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SUPPLEMENTARY INFORMATION

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Contrasting response of European forest and grassland energy exchange to heatwaves

Supplementary information

Teuling et al. (2010)

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Title: Supplementary Figures

Summary: Table 1 contains information on the eddy covariance flux tower sites. Figures 1-5 show the atmospheric circulation during heatwave months, the relation between forcing and energy partitioning, the heatwave anomalies, the climatology estimation error, and soil moisture.

Supplementary Table 1 | List of flux tower sites, site characteristics, and site references for additional site information (see full references on following pages). For the sites without reference we refer to www.fluxdata.org for additional information. T_{max} is the mean summer (JJA) daily maximum temperature excluding heatwave months June-August 2003 and July 2006.

Abbr.	Site name	Lat.	Long.	Elev. (m)	Clim.	IGBP class	Years	T_{max} (°C)	Site reference
AT-Neu	Neustift/Stubai Valley	47.117	11.318	970.	Cfb	Grassland	2002–2006	21.41	Hammerle et al. (2008)
BE-Bra	Brasschaat (De Inslag Forest)	51.309	4.521	16.	Cfb	Mixed forest	1997–2006	20.60	Gielen et al. (2010)
BE-Lon	Lonzee	50.552	4.745	165.	Cfb	Cropland	2004–2006	21.29	Moureaux et al. (2006)
BE-Vie	Vielsalm	50.306	5.997	450.	Cfb	Mixed forest	1996–2006	18.89	Aubinet et al. (2001)
CH-Oe1	Oensingen 1	47.286	7.732	450.	Cfb	Grassland	2002–2006	22.49	Ammann et al. (2007)
DE-Bay	Bayreuth-Waldstein	50.142	11.867	775.	Cfb	Evergreen needleleaf forest	1996–1999	17.76	Staudt et al. (2007)
DE-Geb	Gebesee	51.100	10.914	161.	Cfb	Cropland	2004–2006	22.05	Anthoni et al. (2004)
DE-Gri	Grillenburg	50.950	13.513	385.	Cfb	Grassland	2005–2006	20.65	Gilmanov et al. (2006)
DE-Hai	Hainich	51.079	10.452	430.	Cfb	Deciduous broadleaf forest	2000–2006	19.14	Kutsch et al. (2010)
DE-Har	Hartheim	47.934	7.601	201.	Cfb	Evergreen needleleaf forest	2005–2006	23.58	Schindler et al. (2006)
DE-Kli	Klingenberg	50.893	13.523	480.	Cfb	Cropland	2004–2006	19.70	Prescher et al. (2010)
DE-Meh	Mehrstedt 1	51.275	10.656	286.	Cfb	Grassland	2003–2006	21.52	Don et al. (2009)
DE-Tha	Tharandt (Anchor Station)	50.964	13.567	380.	Cfb	Evergreen needleleaf forest	1996–2006	20.32	Grünwald et al. (2007)
DE-Wet	Wetzstein	50.453	11.458	785.	Cfb	Evergreen needleleaf forest	2002–2006	17.55	Rebmann et al. (2010)
DK-Sor	Soroe (LilleBogeskov)	55.487	11.646	40.	Cfb	Deciduous broadleaf forest	1996–2006	18.75	Pilegaard et al. (2003)
FR-Fon	Fontainebleau	48.476	2.780	90.	Cfb	Deciduous broadleaf forest	2005–2006	22.29	see www.fluxdata.org
FR-Gri	Grignon	48.844	1.952	125.	Cfb	Cropland	2005–2006	22.77	Hibbard et al. (2005)
FR-Hes	Hesse Forest (Sarrebourg)	48.674	7.065	300.	Cfb	Deciduous broadleaf forest	1997–2006	21.78	Granier et al. (2008)
FR-LBr	Le Bray	44.717	−0.769	61.	Cfb	Evergreen needleleaf forest	1996–2006	24.97	Berbigier et al. (2001)
FR-Lq1	Laqueuille	45.644	2.737	1040.	Cfb	Grassland	2003–2006	18.67	Allard et al. (2007)
FR-Lq2	Laqueuille extensive	45.639	2.737	1040.	Cfb	Grassland	2003–2006	18.67	Allard et al. (2007)
IT-Lav	Lavarone	45.955	11.281	1353.	Cfb	Evergreen needleleaf forest	2000–2006	18.37	Marcolla et al. (2003)
IT-MBo	Monte Bondone	46.016	11.047	1550.	Cfb	Grassland	2003–2006	16.29	Gianelle et al. (2009)
IT-Mal	Malga Arpaco	46.117	11.703	1730.	Cfb	Grassland	2003–2006	15.01	see www.fluxdata.org
IT-Ren	Renon/Ritten	46.588	11.435	1730.	Dfb	Evergreen needleleaf forest	1999–2006	17.20	Montagnani et al. (2009)
NL-Ca1	Cabauw1	51.971	4.927	0.7	Cfb	Grassland	2003–2006	20.60	Jacobs et al. (2007)
NL-Hor	Horstermeer	52.029	5.068	−2.2	Cfb	Grassland	2004–2006	22.49	Jacobs et al. (2007)
NL-Loo	Loobos	52.168	5.744	25.	Cfb	Evergreen needleleaf forest	1996–2006	20.58	Dolman et al. (2002)
UK-PL3	Pang/Lambourne	51.45	−1.267	115.	Cfb	Deciduous broadleaf forest	2005–2006	23.02	see www.fluxdata.org
UK-Ham	Hampshire	51.121	−0.861	80.	Cfb	Deciduous broadleaf forest	2004–2005	20.88	see www.fluxdata.org

Supplementary Table 1 (cont.) | Full site references.

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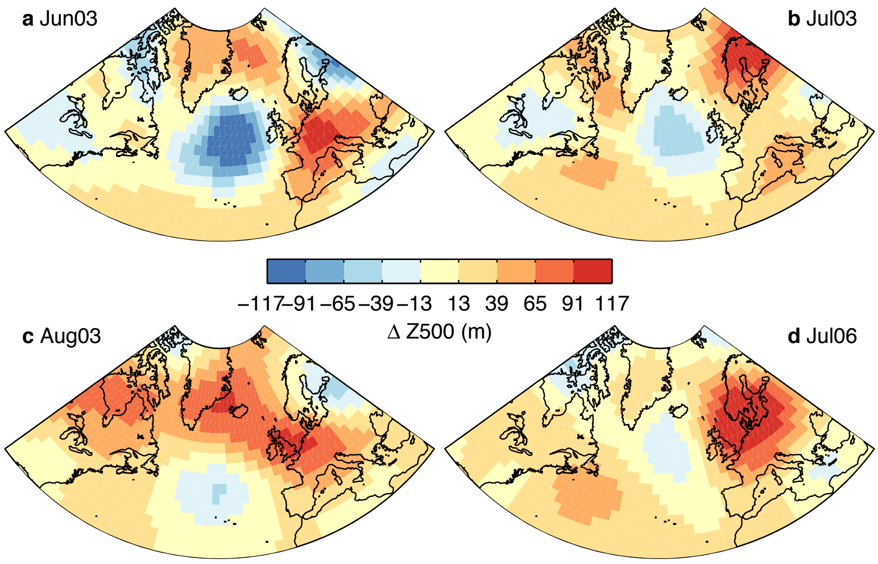

Supplementary Figure 1 | Distribution of the monthly average 500 hPa height anomaly (Z500) with respect to the climatology over the years 1948–2002. **a**, June 2003. **b**, July 2003. **c**, August 2003. **d**, July 2006. Data come from the NCEP/NCAR Reanalysis and have been obtained from the Climate Explorer (climexp.knmi.nl). The atmospheric circulation regime in June 2003 is dominated by a deep anomalous trough covering the North Atlantic, while heatwave conditions in July and August 2003 and July 2006 were caused by an Omega Blocking situation with an extensive high located over Northern Europe.

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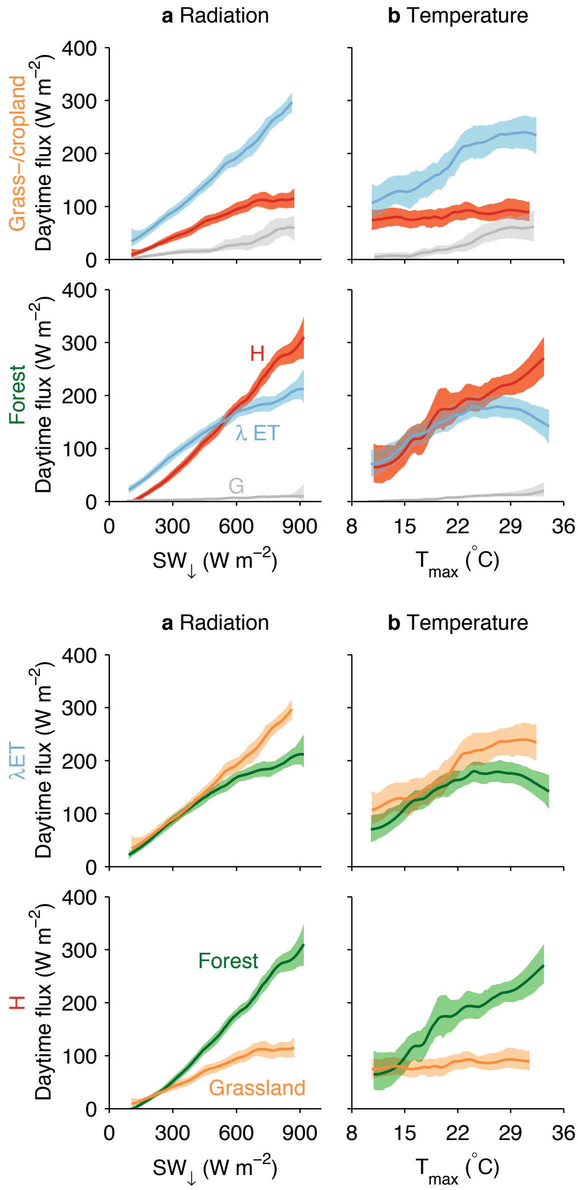
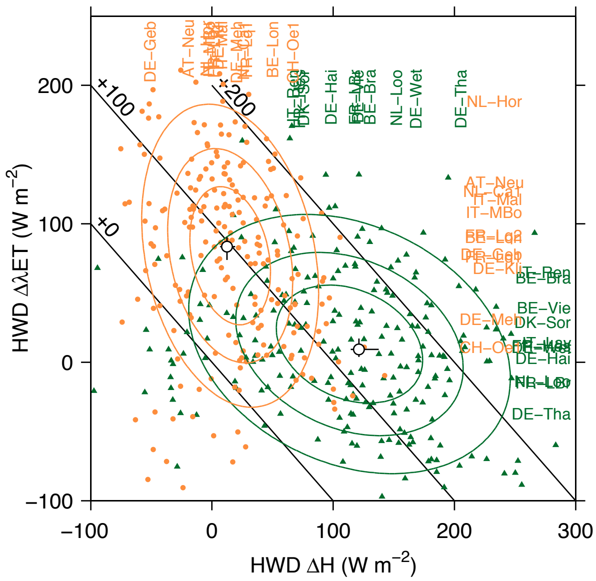


Supplementary Figure 2 | Functional relationships between midday surface fluxes of sensible heat (H), latent heat (λET), and ground heat (G) and environmental conditions. **a**, Incoming shortwave radiation ($SW_{\downarrow}$). **b**, Daily maximum air temperature (T_{max}, see Supplementary Table 1 for non-heatwave site averages). Curves have been derived using locally weighted polynomial regression (LOESS) on all midday data (9:00–13:00 UTC, heatwave days included) in the months June–August for all sites. Uncertainty bounds reflect 5% and 95% percentiles of the LOESS regression as determined by bootstrapping. The upper plot displays the relations per land use type separately; in the lower plot the relations are shown for H and λET separately. Relationships with radiation are stronger than with temperature as indicated by the smaller uncertainty bounds. Note that grassland and forest have different maxima in their T,λET-relationships, with forest becoming temperature limited at lower temperatures. The sensible heat flux over grassland shows no clear relation with temperature over the observed range of temperatures, whereas it strongly increases with temperature over forest.



Supplementary Figure 3 | Relation between heatwave day (HWD) anomalies of sensible (H) and latent (λET) heat flux for forest (triangles) and grass-/cropland (circles) sites. Lines indicate levels of available energy. Site abbreviations indicate the HWD medians. The single-component Gaussian density contours reveal a distinct clustering between forest and grass-/cropland sites.

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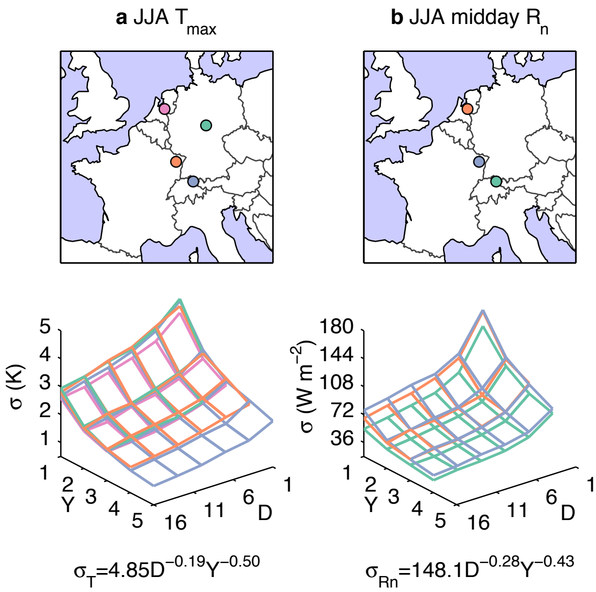
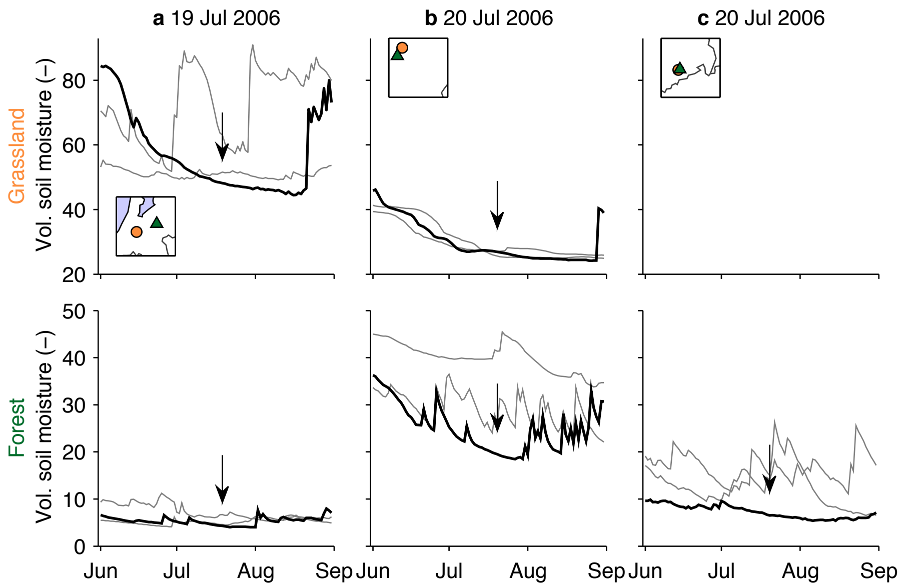


Supplementary Figure 4 | Reduction in uncertainty of the estimated summer (June–August) climatology as a function of the number of days (D) and the number of years (Y) of the averaging period as determined by the random combination method. Data are taken from flux tower sites with the longest continuous records (Hainich, Hesse Forest, Loobos) and the Rietholzbach experimental site in Switzerland (www.iac.ethz.ch/url/rietholzbach). Note that the exponents will converge to −0.50 for uncorrelated data. The strong temporal autocorrelation makes it more effective to increasing the number of years to reduce the uncertainty than increasing the number of days around the day of interest (roughly by a factor 3). For temperature, estimating the climatology from 5 years of data and using a 15-day window reduces the uncertainty by 73% of the interannual variability of daily temperature. For fluxes, which have a lower temporal autocorrelation, this reduction is 77%. Here we use at least 2 years of data and a 15-day window, corresponding to minimum reductions of 58% and 65%, respectively.



Supplementary Figure 5 | Observed summer soil moisture evolution for the site pairs shown in Figure 2. **a**, Cabauw and Loobos (distance 60 km). **b**, Mehrstedt and Hainich (distance 26 km). **c**, Grillenburg and Tharandt (distance 4 km). Thick lines indicate observations for the year 2006, grey lines show observations for 2004 and 2005 as reference. Arrows indicate the dates. Soil moisture observations are made at approximately 30 cm depth using Time Domain Reflectometry. Note that soil moisture levels at the peak of the 2006 heatwave were not necessary below 2004 and 2005 levels for the forest sites that show a large increase in sensible heat flux. No soil moisture observations are available for Grillenburg. The plots also illustrate the difficulty when comparing soil moisture across sites: volumetric soil moisture values can be in completely different ranges due to differences in soil texture, and the measurements represent only a small part of the total volume of soil over which plants take up their water. Moreover, the uptake of plants is a dynamic process and might not be represented well by measurements at a single depth.