \quad \text{soil heat flux} \ (W \ m^{-2}) \\
H & \quad \text{sensible heat flux} \ (W \ m^{-2}) \\
L & \quad \text{latent heat of vaporization of water} \ (J \ kg^{-1}) \\
\text{LAI} & \quad \text{leaf area index or needle area (projected area basis)/unit area of ground surface (dimensionless)} \\
\text{LAI}_j & \quad \text{LAI of } j\text{th canopy layer (dimensionless)} \\
LE & \quad \text{latent heat flux} \ (W \ m^{-2}) \\
M & \quad \text{rate of heat storage in canopy volume on an area basis} \ (W \ m^{-2}) \\
R_n & \quad \text{net radiation flux} \ (W \ m^{-2}) \\
c_p & \quad \text{specific heat of moist air} \ (J \ kg^{-1} \ K^{-1}) \\
e_z & \quad \text{water vapour pressure at height } z \ (mb) \\
e_z^* & \quad \text{saturation water vapour pressure at height } z \ (mb) \\
r_c & \quad \text{canopy or surface resistance} \ (s \ cm^{-1}) \\
r_{ci} & \quad \text{canopy resistance at the } i\text{th hour of the daytime} \ (s \ cm^{-1}) \\
r_{c} & \quad \text{mean daytime canopy resistance; defined by equation (6)} \ (s \ cm^{-1}) \\
r_H & \quad \text{aerodynamic resistance to heat exchange between the forest and the height } z \ (s \ cm^{-1}) \\
r_s & \quad \text{stomatal resistance on a projected leaf area basis} \ (s \ cm^{-1}) \\
r_{sj} & \quad \text{stomatal resistance of the } j\text{th canopy layer} \ (s \ cm^{-1}) \\
r_v & \quad \text{aerodynamic resistance to water vapour exchange between the forest and the height } z \ (s \ cm^{-1})
\end{align*}
Improved procedures of estimating evapotranspiration are required in hydrological studies of vegetated areas. Hydrologists are well aware that potential evaporation estimates can often greatly exceed actual values of evapotranspiration. Any realistic evapotranspiration model must include plant or soil parameters that provide an accurate description of the process when it is limited by the supply of water. One such parameter is the canopy or surface resistance which is contained in the Penman–Monteith model of transpiration (Monteith, 1965). In view of the complexity of many plant canopies, this is a greatly simplified model; however, it has been remarkably successful in its application to agricultural crops (Monteith et al., 1965; Black et al., 1970; Szeicz et al., 1973). These workers have shown that for well-ventilated agricultural crop canopies, the canopy resistance is approximately equal to the stomatal resistance of the leaves acting in parallel. Recently, several forest micrometeorologists have calculated, using the Penman–Monteith model, hourly, daily and monthly values of canopy resistance of forests in various parts of the world (e.g., Szeicz and Long, 1969; Stewart and Thom, 1973; McNaughton and Black, 1973; Gash and Stewart, 1975). Little is known as to the physiological nature of the forest canopy resistance and whether it is possible to model it from an understanding of the behaviour of the stomata of the trees (Federer, 1975). The objectives of this paper are: (i), to show the relationship between canopy and stomatal resistance in a 21-yr old Douglas-fir forest; (ii), to describe the relationship between canopy resistance and environmental parameters; and (iii), to assess whether canopy resistance behaviour can be inferred from knowledge of stomatal response to environmental parameters.

### 2. Theory

Total evapotranspiration can be considered as mainly transpiration with small error for forests with no intercepted water present, since evaporation from the soil is small. The Penman–Monteith model of transpiration assumes that the canopy is isothermal and that the canopy resistance $r_c$ is the resistance of all stomata of the leaves acting