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Interannual environmental-soil thawing rate variation and its control on transpiration from *Larix cajanderi*, Central Yakutia, Eastern Siberia

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Soil thawing rate

Summary Sapflow measurements were carried out in a larch forest in eastern Siberia, an area of wide permafrost distribution. Canopy transpiration and canopy conductance were scaled up from these values. The objective was to analyze the relationship between environmental variables, mainly vapour pressure deficit (D), soil moisture and soil thawing rate with canopy transpiration and canopy conductance. Maximum sapflow rate was 42.4 kg d^{-1} $tree^{-1}$ with bigger trees showing a more accentuated response to environmental changes. Canopy transpiration (E_c) showed inter-annual variability, with a maximum value of 1.7 mm d^{-1} in 2003 and 1.2 mm d^{-1} in 2004. Soil moisture was higher in 2003 because of higher precipitation (230 mm in 2003 compared to 110 mm in 2004 for the total growing season). Maximum soil thawing rate in 2003 and 2004 was 140 cm and 120 cm, respectively, because of different air temperature, soil water content and precipitation regime among other factors. Canopy conductance (g_c) was positively correlated with D during fine weather and well-watered days in both years. On the other hand, canopy conductance was well correlated with soil moisture ($R^2 = 0.83$) in the upper layers (20–30 cm depth) during 2003 (wet year) but not in 2004 (dry year), representing its strong but limited control over water fluxes from the forest. By comparison with other studies in this region, canopy transpiration is estimated to contribute to almost 50% of the total forest evaporation, highlighting the important role of understorey transpiration in permafrost

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regions. Our results show that it is not only the impermeability of permafrost with the property of keeping soil moisture in the thin active layer but it is also the slow soil thawing rate that plays the important role of controlling the amount of water available for trees roots in the upper soil layers during dry years.

Introduction

Water loss from boreal forests is of global importance because of their distribution (12.0—14.7 million km^2). In eastern Siberia, boreal forest grows over continuous permafrost, of which 54% is occupied by *Larix* (Shvidenko and Nilsson, 1994). Growing evidence of a higher frequency of climatic extremes as a result of global climate change (Karl et al., 1995) makes it necessary to understand the response of forest functioning to environmental as well as ground thermal conditions in permafrost regions. Forests in Siberia exist with an annual precipitation regime of 230 mm, of which half occurred during the growing season (May—September). Annual variability of precipitation in eastern Siberia during the growing season affects greatly the thin active layer (1.0—1.5 m depth) where the boreal forest stands. Precipitated water in autumn becomes a water reservoir for the next growing season (Sugimoto et al., 2003) and changes the rate of soil thawing, which is a function of the thermal parameters of soil thermal conductivity and latent heat of the soil moisture (Romanovsky et al., 1997). According to recent studies, active layer depth is increasing due to climatic warming (Osterkamp and Romanovsky, 1999; Fedorov and Konstantinov, 2003; Jorgenson et al., 2006) and this can have a great effect on the soil water supply for *Larix* forests. It has been suggested that during dry years, thawed permafrost, caused by active layer thickness increase, can supply water for trees to keep the forest functioning (Sugimoto et al., 2002).

In eastern Siberia, forest evaporation (Kelliher et al., 1997; Ohta et al., 2001; Dolman et al., 2004) and canopy transpiration have been estimated by different methods. However, measurements have been short-term (Arneth et al., 1996) or the number of trees necessary for scaling up to canopy transpiration (Cermak et al., 1995) has been insufficient (Kuwada et al., 2002). Long-term measurements and scaling up methods are important when modeling canopy conductance (g_c) because of the large control it exerts on transpiration from coniferous forests in boreal regions (Jarvis and McNaughton, 1986). Under given concentrations of nitrogen in the soil, g_c is mostly limited by vapour pressure deficit, by soil water deficit or by a combination of both factors (Cienciala et al., 1997). The active layer response to environmental conditions and its relationship with soil moisture and canopy transpiration still needs to be studied in permafrost regions.

The objectives of this study are: 1. to elucidate the relationship between canopy transpiration and the environmental parameters under two different precipitation regimes; 2. to determine the role of soil thawing depth on soil moisture availability and its relation with canopy transpiration; 3. to determine the relationship between g_c—D and g_c—soil moisture.

Materials and methods

Study site

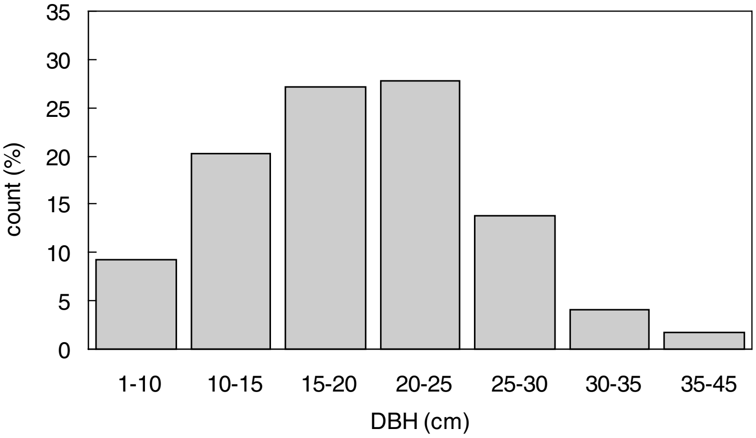
The site, Spasskaya Pad, is located at 35 km NNW from the city of Yakutsk in eastern Siberia (62°15′N, 129°37′E, altitude 220 m). The climate in this area is dry, with annual precipitation of approximately 230 mm and mean annual air temperature of −10 °C. The content of the soil upper layers is sandy loam whereas soil horizons in deeper layers are silty loam. The forest is dominated by a 160-year-old *Larix cajanderi* monoculture. Tree density is 1000 trees per ha. The sapwood basal area is 4.7 m^{2}ha^{-1} and the mean height is 13 m. The frequency diameter at breast height (dbh) and tree characteristics are described in Fig. 1. The understorey vegetation is mainly composed of *Vaccinium vitis-idaea* and *Arctous erythrocarpus* Small. According to Ohta et al. (2001) the plant area index (PAI) for the fully leaved season is 3.7.

Measurements

Weather conditions during the period July 7th—September 30th, 2003—May 20th—September 27th 2004 were recorded continuously every 10 min (CR10X datalogger, Campbell) at the top of a 32 m height scaffolding tower built by Ohta et al. (2001). The variables measured were rainfall (Young Inc., USA), solar radiation (Pyranometer, CPR-PCM-01, Prede, Japan), relative humidity—air temperature (HMP-35D, Vaisala, Finland) and wind speed (Young Inc., USA).

Soil temperature moisture and measurements started on June 7th 2003 (one month before the installation of instruments in the meteorological tower and the sapflow sensors) and May 7th in 2004. Soil temperatures were measured at depths of 0.01, 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8, and 2.0 m using calibrated thermistors (104ET, Ishizuka Denshi, Tokyo, Japan). Soil temperature probes were calibrated with an ice-water bath. Soil moisture was measured by the FDR method (EnviroSMART, Sentek Pty Ltd., Australia) at depths of 0.1, 0.2, 0.3, 0.4, 0.6, and 0.8 m. Calibrations for FDR sensors were conducted separately for the depth of 0.1 m (the boundary between organic mat layer and mineral soil layer) and the depth below 0.2 m (mineral soil layer). Eleven in situ soil samples of various moisture conditions were taken and the volumetric water content was determined gravimetrically to construct the calibration curve.

The soil temperature measurements were conducted every 30 s and stored every 30 min as averages. Soil moisture measurements were conducted every 30 min and recorded. All data were logged using a CR10X datalogger (Campbell Scientific, Inc.).



Crown class	Tree	DBH (cm)	Height (m)	SW_{thick} (cm)	SW_{area} (cm^2)	a (%)	b (%)	PCA (m^2)
D	C-148	36.5	21.3	0.95	92.0	0.47	0.53	27.7
D	C-159	34.6	19.6	0.92	87.0	0.46	0.54	28.8
C	C-203	27.6	20.5	0.54	68.6	0.27	0.73	10.6
C	C-243	26.1	23.2	0.51	64.6	0.25	0.75	14.2
C	C-119	24.0	18.3	0.71	59.1	0.36	0.64	14.6
C	C-151	20.5	18.1	0.67	49.9	0.33	0.67	14.7
S	C-132	20.0	17.8	0.89	48.6	0.44	0.56	8.3
S	C-211	19.8	17.0	0.58	48.1	0.29	0.71	11.0
S	C-144	15.9	17.9	1.07	37.8	0.54	0.46	10.6
S	C-158	12.9	14.5	1.07	29.9	0.54	0.46	12.1

Figure 1 Diameter at breast height (dbh) distribution of the studied stand (above). Characteristics of the sampled trees for sapflow measurements at the experimental site.

Sapflow and canopy transpiration

Sapflow was measured continuously during the two growing seasons by the thermal dissipation technique (Granier, 1985, 1987) with 20 mm long radial sapflow meters (UP Umweltanalytische Produkte, Germany) installed at a height of 1.3 m in the stems. Sapflow sensors in each crown class were installed following the dbh distribution (Fig. 1). Sap flux density (U, m^3 m^{-2} s^{-1}) was estimated by this technique. Measurements of sapflow were operated each 10 s and 10-min average values were stored on a CR10X Campbell Scientific (Shepshed, UK) datalogger. Total tree sapflow F was calculated as the product of U by the sapwood cross-section. Sapwood cross-section of the studied trees and total stand sapwood were estimated from cores. Sapwood thickness was manually measured, since it is easy to distinguish the difference in color between sapwood and heartwood, due to differences in water content. The relationship between sapwood and tree diameter (Fig. 2) was used to estimate sapwood area for each crown class. Individual tree sapflow values (Granier, 1987) were corrected (Clearwater et al., 1999) for differences in needle length (20 mm) and sapwood thickness. Sapflow measurements carried out throughout the two growing seasons in individual trees were scaled up to stand level using sapwood area distribution as described in Granier et al. (1996). Stand sapflow E_c was calculated as:

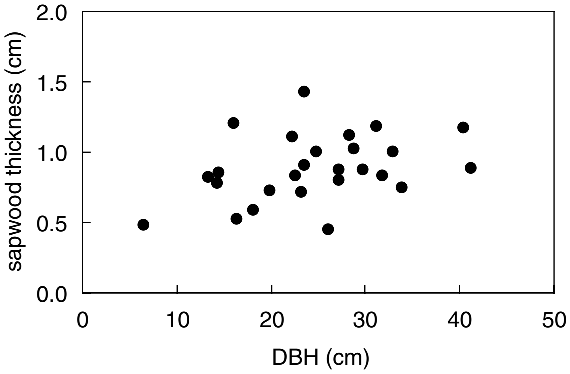


Figure 2 Relationship between tree diameter (at breast height) and sapwood thickness measured on cores. The number of trees selected was 26.

$$E_c = S_T \sum p_i U_i$$

where S_T is the stand sapwood area per unit of ground area (m^2 m^{-2}), p_i is the proportion of sapwood in the class i and U_i is the average sap flux density in the class i. To avoid short-time lags between courses of sapflow and transpiration, calculations were based on 1 day interval data.

Canopy conductance

Canopy conductance was derived from the Penman–Monteith equation assuming that stand sapflow E_c was equal to tree transpiration:

$$E_c = \frac{\Delta(R_n - G) + \rho C_p D g_a}{\lambda[\Delta + \gamma(1 + g_a/g_c]}$$

where Δ is the rate of change of saturation vapour pressure (Pa C^{-1}), R_n is the net radiation above stand (W m^{-2}), G is the rate of change of sensible heat in the biomass plus heat flux in the soil (W m^{-2}), ρ is the density of dry air at constant pressure (J kg^{-1} C^{-1}), D is the vapour pressure deficit (Pa), g_a is the aerodynamic conductance (m s^{-1}), gc is the canopy conductance (m s^{-1}), λ is the latent heat of vaporization of water (J kg^{-1}), and γ is the psychrometric constant (Pa C^{-1}). In this study, heat flow in the soil was neglected due to the low incoming energy. Net radiation (R_n) was derived from solar radiation measurements as $R_n = a_1 + a_2R_s$. The coefficients a_1 and a_2 were determined from hourly daytime values of net and solar radiation measured at a nearby meteorological station. Aerodynamic conductance (g_a, m s^{-1}) was calculated as

$$g_a = \frac{k^2 u}{\{\ln[(z - d)/z_0]\}^2}$$

The displacement height (d) was set as $0.67h$ and the roughness length as $0.1h$, where h is stand height, k is von Karman's constant (0.40) and u is wind speed at height z above the canopy (Brutsaert, 1982). The acceptability of the accuracy of this equation relies on the importance of g_c in equation 2 since $g_c << g_a$.

Results

Meteorological conditions

Inter-annual variation of climate in Siberia is one of the most important characteristics affecting the growing season in the forest. The year 2003 was characterized as rainy (total precipitation from May to September was 230 mm, rainfall data for May 2003 was obtained from a station 8 km away from Spasskaya Pad) and daily average temperatures remained above 20 °C during summer. In contrast, 2004 was characterized by lower precipitation (for the same period 110 mm) and lower air temperatures, with few days with daily values higher than 20 °C. Wind speed was similar for both years except for some windy days in 2004 when mean daily value reached 7 m s^{-1}. Solar radiation from July to the end of the season was similar in 2003 and 2004 (Fig. 3).

Soil moisture and soil temperature

Soil moisture in the upper 10 cm of the active layer experiences the largest variations after rainfall events (reaching a maximum of 34 m^3 m^{-3}) followed by smaller increases in soil moisture in deeper layers. Soil moisture increased after precipitation (July 24th), but then decreased steadily reaching a minimum value of 14 m^3 m^{-3} in mid August, after a three-week rainless period in 2003. In 2004, the sensor at 20 cm malfunctioned and therefore data for this depth was extrapolated. Soil moisture at the soil surface showed a steady decrease from the beginning of the season (33 m^3 m^{-3}, after snow melting) until mid July (13 m^3 m^{-3}), when after a total of 19 mm of three continuous days precipitation, it increased again to 21 m^3 m^{-3}. A rainless period of two weeks July, 7th–23rd, was selected for both years to observe how soil moisture was used at different soil depths under two different precipitation regimes. During the rainy year (2003) soil moisture at 10 cm decreased significantly partly as tree water uptake and partly lost to deeper layers by filtration (40.5%). In contrast in 2004, soil moisture decreased 22.7% at the same depth. At the same time the change in soil moisture at 20 cm was only 4.7% in 2003 and 12.0% in 2004. At 30 cm, soil moisture decreased 3.6% and 4.3% for the same period of time in 2003 and 2004, respectively. These results reveal a different use of soil moisture by trees when adjusting to water availability in the soil.

Soil moisture shows its actual value after soil thaws, since the sensor is not able to measure accurately moisture when the soil is frozen. In 2003, soil at 80 cm depth thawed approximately on July 20th whereas in 2004, soil at 80 cm thawed approximately on August 16th, almost one month later than in 2003. In 2003, measurements started when the soil thawing depth had reached 37 cm, on June 7th. In 2004, on the same day, the thawing depth was 30 cm. On July 1st the thawing depth reached 76 cm and 56 cm in 2003 and 2004, respectively, and on August 15th, the thawing depth was 134 and 107 cm in 2003 and 2004, respectively. Soil thawing, as mentioned above, occurred at a higher rate in 2003 than in 2004 and consequently the thawing depth at the end of the growing season reached approximately 140 cm depth on September 17th in 2003, whereas in 2004 the thawing depth was approximately 120 cm on September 20th (Fig. 4). It is important to mention that despite lower precipitation the layer of soil containing high water (and ice) content beneath 120 cm was not made available for tree use during this year and which according to Sugimoto et al. (2003) ranges annually between 0.4 and 0.7 g cm^{-3}.

Tree sapflow and soil moisture availability

Maximum values of sapflow of individual trees were higher in 2003 than 2004. Dominant trees (C-159 and C-148) reached values between 2.5 and 3.0 kg h^{-1}, respectively, on July 14th and 15th and decrease to an average 2.2 kg h^{-1} in response to increases in diurnal D. Meanwhile, codominant (C-151, C-203) trees showed lower sapflow rates that ranged between 1.6 and 2.0 kg h^{-1} without any apparent effect caused by changes in diurnal D on July 16th. Suppressed trees values ranged from 0.8 to 1.0 kg h^{-1} showing the same behavior toward D as the codominant trees. In contrast, in 2004, the differences among the three different crown classes narrowed. Maximum values for the dominant trees were between 1.4 and 1.7 kg h^{-1}, codominant ranged between 1.2 and 1.4 kg h^{-1} and suppressed trees ranged from 0.3 to 0.4 kg h^{-1} from July 6th to 8th (Fig. 5a). Light trapping ability by taller tree canopies made dominant trees start transpiring earlier than smaller trees (between 1 or 2 h earlier) due to induced stomata opening. The response of tree

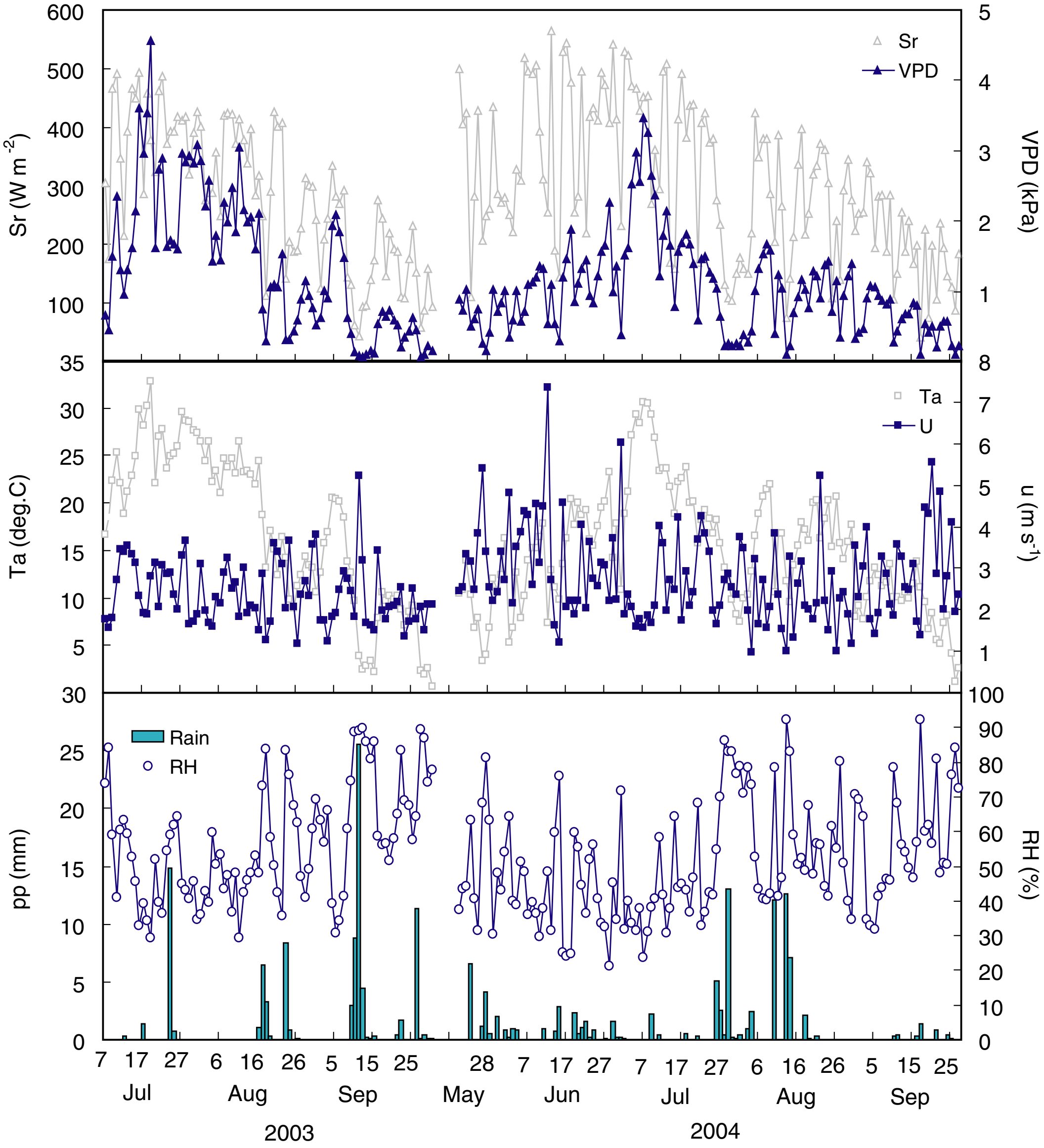


Figure 3 Meteorological conditions in 2003 and 2004 at Spasskaya.

sapflow to diurnal changes in D (Fig. 5b) appears to diminish when soil moisture decrease below 20 $m^3\ m^{-3}$ in the upper layers.

The maximum sapflow rate of 42.4 and 26.5 kg h^{-1} corresponded to dominant trees on July 27th 2003 and June 28th in 2004, respectively. In general, daily sapflow rates were lower in 2004. Following the diurnal change in 2003, bigger and high transpiring dominant trees showed larger values than codominant and suppressed trees. In 2004, sapflow from dominant trees decreased, bringing them closer to the codominant trees sapflow rates. The maximum value of sapflow found in this study was lower than the maximum value (67 kg h^{-1}) found by Arneth et al. (1996) for *Larix gmelinii* in another location in eastern Siberia or by Schulze et al. (1985) in Europe, where the value reached 74.4 kg h^{-1} for *Larix* sp. In the study carried out by Kuwada et al. (2002), only sapflow total average values were presented and not individual tree values, making comparison difficult.

Scaled up transpiration (E_c) and canopy conductance (g_c)

The maximum E_c value found for 2003 and 2004 was 1.7 and 1.2, respectively. After intensive precipitation at the end of July and relatively high air temperature, transpiration steadily decreased to 0.2 mm d^{-1} because of a rainless precipitation span of almost three weeks and the limited water storage capacity of sandy soils, where saturation of soil water and ice content in the larch forest ranges from 0.27 to 0.35 g cm^{-3} (Sugimoto et al., 2003). On August 11th 2003, when E_c was 0.4 mm d^{-1}, solar radiation (around 392.7 W m^{-2}), and D (3.0 kPa) did not show different values from those found (394.7 W m^{-2} and 3.1 kPa, respectively) when transpiration reached its peak values (1.6 mm d^{-1} on July 27th). From July 7th until the end of July, transpiration remained constant at an average value of 1.3 mm d^{-1} in 2003 while in 2004 the average for the

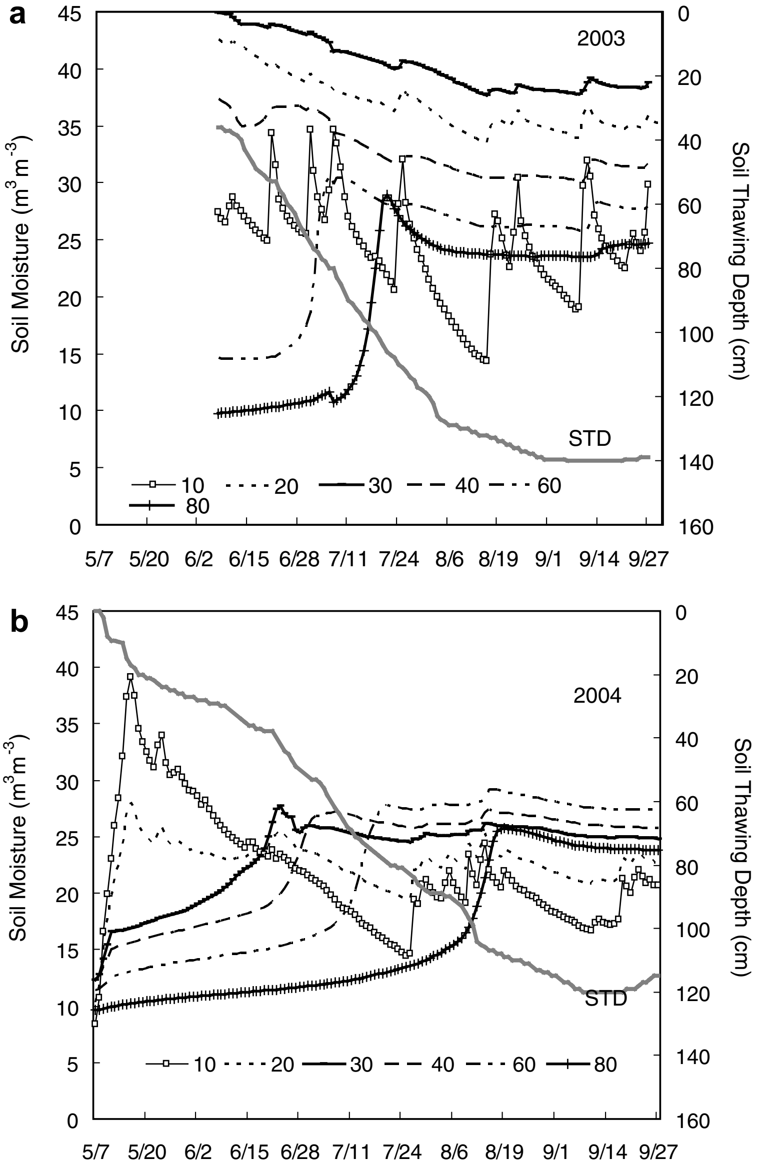


Figure 4 Soil moisture in 2003 (June 6th—September 30th) and 2004 (May 7th—September 27th) at the experimental site. Soil thawing depth (STD) is represented by the '0' isotherm measured simultaneously with soil moisture. Maximum soil thawing depth in 2003 was 140 cm on September 17th and 120 cm on September 20th 2004.

same period of time was 0.9 mm d^{-1}. In August, there was an increase of transpiration as a response to precipitation but its peak was much lower than the peak observed in June-July, signaling the lower transpiration capacity of larch trees at this time of the season. At the beginning of September, E_c decrease is accompanied with leaf shedding, setting the end of the growing season (Fig. 6). The maximum value of transpiration found in this study was 1.7 mm d^{-1} and the average during the growing season was of 0.79 mm d^{-1}.

The correlation coefficient between E_c and D was 0.05 and 0.81 in 2003 and 2004, respectively. At higher values, E_c appears to reach a plateau which is exactly the period measured in 2003 and thus the correlation appears significantly low for this year. Canopy conductance showed a strong relationship with D in 2003 and 2004 ($r^2 = 0.72$ and 0.71, respectively). Maximum average g_c value was 3.1 mm s^{-1} and 3.7 mm s^{-1} in 2003 and 2004 and minimum values were 0.91 and 0.84 mm s^{-1} when D was around 3.5 kPa (Fig. 7). In 2003, g_c values were higher than in 2004 at the same values of D because of inter-annual differences in soil moisture. Soil moisture at 10, 20 and 30 cm depth showed a good correlation with g_c (0.68, 0.80 and 0.83, respectively) in 2003 but there was no relationship between g_c and soil moisture at the same depths in 2004 (Fig. 8). The difference in slope can be interpreted as differences in root water uptake zones. Soil moisture at 10 cm is affected by rapid filtration because of the abundance of organic material and root water uptake. Soil moisture at 20 cm is predominantly affected by root water uptake and lower filtration rate because of its mineral composition.

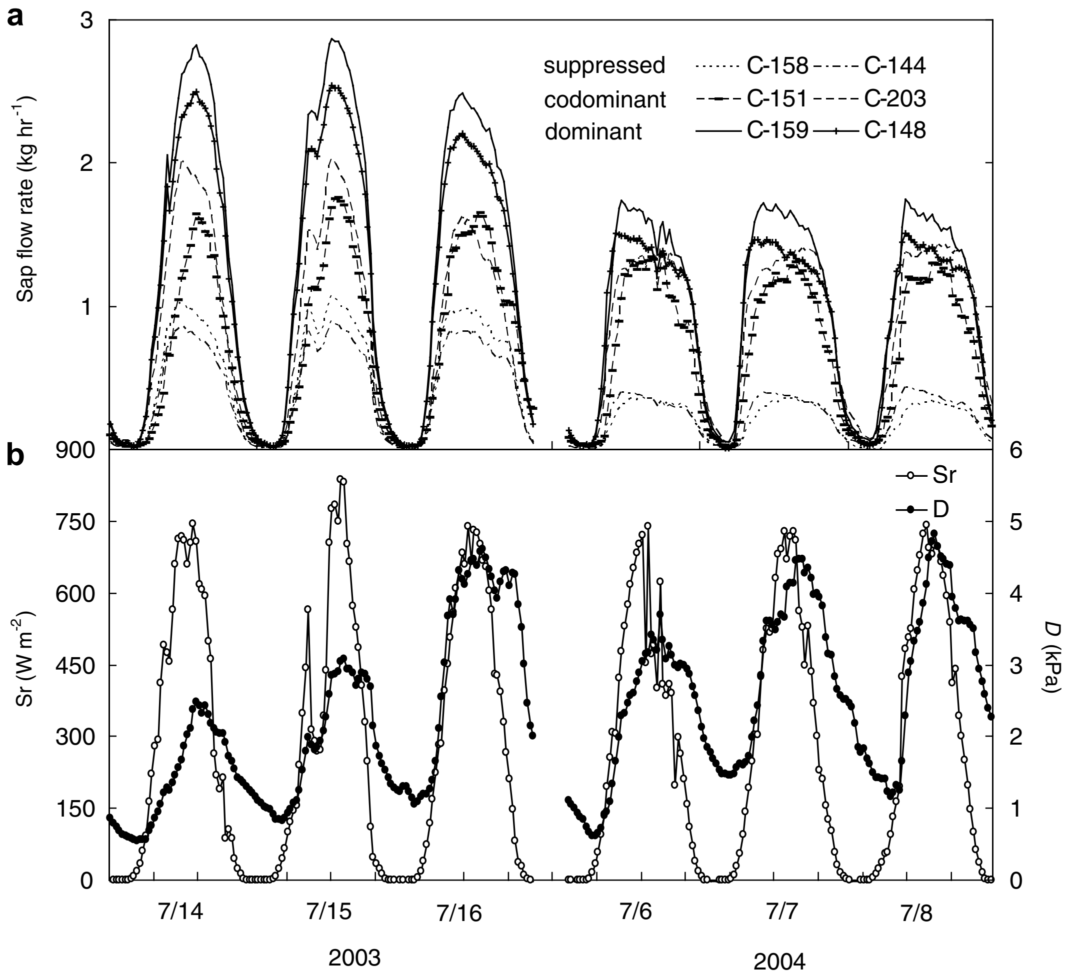


Figure 5 Half-hourly averages of sapflow rates, during a 3-day measurement period in 2003 (July 14th–15th) and in 2004 (July 6th–7th): dominant trees, codominant trees and suppressed trees (a) and half-hourly averages of solar radiation (S_r) and vapor pressure deficit (D) (b). The labels in the right upper side of the above graph indicate the tree crown class as specified in Fig. 1.

Discussion

Sapflow rate and total transpiration

Higher sapflow rates corresponded to trees with bigger diameters or higher tree crown class. However, bigger trees lowered their water loss rate more than suppressed trees when soil moisture was less available, as could be observed in this study because of differences in diurnal changes in *D* or precipitation regimes. As expected for coniferous trees *D* is an important variable controlling sapflow movement and its control remains strong even at lower soil moisture values, especially in the upper soil layers. There is a seasonal and inter-annual response of tree sapflow to environmental variables and soil moisture. The maximum values of sapflow found in this study were lower than those reported by Arneth et al. (1996) probably as a result of soil texture differences (silty loam versus sandy loam in this study) in eastern Siberia and differences in precipitation regimes (702 mm) and soil texture (podsolic loam) in a European site (Schulze et al., 1985). By using the eddy covariance technique, forest evaporation was estimated as 3 mm d^{-1} (Ohta et al., 2001; Dolman et al., 2004) which, according to our results, indicates that canopy transpiration contributes to 50% of the total forest evaporation. This is in agreement with Kelliher et al. (1997, 1998), who found the same proportion for a Siberian larch and pine forest, respectively. Average transpiration during the full-leaved growing season was around 1.46 mm d^{-1} (Dolman et al., 2004), which is also in agreement with the approximately 50% contribution of canopy transpiration found in this study (average value 0.79 mm d^{-1}). Furthermore, in comparison with data obtained from eddy correlation measurements in the same site in 2003 (CREST/WCNoF, 2003) and 2004 (Kuwada et al., 2004), it was found that transpiration contributed to 47% and 60% of the total forest evapotranspiration in 2003 and 2004, respectively. This indicates that the partition of water fluxes from tree canopy and understorey has an inter-annual variation depending on the inter-annual climatic conditions. Nevertheless, these results highlight the importance of understorey transpiration in the total forest evapotranspiration.

When values obtained by Arneth et al. (1996) are used for scaling up to canopy transpiration, the maximum value is 2.3 mm d^{-1}, which according to their own conclusions, was 0.6 or 0.7 mm higher than the values reported by Kelliher et al. (1997).

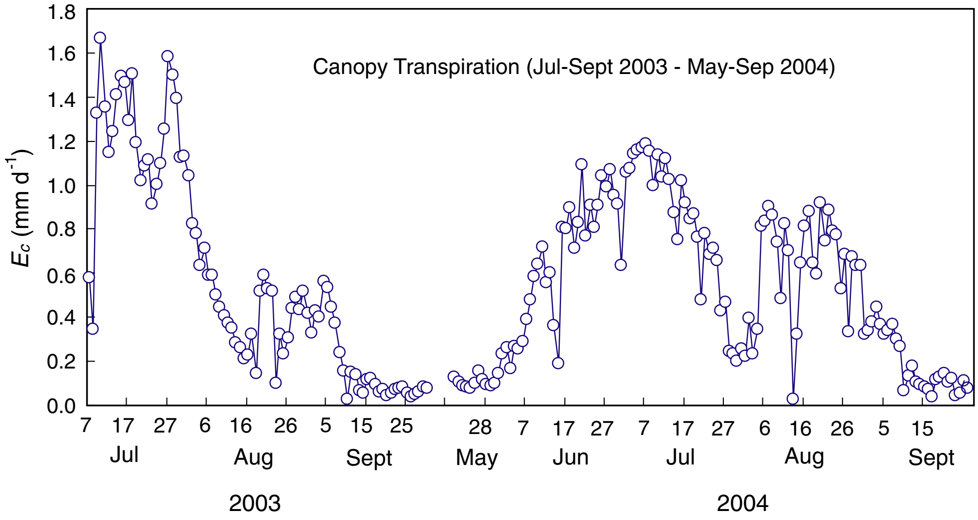


Figure 6 Canopy transpiration (E_c) in 2003 (July 7th—September 30th) and 2004 (May 20th—September 27th). Maximum E_c value in 2003 was 1.7 mm d^{-1} on July 10th and 1.2 mm d^{-1} on July 7th in 2004.

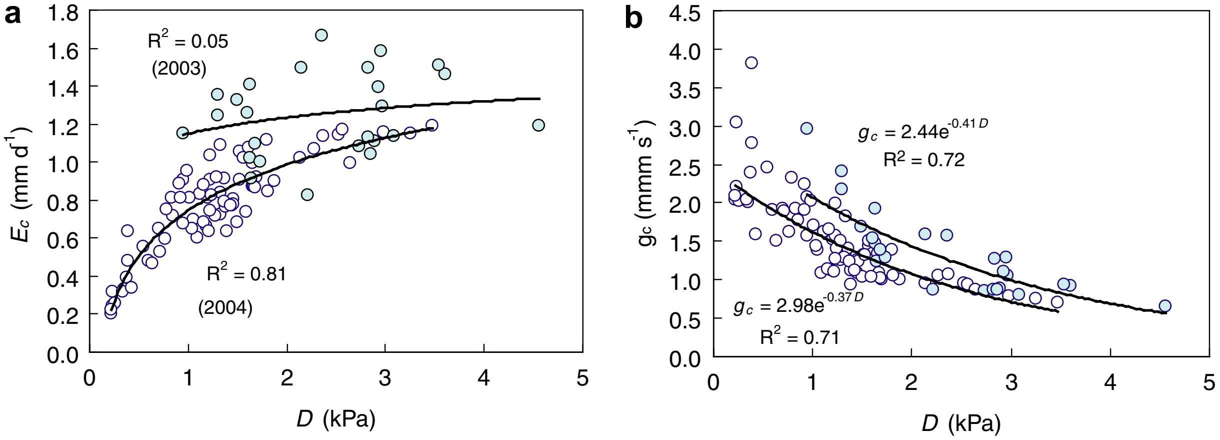


Figure 7 (a) Relationship between E_c and D in 2003 (filled circles) and 2004 (open circles). There was no response of E_c to D in 2003 but the longer period of measurement in 2004 showed a much stronger response of E_c to D (R^2 = 0.81). (b) Relationship between g_c and D in 2003 (filled circles) and 2004 (open circles). The correlation for both years is the same (0.72 and 0.71, respectively). These data correspond to fine weather and well watered days.

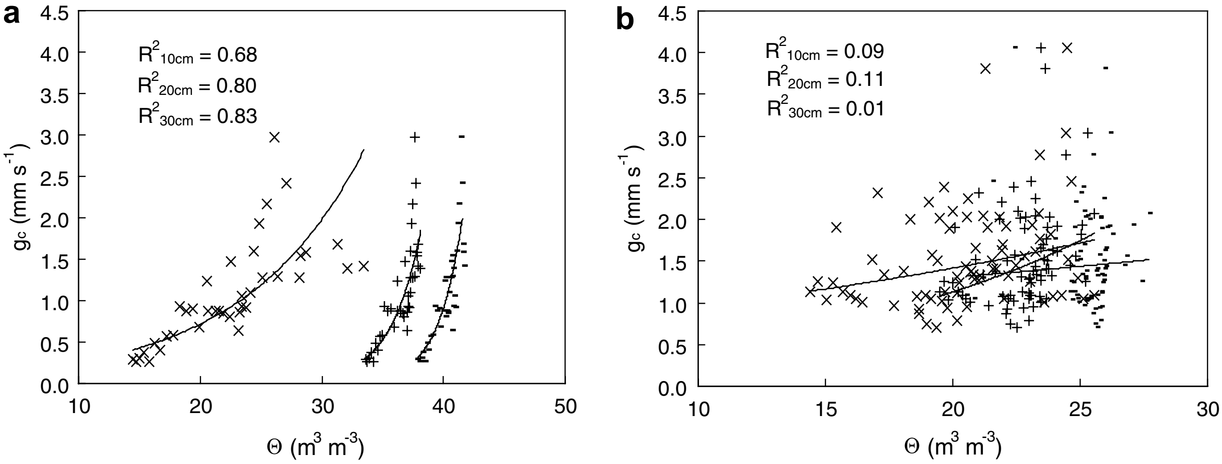


Figure 8 (a) Relationship between g_c and soil moisture at 10 cm (×), 20 cm (+) and 30 cm (—) in 2003 and (b) 2004.

Soil thawing depth, soil moisture and transpiration

Canopy transpiration starts increasing from DOY 152 in 2004 when needles growth is enhanced by root activity resulting from soil thawing depth reaching 25 cm depth. In the study by Dolman et al. (2004) this activity starts on DOY 150, suggesting that understorey transpiration was not detected before canopy transpiration, or that both started simultaneously. During the period of maximum transpiration, from the beginning to the end of July, the thawing depth varied from 77 to 116 cm in 2003 and from 58 to 90 cm in 2004. This is the period of maximum water uptake by roots from the soil. During this period of time deeper layers have not thawed, and consequently neither has the permafrost layer. The results found in this study contradict the findings of Sugimoto et al. (2002), who suggested that trees could use thawed permafrost water for their supply. Following this same criterion, Dolman et al. (2004) suggested that in the year 2000 thawed permafrost water could maintain water supply for tree roots. However, our results suggest that their observations are probably the result of shallow active layers that kept soil moisture available for trees rather than water being supplied from lower soil layers. It is also necessary to clarify that between the active layer and the ice-rich permafrost, there is a layer of soil known as the 'transient layer' or 'shielding layer' (Shur Yu, 1998). This layer is characterized by low-ice-content as a result of deep thawing in warm years (Brouchkov et al., 2004).

It is in mid August of 2003 and 2004 that the thawing depth reached deeper layers, but by this time water demand by trees was lower than in mid July. In this study, the difference in thawing depth was 20 cm at the end of the growing season, which remained frozen in 2004 but it was part of the active layer in 2003. Soil moisture below 80 cm does not significantly contribute to tree transpiration as deduced from the lack of change in the 80 cm soil moisture curve during the growing season of 2003 and 2004.

Larch tree roots need to be distributed in the upper layers to uptake water as early as possible to complete the approximately 100 days leaved growing season cycle in Siberia. Thus, the thawing of upper soil layers from mid May sets the start of larch tree activity. Soil moisture at 0—30 cm strongly controls the variation in transpiration (where the bulk of the roots distribute, Kuwada et al., 2002). In 2004, precipitation was nearly half of that in 2003 but the difference in distribution during the growing season allowed through, more frequent but less intense precipitation to keep transpiration going at a nearly constant rate, together with shallow thawed soil layers, from June to early July. In 2003, a rainless period of nearly 20 days set the conditions for a steady decrease in transpiration. Soil moisture at 20 and 30 cm decreased proportionally and more in 2004 than in 2003, reflecting more active tree water uptake from deeper layers as a result of lower precipitation.

Canopy transpiration, canopy conductance and environmental variables

Higher air temperature (mean daily value of 25 °C), higher *VPD* (mean daily value of 2 kPa) and precipitation, promoted higher transpiration rates during the growing season of 2003. As expected for coniferous trees D is an important variable controlling sapflow movement during fine weather days but this response decreases when soil moisture in the upper layers is low. Our results concur with Dolman et al. (2004), in that years with higher soil moisture and fine weather, forest evaporation and consequently canopy transpiration is high. In August 2003, when soil moisture decreased during a rainless period, g_c was not coupled with D, but during the same period it was well coupled with soil moisture at 10, 20 and 30 cm. This is in contrast to the results of Ohta et al. (2001), where a clear relationship between canopy conductance and soil moisture was not found because of the dual-source nature of forest evaporation and the nearly equal contribution of understorey and tree canopy. This suggests that understorey vegetation plays a higher role in the total forest evaporation than previously estimated (Ohta et al., 2001), because of the openness of larch forests in Siberia (Nikolov and Helmisaari, 1993).

Conclusions

1. Inter annual variation in total transpiration because of environmental conditions is influenced by larger sapflow rate variability of dominant trees. Maximum daily sapflow rate for larch trees in eastern Siberia was 42.4 kg d^{-1}.
2. The upper soil layer played an important role in the control of transpiration. Maximum canopy transpiration was 1.7 mm d^{-1} during fine weather and well watered conditions and 1.2 mm during a dry year. Results indicate that tree canopy transpiration contribution to the total forest evapotranspiration ranges between 50% and 60% and that water flux partition between trees and understorey is affected by inter-annual climatic conditions.
3. Seasonal lower soil thawing rates set off the effect of low precipitation regimes that otherwise will lower soil moisture content by filtration in sandy loam soils. Therefore it is not only the presence of permafrost that keeps moisture in the thin active layer, but it is the soil thawing rate that plays the important role of controlling the amount of water available for trees in response to changing environmental conditions during the growing season.

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