Supplementary Material

Response of water use efficiency to summer drought in boreal Scots pine forests in Finland

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Regression analysis

The relationships between gross primary production (GPP) and evapotranspiration/transpiration (ET/T), and their relationships to environmental variables (incoming solar radiation (Rs), air temperature (Ta), vapour pressure deficit (VPD) and soil moisture index (SMI)) under different soil moisture conditions were studied by regression analysis at both sites. We used curve or linear fitting procedures in R software (R Core Team, 2013) to derive the best fitting parameters and coefficients of determination for the prescribed functions. These fittings were adopted to provide general information as to the relationships of those variables, but should not be used to predict plant functioning.

For the relationships between GPP and ET/T, the outliers of the data (deviated groups a and b) were defined based on the residuals from the fitted line. We consider that the data with residuals within the 2.5^{th} and 97.5^{th} percentiles mostly happen under normal weather conditions, whereas data with residuals outside the percentiles are influenced by extreme weather or uncertainties in the measurements.

The fitting function for the relationship between GPP (as Y) and ET/T (as X) is

$$Y= D+A\times(1- \exp(-X/B))^{c}. \quad (1)$$

For Hyytiälä, the derived parameters for the relationship between GPP and ET from the observed dataset are: A = 11.42, B = 3.08, C = 0.61, D = 0;
and the derived parameters for the relationship between GPP and ET from the simulation are: A = 10.64, B = 3.74, C = 1, D = 3.52;
and the derived parameters for the relationship between GPP and T from the simulation are: A = 8.18, B = 1.98, C = 1, D = 4.17.

For Sodankylä, the derived parameters for the relationship between GPP and ET from the observed dataset are: A = 15, B = -4.80, C = 1, D = 0;

and the derived parameters for the relationship between GPP and ET from the simulation are: A = 17.43, B = 20.40, C = 1, D = 3.31;

and the derived parameters for the relationship between GPP and T from the simulation are: A = 6.52, B = 4.07, C = 1, D = 3.25.

The fitting functions and parameters for the relationships between GPP or ET/T to the environmental variables under different soil moisture conditions are summarized in Table S1 and Table S2.

References

R Core Team: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, URL http://www.R-project.org/, 2013.

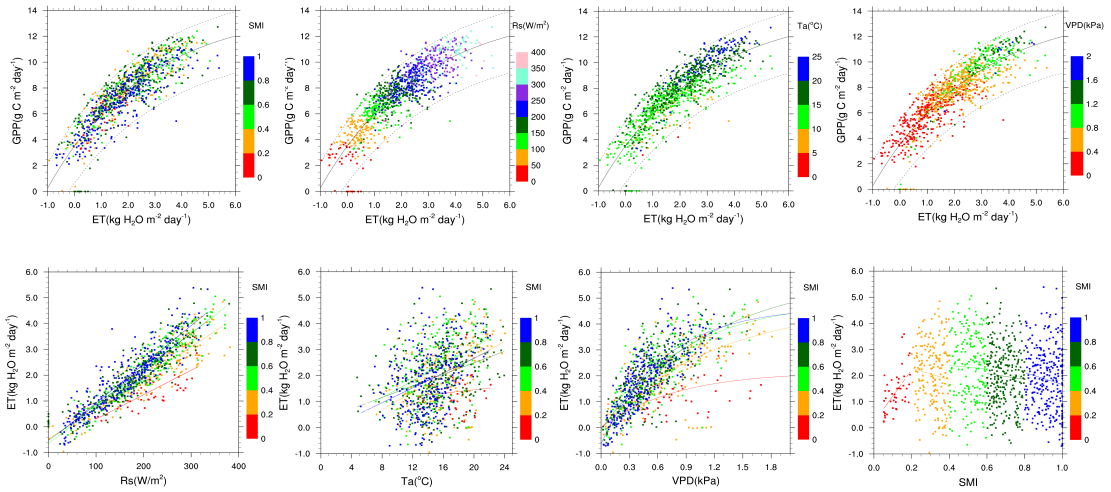

Figure S1: Upper panel: relationship between daily gross primary production (GPP) and evapotranspiration (ET) from the simulated dataset at Hyytiälä. Data are categorized according to environmental variables (soil moisture index (SMI), incoming solar radiation (Rs), air temperature (Ta) and vapour pressure deficit (VPD)). The solid lines are fitted regression lines, and the dashed lines show the 97.5th (upper dashed line) and 2.5 th (lower dashed line) percentiles of the data. Lower panel: Response of daily evapotranspiration (ET) to environmental variables from the simulated dataset at Hyytiälä, categorized with soil moisture conditions. The lines are fitted regression lines for the categorized SMI groups.

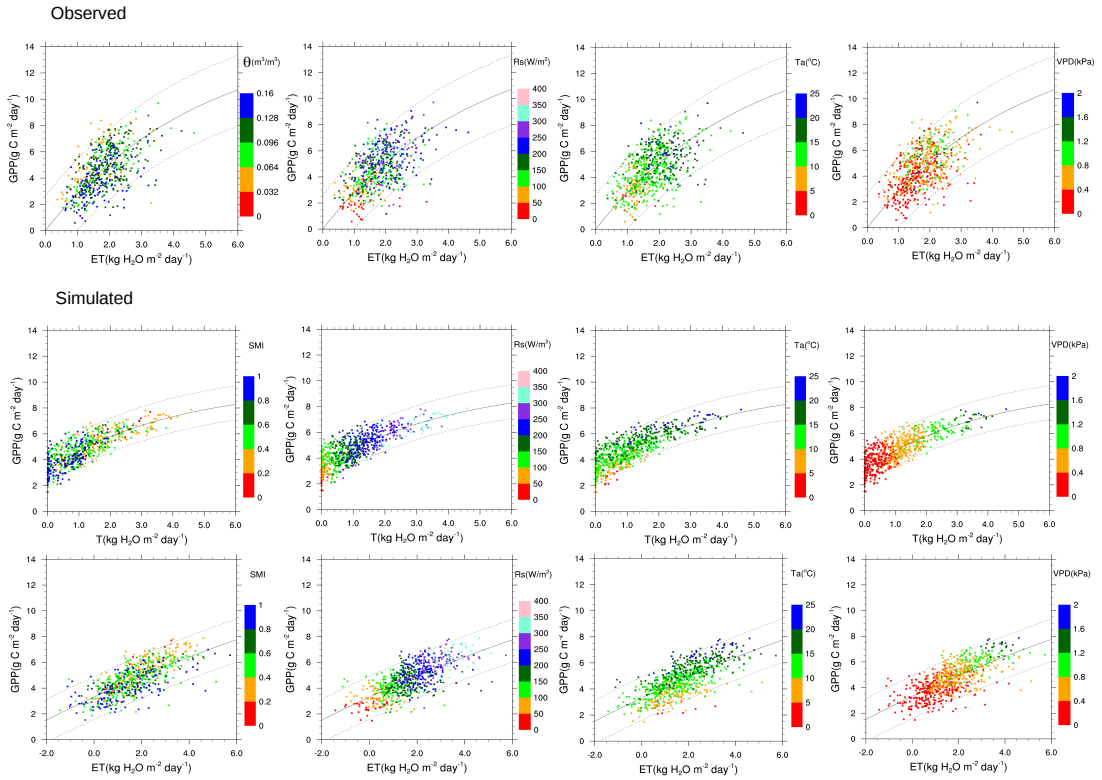

Figure S2: Relationship between daily gross primary production (GPP) and evapotranspiration/transpiration (ET/T) at Sodankylä. Data are categorized according to soil moisture index (SMI), incoming solar radiation (Rs), air temperature (Ta) and vapour pressure deficit (VPD). The solid lines are fitted regression lines, and the dashed lines show the 97.5th (upper dashed line) and 2.5th (lower dashed line) percentiles of the data.

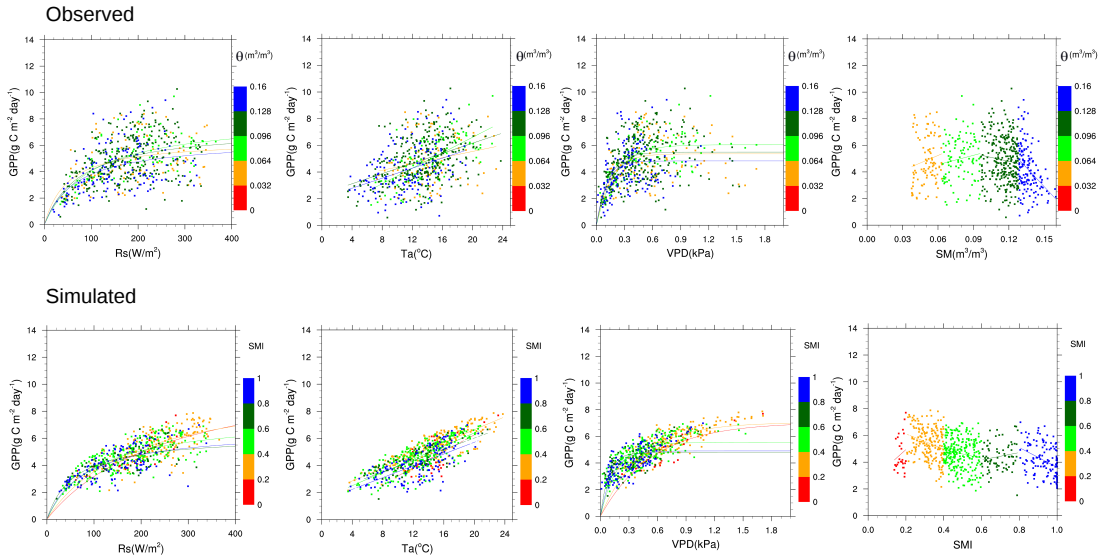

Figure S3: Response of daily gross primary production (GPP) to incoming solar radiation (Rs), air temperature (Ta), vapour pressure deficit (VPD) and soil moisture index (SMI) at Sodankylä, categorized with soil moisture conditions. The lines are fitted regression lines for categorized SMI groups.

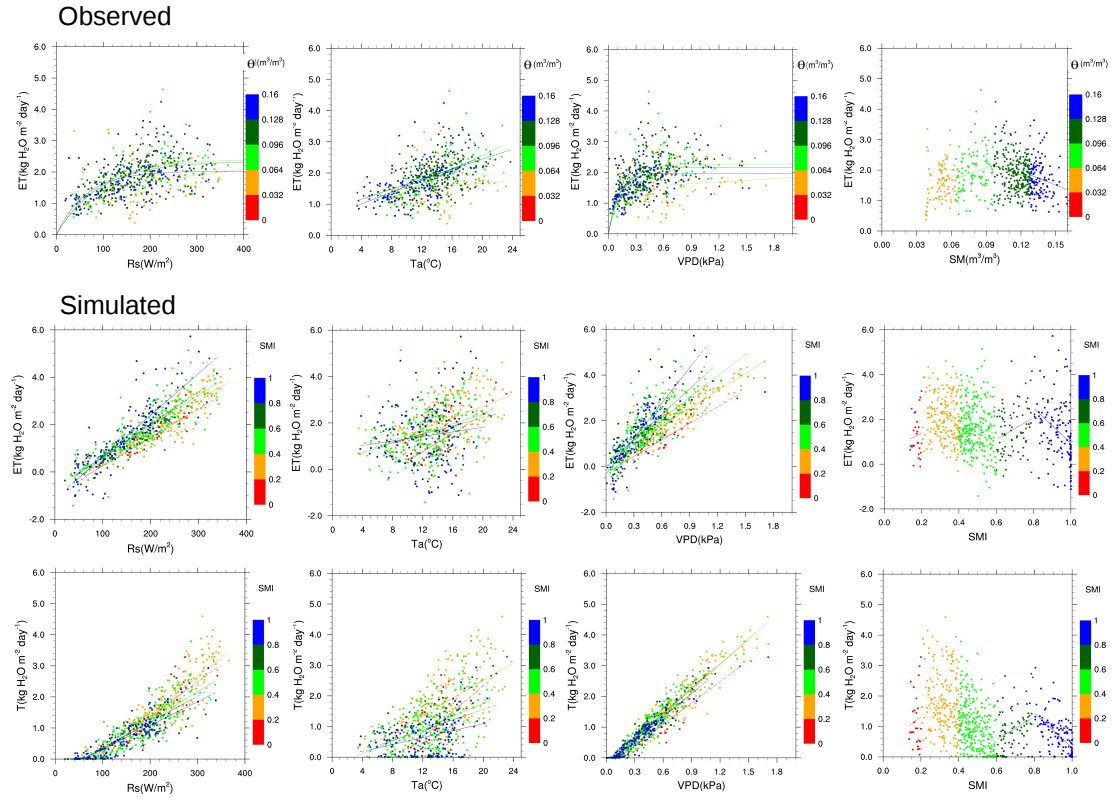

Figure S4: Response of daily evapotranspiration/transpiration (ET/T) to incoming solar radiation (Rs), air temperature (Ta), vapour pressure deficit (VPD) and soil moisture index (SMI) at Sodankylä, categorized with soil moisture conditions. The lines are fitted regression lines for the categorized SMI groups.

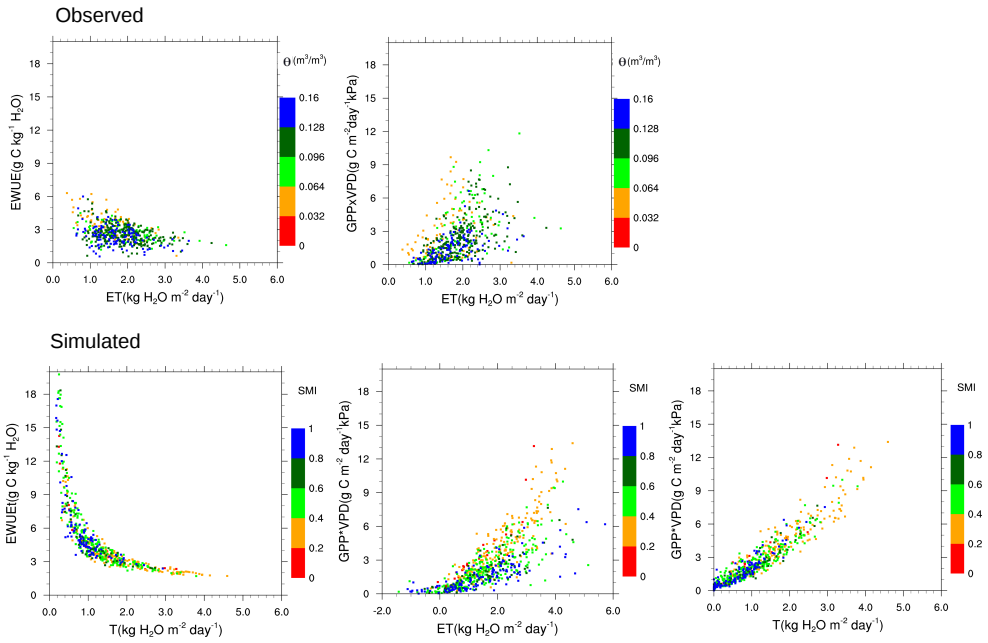

Figure S5: Relationship between daily ecosystem water use efficiency (EWUE) and evapotranspiration (ET), and between daily gross primary production (GPP) multiplied by vapour pressure deficit (GPP × VPD) and ET based on the observed dataset at Sodankylä; relationship between transpiration-based ecosystem water use efficiency (EWUEt) and transpiration (T), and between GPP × VPD and ET/T using the simulated dataset at Sodankylä.

Table S1: Regression parameters and the coefficients of determination between daily gross primary production (GPP) and environmental variables (incoming solar radiation (Rs), air temperature (Ta), vapour pressure deficit (VPD) and soil moisture index (SMI)) categorized with SMI at Hyytiälä.

Environmental Variable			Rs			Ta			SMI			VPD			
Fitting function			Michaelis-Menten function			Linear function			Linear function			Exponential decay function			
Parameter			Vm	K	r^2	slop	interception	r^2	slop	interception	r^2	C/slope	k/interception	A	r^2
GPP	observation	N1	6.950	72.840	0.110	-0.565	15.027	0.490	57.990	-4.088	0.620	*-3.001	*6.567	NA	*0.170
		N2	11.010	87.660	0.480	0.158	4.556	0.080	5.434	4.700	0.020	7.728	-6.756	0.000	0.370
		N3	11.390	81.290	0.650	0.155	5.338	0.100	2.637	6.503	0.010	8.563	-6.837	0.000	0.560
		N4	10.190	75.780	0.600	0.141	4.942	0.100	8.559	-2.382	0.010	7.886	-4.946	0.000	0.460
		N5	10.400	74.330	0.590	0.392	1.039	0.290	21.747	-17.777	0.220	7.968	-6.006	0.000	0.610
	simulation	N1	17.470	403.390	0.750	-0.175	9.261	0.060	31.118	2.597	0.670	6.513	-4.761	0.000	0.050
		N2	16.400	214.030	0.940	0.343	2.325	0.200	10.045	-7.000	0.020	10.064	-3.048	0.000	0.530
		N3	17.450	208.730	0.940	0.374	2.532	0.310	9.424	-2.389	0.004	10.370	-3.218	0.000	0.650
		N4	16.190	188.670	0.930	0.362	2.231	0.310	9.970	-3.179	0.006	10.445	-3.373	0.000	0.630
		N5	18.530	233.070	0.980	0.382	1.620	0.270	15.220	-8.891	0.060	10.256	-2.957	0.000	0.680
Fitting function			Exponential Decay function			Linear function			Linear function			Exponential decay function			
Parameter			C/slope	k/interception	r^2	slop	interception	r^2	slop	interception	r^2	C/slope	k/interception	A	r^2
ET	observation	N1	2.584	-0.004	0.320	-0.053	2.377	0.045	9.990	0.217	0.560	*0.0382	*1.399	NA	*0.001
		N2	2.942	-0.007	0.510	0.092	0.584	0.160	-2.215	2.729	0.040	2.389	-4.705	0.000	0.340
		N3	3.513	-0.006	0.580	0.097	0.786	0.160	-0.622	2.633	0.010	2.818	-4.225	0.000	0.440
		N4	3.178	-0.006	0.550	0.083	0.857	0.150	-1.108	2.742	0.013	2.877	-2.417	0.000	0.470
		N5	2.845	-0.008	0.600	0.128	-0.027	0.220	-2.319	3.974	0.080	2.888	-2.856	0.000	0.660
	simulation	N1	*0.009	*-0.653	*0.600	0.033	0.801	0.010	17.073	-1.243	0.330	2.167	-1.273	0.000	0.150
		N2	*0.012	*-0.475	*0.820	0.164	-0.603	0.220	3.246	0.923	0.010	4.770	-0.832	0.000	0.490
		N3	*0.014	*-0.645	*0.880	0.162	-0.134	0.170	1.423	1.634	0.001	5.038	-1.140	-0.121	0.610
		N4	*0.014	*-0.527	*0.830	0.111	0.277	0.140	1.533	0.952	0.003	6.019	-0.829	-0.062	0.590
		N5	*0.015	*-0.578	*0.840	0.143	-0.179	0.120	-4.117	5.275	0.014	5.296	-1.486	-0.623	0.690
T	simulation	N1	*0.009	*-0.790	*0.780	0.035	0.439	0.017	6.778	0.274	0.230	*1.086	*0.130	NA	*0.397
		N2	*0.011	*-0.702	*0.760	0.207	-1.755	0.390	-1.491	2.050	0.005	*2.388	*-0.162	NA	*0.733
		N3	*0.013	*-1.015	*0.810	0.204	-1.328	0.280	-1.590	2.580	0.006	*3.097	*-0.244	NA	*0.846
		N4	*0.012	*-0.821	*0.760	0.134	-0.628	0.230	-1.320	2.331	0.006	*3.223	*-0.290	NA	*0.753
		N5	*0.012	*-0.695	*0.790	0.156	-1.041	0.230	-5.556	6.283	0.130	*3.257	*-0.369	NA	*0.853

The groups N1 to N5 are classified according to soil moisture conditions: N1 ($0 \leq SMI < 0.2$), N2 ($0.2 \leq SMI < 0.4$), N3 ($0.4 \leq SMI < 0.6$), N4 ($0.6 \leq SMI < 0.8$), N5 ($0.8 \leq SMI < 1$). The form of exponential function is $Y = C\times(1-\exp(k\times X))$ or $Y = A+C\times(1-\exp(k\times X))$. The form of Michaelis-Menten function is $Y=Vm\times X/(K+X)$. Values marked with * mean that linear function is adopted as the fitting function for this group of data, which is different to other groups from the observed dataset; NA means there is no data for this group or that the parameter is not needed in the fitting function.

Table S2: Regression parameters and the coefficients of determination between daily evapotranspiration/transpiration (ET/T) and environmental variables (incoming solar radiation (Rs), air temperature (Ta), vapour pressure deficit (VPD) and soil moisture content (θ)/soil moisture index (SMI)) categorized with θ/SMI at Sodankylä.

Environmental Variable			Rs			Ta			SMI			VPD		
Fitting function			Michaelis-Menten function			Linear function			Linear function			Exponential decay function		
Parameter			Vm	K	r^2	slop	interception	r^2	slop	interception	r^2	C	k	r^2
GPP	observation	N1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		N2	6.414	49.874	0.140	0.117	3.194	0.058	37.713	2.974	0.024	5.359	-6.781	0.170
		N3	8.118	100.297	0.510	0.290	0.802	0.440	23.336	3.148	0.020	6.039	-4.964	0.550
		N4	7.331	77.857	0.230	0.190	2.359	0.171	-19.716	7.161	0.010	5.492	-7.474	0.220
		N5	6.393	68.408	0.270	0.188	2.032	0.146	-95.103	17.151	0.141	4.827	-9.322	0.220
	simulation	N1	11.547	264.615	0.610	0.303	0.203	0.449	12.703	2.398	0.033	7.044	-1.848	0.540
		N2	10.124	186.965	0.510	0.237	1.909	0.655	-5.682	7.248	0.068	7.040	-2.379	0.680
		N3	7.620	100.031	0.590	0.243	1.538	0.627	-3.135	6.176	0.025	5.539	-5.632	0.510
		N4	6.187	57.301	0.470	0.208	1.854	0.579	2.756	2.511	0.026	4.772	-11.735	0.250
		N5	6.666	78.950	0.490	0.218	1.364	0.469	-7.349	10.970	0.145	4.903	-7.955	0.380
Fitting function			Exponential Decay function			Linear function			Linear function			Exponential decay function		
Parameter			C/slope	k/interception	r^2	slop	interception	r^2	slop	interception	r^2	C/slope	k/interception	r^2
ET	observation	N1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
		N2	*0.002	*1.293	*0.036	0.017	1.336	0.009	21.392	0.484	0.066	*0.184	*1.469	*0.010
		N3	2.406	-0.011	0.360	0.114	0.290	0.372	13.585	0.854	0.034	2.273	-5.829	0.330
		N4	2.341	-0.011	0.310	0.080	0.841	0.256	-13.490	3.459	0.041	2.163	-7.209	0.250
		N5	2.029	-0.016	0.200	0.095	0.628	0.288	-15.059	3.765	0.032	1.973	-9.307	0.100
	simulation	N1	*0.012	*-0.950	*0.836	0.049	0.826	0.017	0.550	4.159	0.007	*0.909	*29.715	*0.826
		N2	*0.013	*-0.819	*0.771	0.089	0.451	0.089	2.882	-2.471	0.018	*2.558	*0.235	*0.745
		N3	*0.013	*-0.675	*0.755	0.104	0.294	0.122	2.759	-2.320	0.015	*3.124	*0.212	*0.602
		N4	*0.014	*-0.742	*0.739	0.124	0.253	0.245	4.914	-1.851	0.072	*3.712	*0.057	*0.689
		N5	*0.018	*-1.127	*0.740	0.200	-1.634	0.373	-7.869	8.803	0.118	*5.170	*-0.329	*0.693
T	simulation	N1	*0.011	*-0.868	*0.791	0.209	-1.845	0.449	4.422	0.424	0.008	*2.318	*-0.302	*0.842
		N2	*0.012	*-1.019	*0.751	0.143	-0.352	0.347	-2.331	2.520	0.017	*2.704	*-0.188	*0.881
		N3	*0.009	*-0.631	*0.767	0.102	-0.294	0.234	-4.962	3.430	0.133	*2.709	*-0.213	*0.900
		N4	*0.008	*-0.483	*0.670	0.084	-0.131	0.199	3.710	-1.656	0.101	*2.741	*-0.190	*0.919
		N5	*0.008	*-0.439	*0.747	0.057	-0.040	0.122	-5.717	6.017	0.336	*2.553	*-0.203	*0.912

The groups N1 to N5 are classified according to soil moisture conditions. For the observed dataset at Sodankylä, soil moisture content (θ) [m^3 H_2O m^{-3}] was used for classification of the groups: N1 ($0 \leq \theta < 0.032$), N2 ($0.032 \leq \theta < 0.064$), N3 ($0.064 \leq \theta < 0.096$), N4 ($0.096 \leq \theta < 0128$), N5 ($0.128 \leq \theta < 0.16$). For the simulated results, SMI was used to define the groups: N1 ($0 \leq$SMI < 0.2), N2 ($0.2 \leq$ SMI < 0.4), N3 ($0.4 \leq$ SMI < 0.6), N4 ($0.6 \leq$ SMI < 0.8), N5 ($0.8 \leq$ SMI < 1). The form of exponential function is $Y = C\times(1-\exp(k\times X))$ or $Y = A+C\times(1-\exp(k\times X))$. The form of Michaelis-Menten function is $Y = Vm\times X/(K+X)$. Values marked with * mean that linear function is adopted as the fitting function for this group of data, which is different to other groups from the observed dataset; NA means there is no data for this group or that the parameter is not needed in the fitting function.