Supplement of Hydrol. Earth Syst. Sci., 25, 447–471, 2021
https://doi.org/10.5194/hess-25-447-2021-supplement

Hydrology and Earth System Sciences
Open Access

Supplement of

Evaluating a land surface model at a water-limited site: implications for land surface contributions to droughts and heatwaves

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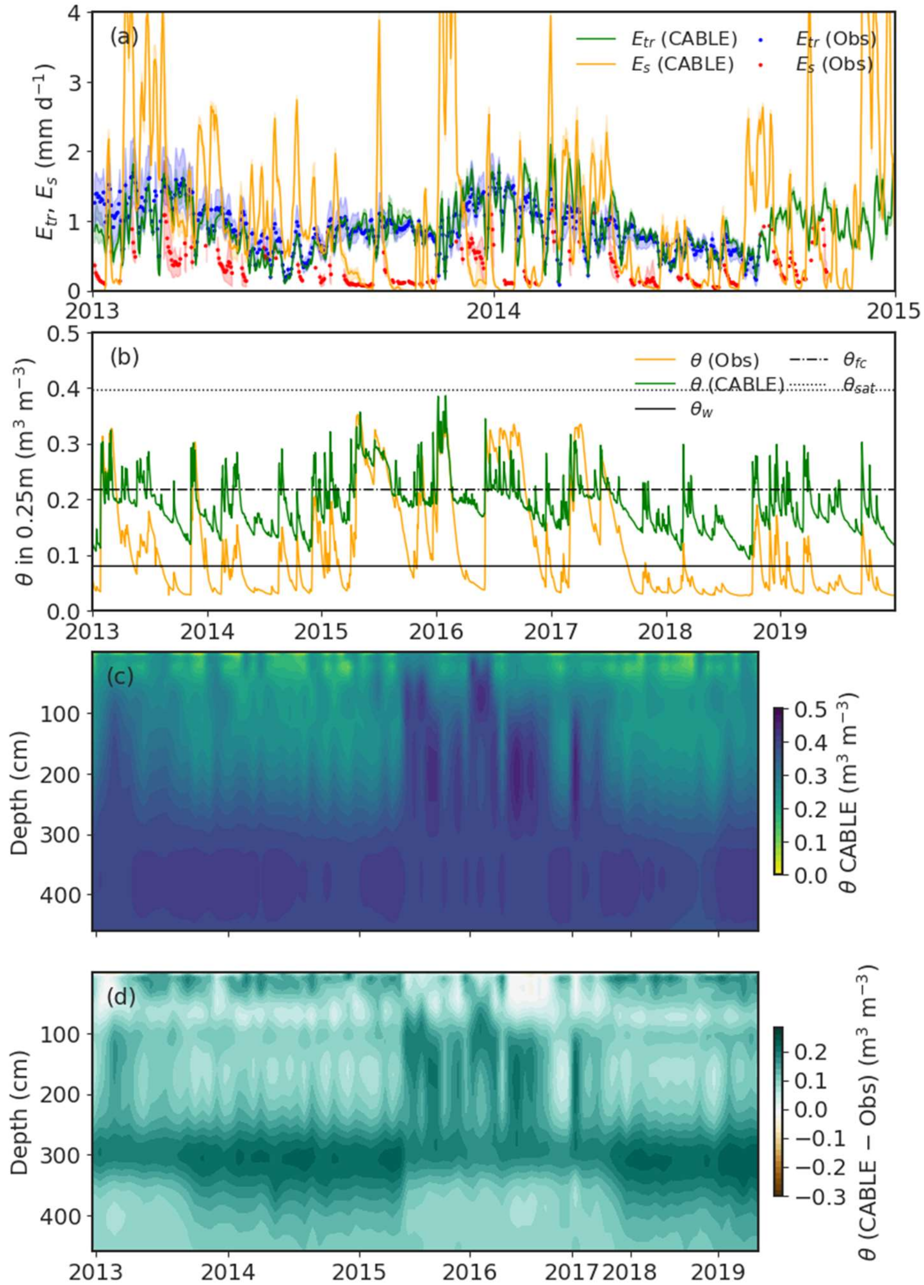

Figure S1. Out-of-box CABLE experiment which uses the model default plant physiological and soil hydraulic parameters and the default 6 soil layers. (a) E_{tr} and E_s between 2013 and 2015. The shaded areas represent uncertainty between three ambient rings. Both simulations and observations are smoothed to aid visualisation. (b) θ in the top 0.25m from 2013 to 2019. (c) vertical distribution of θ in the out-of-box CABLE simulation at observed dates from 2013 to 2019. (d) θ difference between CABLE and observations. Note the different time axis for (c-d) relative to (a-b) due to different sampling intervals for soil moisture and fluxes.

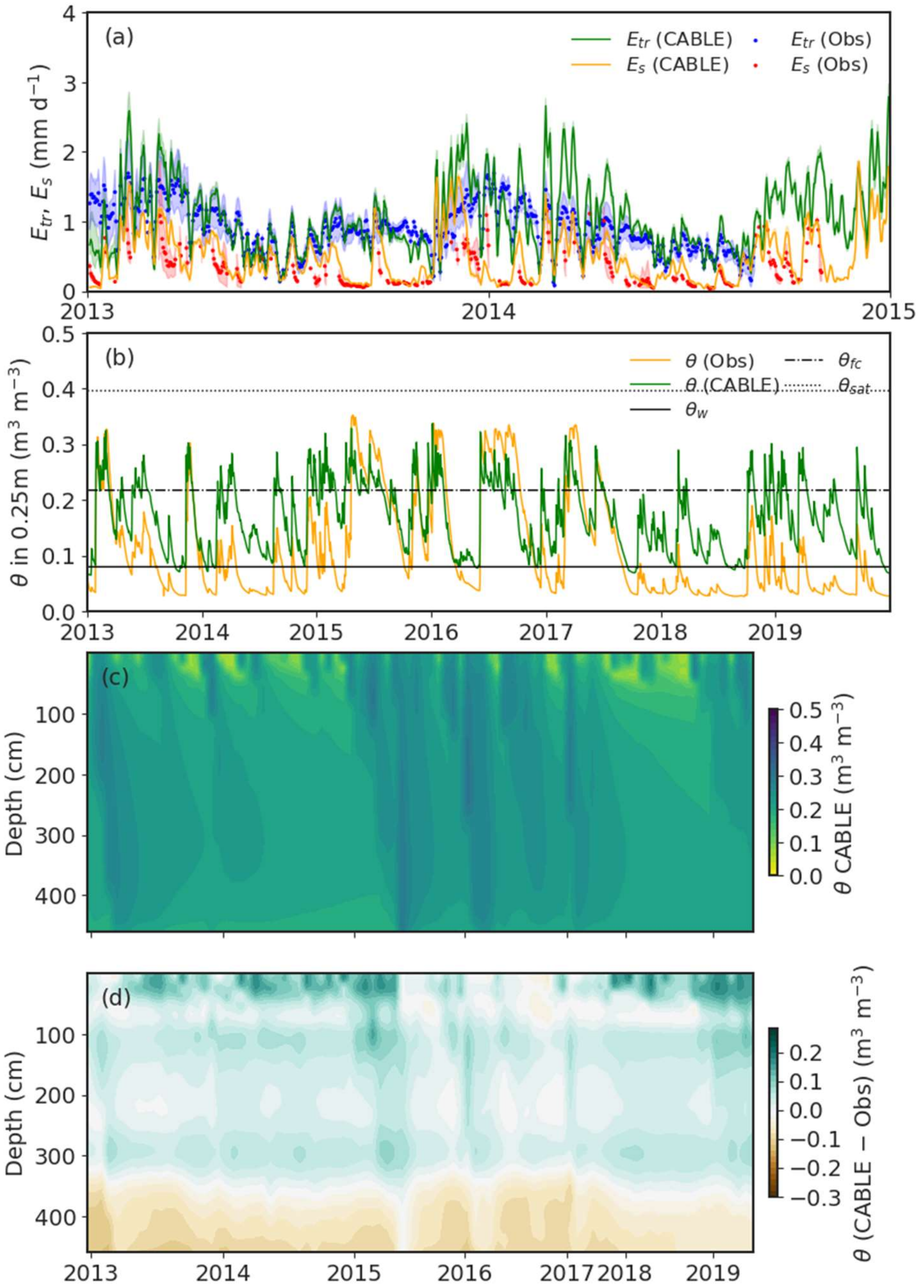

Figure S2. High soil resolution experiment (*Hi-Res-1*) which uses 31 soil layers but the soil parameters do not change with depth. (a) E_{tr} and E_s between 2013 and 2015. The shaded areas represent uncertainty between three ambient rings. Both simulations and observations are smoothed to aid visualisation. (b) θ in the top 0.25m from 2013 to 2019. (c) vertical distribution of θ in *Hi-Res-1* at observed dates from 2013 to 2019. (d) θ difference between CABLE and observations. Note the different time axis for (c-d) relative to (a-b) due to different sampling intervals for soil moisture and fluxes.

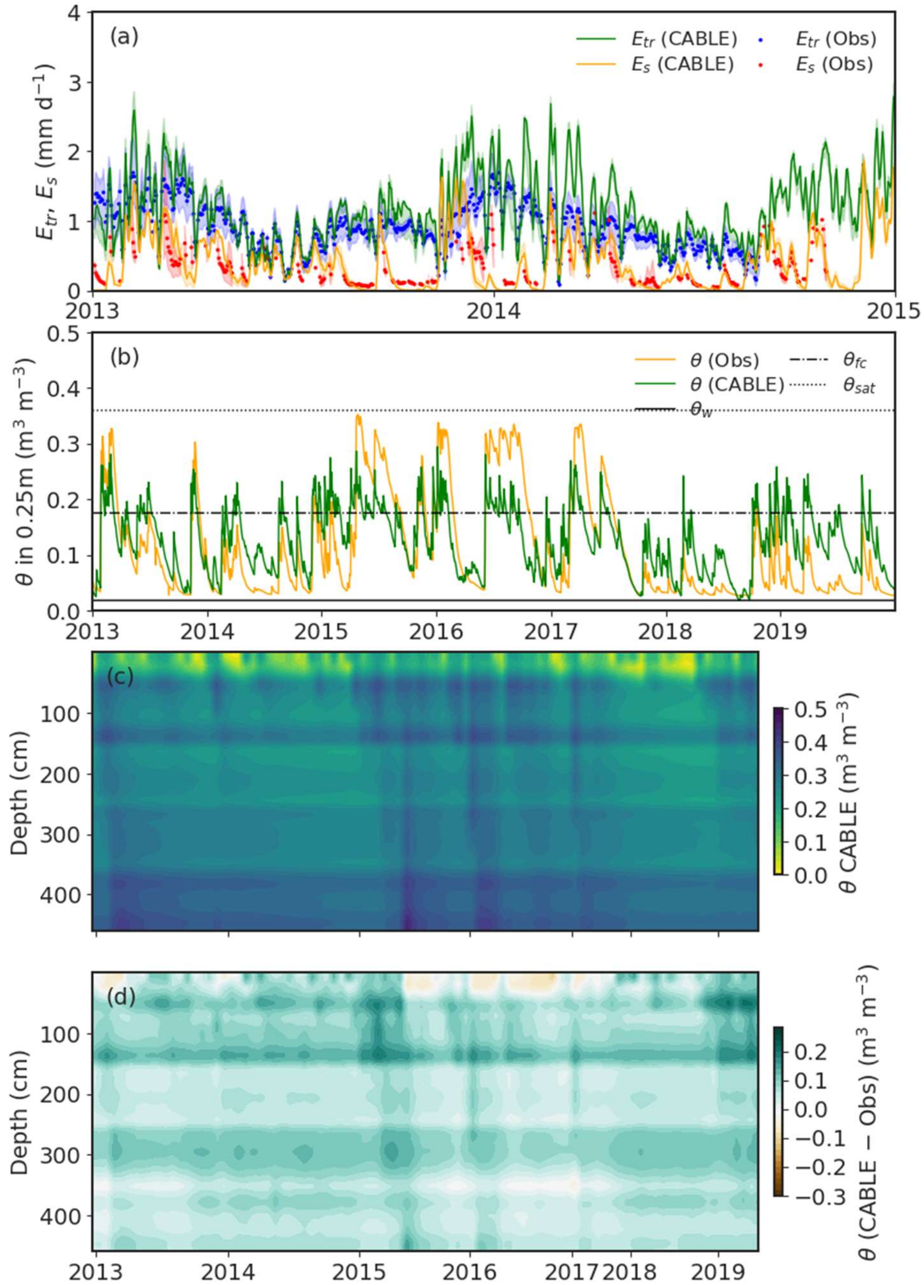

Figure S3. Experiment based on *Hi-Res-2* but uses the observed soil moisture minima at each soil layer across 4.6 m to constrain θ_w and uses the observed maxima to set θ_{sat} over the top 0.3m. (a) E_{tr} and E_s between 2013 and 2015. The shaded areas represent uncertainty between three ambient rings. Simulations and observations are smoothed using a 3-day running mean to aid visualisation. (b) θ in the top 0.25m from 2013 to 2019. (c) The vertical distribution of θ in this experiment at observed dates between 2013 to 2019. (d) The differences in θ between CABLE and the observations. Note the different time axis for (c-d) relative to (a-b) due to different sampling intervals for soil moisture and fluxes.

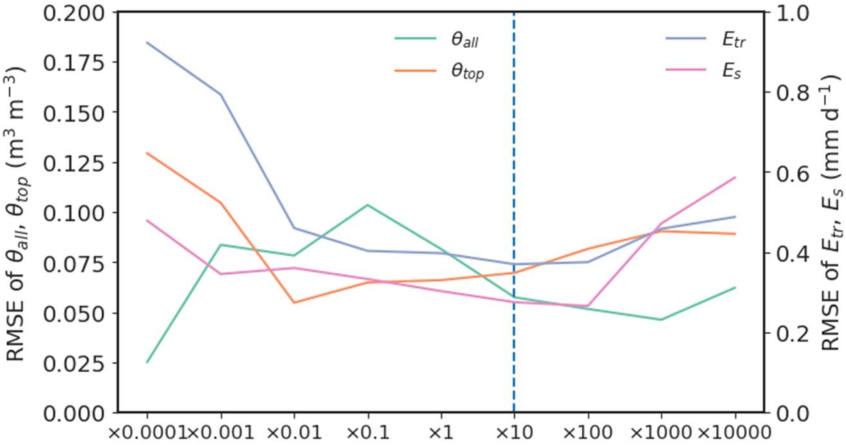

Figure S4. Optimising K_{sat} for the 4.6m soil column against observed θ over 4.6 m (θ_{all}), θ in top 0.25 m (θ_{top}), E_{tr} and E_s. The lower root mean square error (RMSE) represents the better optimised value. K_{sat} × 10 is the optimal value which is emphasized by the vertical dashed line.

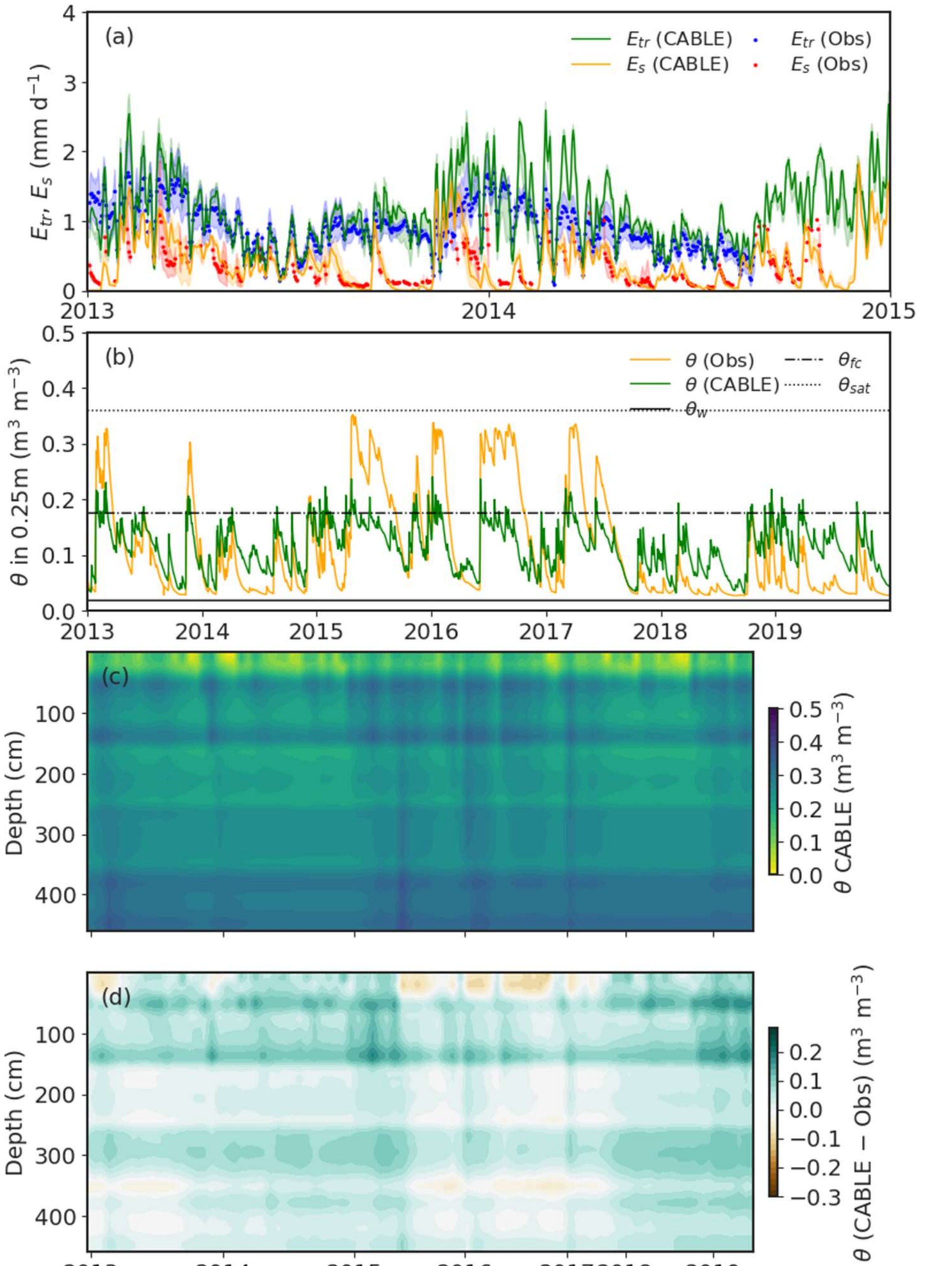

Figure S5. Soil parameter optimisation experiment (*Opt*) which uses the observed soil moisture minima at each soil layer across 4.6 m to constrain θ_w, uses the observed maxima to set θ_{sat} over the top 0.3m and uses the optimal K_{sat} × 10. (a) E_{tr} and E_s between 2013 and 2015. The shaded areas represent uncertainty between three ambient rings. Simulations and observations are smoothed using a 3-day running mean to aid visualisation. (b) θ in the top 0.25m from 2013 to 2019. (c) The vertical distribution of θ in the *Opt* experiment at observed dates between 2013 to 2019. (d) The differences in θ between CABLE and the observations. Note the different time axis for (c-d) relative to (a-b) due to different sampling intervals for soil moisture and fluxes.

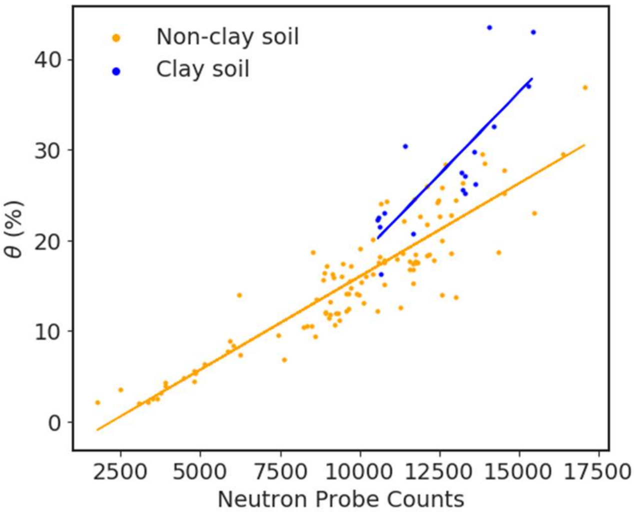

Figure S6. The lab measured θ against the raw neutron probe counts. The θ measurement via drying method is from soil samples collected at the same depths as the neutron probe readings (Gemino et al., 2018).

Table S1. Physiology parameters comparison between CABLE default values and EucFACE measured values. Citations: * Wang et al. (2011) ; ** Yang et al. (2020) ; *** De Kauwe et al. (2015).

Parameters	Definitions	Units	Values	
			CABLE*	EucFACE**
α_J	Quantum yield of electron transport rate	µmol electron µmol^{-1} photon	0.2	0.3
θ_J	Curvature of leaf response of electron transport to absorbed photosynthetically active radiation	-	0.7	0.48
ΔS	Entropy factor	J mol^{-1} K^{-1}	486.0 (V_{cmax}) 495.0 (J_{max})	639.60 (V_{cmax}) 638.06 (J_{max})
E_a	Activation energy	J mol^{-1}	73637 (V_{cmax}) 50300 (J_{max})	66386 (V_{cmax}) 32292 (J_{max})
g_1	Parameter represents the g_s sensitivity to photosynthesis	kPa$^{0.5}$	4.1***	5
H_d	Deactivation energy	J mol^{-1}	149252 (V_{cmax}) 152044 (J_{max})	200000
q	The nonlinearity of the g_1 dependence of θ	-	-	0.425
$J_{max,25}$	Value of J_{max} at 25°C	µmol electron m^{-2} s^{-1}	110	159
$V_{cmax,25}$	Value of V_{cmax} at 25°C	µmol C m^{-2} s^{-1}	55	91

Table S2. Performance metrics for θ at the different depths among the different experiments. Bold numbers are the best value among these experiments.

Simulation	θ	r	RMSE m^3 m^{-3}	MBE m^3 m^{-3}	P5 m^3 m^{-3}	P95 m^3 m^{-3}
Ctl	top 0.25m	0.79	0.08	0.05	0.05	-0.05
Sres		**0.82**	0.13	0.11	0.10	**0.00**
Watr		0.71	0.09	0.06	0.05	-0.04
Hi-Res-1		0.71	0.09	0.06	0.05	-0.04
Hi-Res-2		0.72	0.08	0.05	0.05	-0.06
Opt		0.71	0.07	**0.00**	0.02	-0.13
β-hvrd		0.76	**0.07**	-0.01	0.01	-0.14
β-exp		0.72	0.07	0.00	**0.00**	-0.13
Ctl	top 1.5m	**0.92**	0.08	0.07	0.08	0.08
Sres		0.89	0.13	0.13	0.10	0.15
Watr		0.84	0.05	0.05	0.04	0.04
Hi-Res-1		0.77	**0.05**	0.05	0.05	**0.03**
Hi-Res-2		0.76	0.10	0.09	0.10	0.07
Opt		0.72	0.07	0.06	0.07	0.03
β-hvrd		0.78	0.05	**0.05**	**0.03**	0.03

β-exp		0.75	0.06	0.06	0.06	0.03
Ctl	1.5-4.6m	**0.85**	0.15	0.15	0.16	0.13
Sres		0.80	0.16	0.16	0.18	0.13
Watr		0.57	0.03	-0.03	-0.01	-0.04
Hi-Res-1		0.78	**0.02**	**-0.01**	**0.01**	**0.00**
Hi-Res-2		0.80	0.07	0.06	0.07	0.07
Opt		0.57	0.04	0.04	0.05	0.03
β-hvrd		0.76	0.03	0.03	0.04	0.03
β-exp		0.65	0.04	0.03	0.05	0.03

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