Ecohydrological Behaviour of Mountain Beech Forest:
Quantification of Stomatal Conductance Using Sap Flow Measurements

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Introduction

In forested regions, transpiration as a main component of evaporation fluxes is important for evaporation partitioning. Physiological behaviours among various vegetation species are quite different.

The study area experienced bark beetle infestation, and the trees are newly formed, and mixed forest stands (spruce and beech) have transformed into beech stands. From the differences of the rooting depth of each kind of tree, an impact on long-term water regime is expected. Furthermore, trees can change soil moisture distribution or water storage in aquifers by transpiration.

Objective

Thus, an accurate estimation of the transpiration rate from a certain tree species needs specific parameterization of stomatal response to multiple environmental conditions. The sap flow equipment was installed in six trees with varying ages among 32 beech trees in the plot, and the measurements were used to infer the stomatal conductance for the beech forest.

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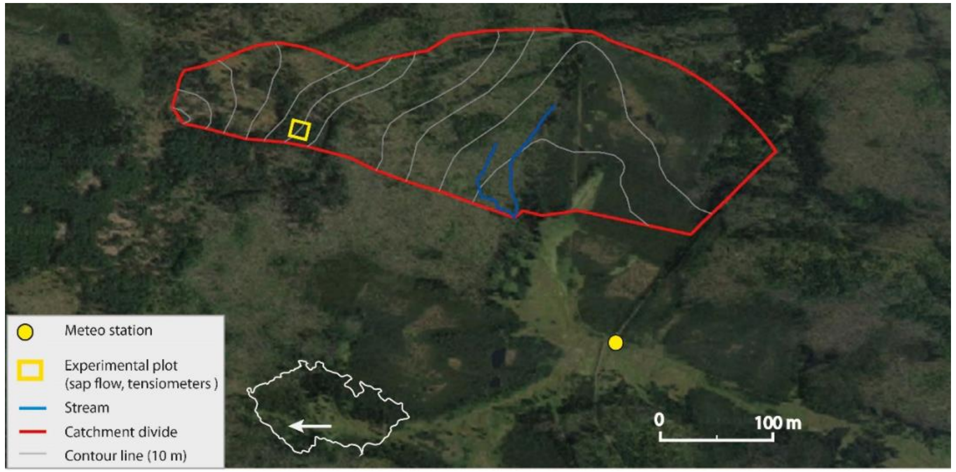
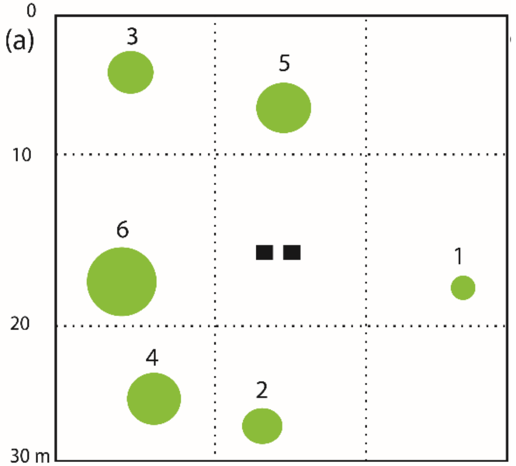
Site description

In this study, we chose a 300-m^2 beech forest plot located in Vydra basin, the Czech Republic, to investigate the transpiration of beech (*Fagus sylvatica)* from the middle of the vegetative period to the beginning of the deciduous period, covering 100 days.

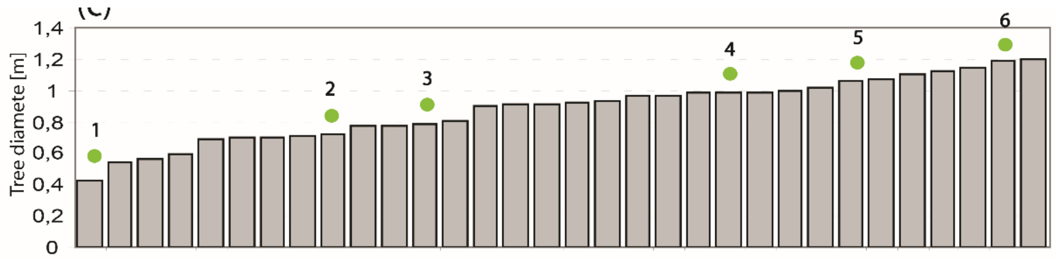


a. Map of experimental plot and location of measurement station

b. Photo of in-site sap flow devices



c. Sketch of trees installed sap flow devices and location of tension meters.



d. Distribution of all tree diameter over the whole plot.

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Methods

In vegetated areas, transpiration rate is dictated by the parameter of stomatal conductance, gc (m s-1). If the transpiration rate (e.g., from sap flow measurement) and climatic measurements are available, the stomatal conductance then can be inversely estimated by rearranging the Penman-Monteith type equation:

$$g_c = \frac{g_a \gamma \lambda E}{\Delta R_{can} + \rho_a C_p (e_s - e_a) g_a - \lambda E (\Delta + \gamma)}$$

The stomatal conductance is controlled by stomatal aperture in response to the availability of energy, carbon, and water in soil. Considering the impact of multiple environmental factors on stomatal conductance, this study adopted the Jarvis-Stewart model which consists of multiplicative nonlinear functions of environmental variables:

$$g_c = I_{LAI} g_{c,max} \prod_i F_i(x),$$

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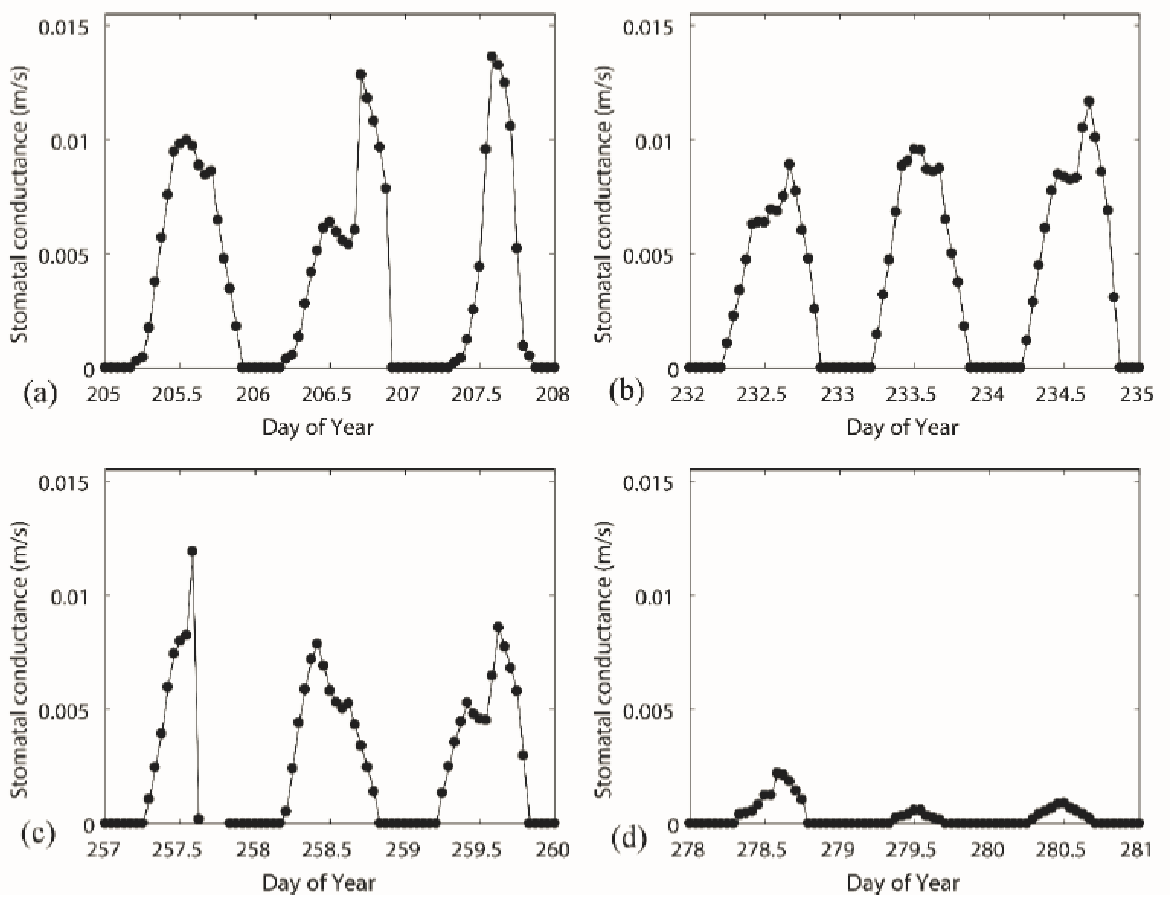
Results

The stomatal conductance was inversely estimated by rearranging the Penman-Monteith type equation, and diurnal variation of stomatal conductance had common patterns for different vegetation periods four selected periods were given below:



1. diurnal behavior
2. The lower stomatal conductance during midday (13.00) than before and after about 13.00, Figure c, for instance, which can be attributed to the higher vapour deficit.
3. In autumn periods (Figure d), the inversely calculated stomatal conductance values approach smaller values.

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Results

Response of stress functions in canopy conductance to net radiation (*Rs*), vapor pressure deficit (*D*), temperature (*T*), and soil moisture (θ). The line is using the parameter given by Zhou et al. [46], see Table 1.

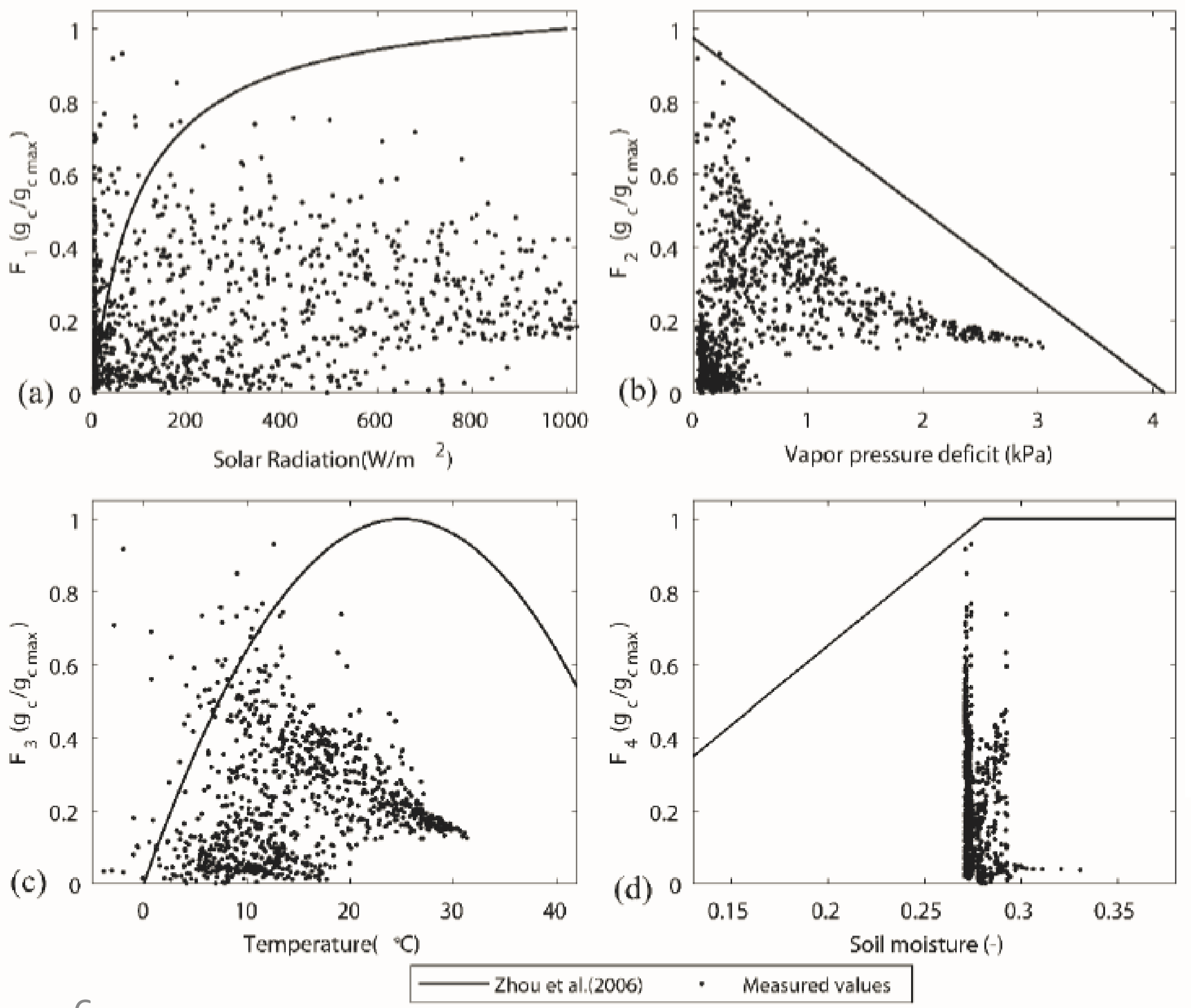

Table 1. The stress functions of canopy conductance to net radiation (*Rs*), vapor pressure deficit (*D*), temperature (*T*), and soil moisture (θ) giving with calibrated parameters and the Zhou et al. [46]'s parameters (see the blue line and line given in Figure 6).

Stress function (Typical Parameters)	Reference	Stress Function (Zhou et al. [46]'s Parameters)
$F_1(R_s) = \frac{R_s}{1000}\frac{1000+k_c}{R_s+k_c}$ [1]	[40,42,43]	$F_1(R_s) = \frac{R_s}{10}\frac{11}{R_s+100}$
$F_2(D) = \exp(-kD)$ [2]	[39,40]	$F_2(D) = 1 - 0.238D$
$F_3(T) = \frac{T-T_{min}}{T_{opt}-T_{min}}\left[\frac{T_{max}-T}{T_{max}-T_{opt}}\right]^{\frac{T_{max}-T_{opt}}{T_{opt}-T_{min}}}$ [3]	[39,44,45]	$F_3(T) = 1 - 1.6\times10^{-3}(298-T)^2$ [5]
$F_4(\theta) = \begin{cases} 1, & \theta \geq \theta_f \\ \frac{\theta-\theta_r}{\theta_f-\theta_r}, & \theta_f < \theta < \theta_r \\ 0, & \theta \leq \theta_r \end{cases}$ [4]	[12,43]	$F_4(\theta) = \begin{cases} 1, & \theta \geq \theta_f \\ \frac{\theta-\theta_r}{\theta_f-\theta_r}, & \theta_f < \theta < \theta_r \\ 0, & \theta \leq \theta_r \end{cases}$

[1] k_c is a fitted parameter describing the curvature. [2] k is a free parameter, describing the decrease in g_c with increasing D. [3] T_{min} and T_{max} (K) are minimum and maximum temperatures that indicate the temperatures below and above which complete stomatal closure occurs, and T_{opt} is the optimum temperature that indicates the temperature of maximum stomatal opening. Canopy temperature was assumed to equal air temperature, since temperature gradients are usually small in forest canopies [47]. [4] θ_f is the field capacity below which the plant transpires less than its maximum value, and θ_r is the residual soil moisture content, i.e., willing point below which the plant stops transpiration. [5] The function was defined for condition of $273 < T < 298$.

The response of stomatal conductance showed no pattern with solar radiation and soil moisture, but it did show a clear correlation with the vapour deficit, in particular when explaining the midday drop.

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Conclusion

The findings highlighted that the parametrization of stress functions based on the typical deciduous forest does not perfectly represent the measured stomatal response of beech. Therefore, measurements of sap flow can assist in better understanding transpiration in newly formed beech stands after bark beetle outbreaks in Central Europe.

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