# Improved representation of Soil Moisture simulations through incorporation of cosmic-rays neutron counts measurements

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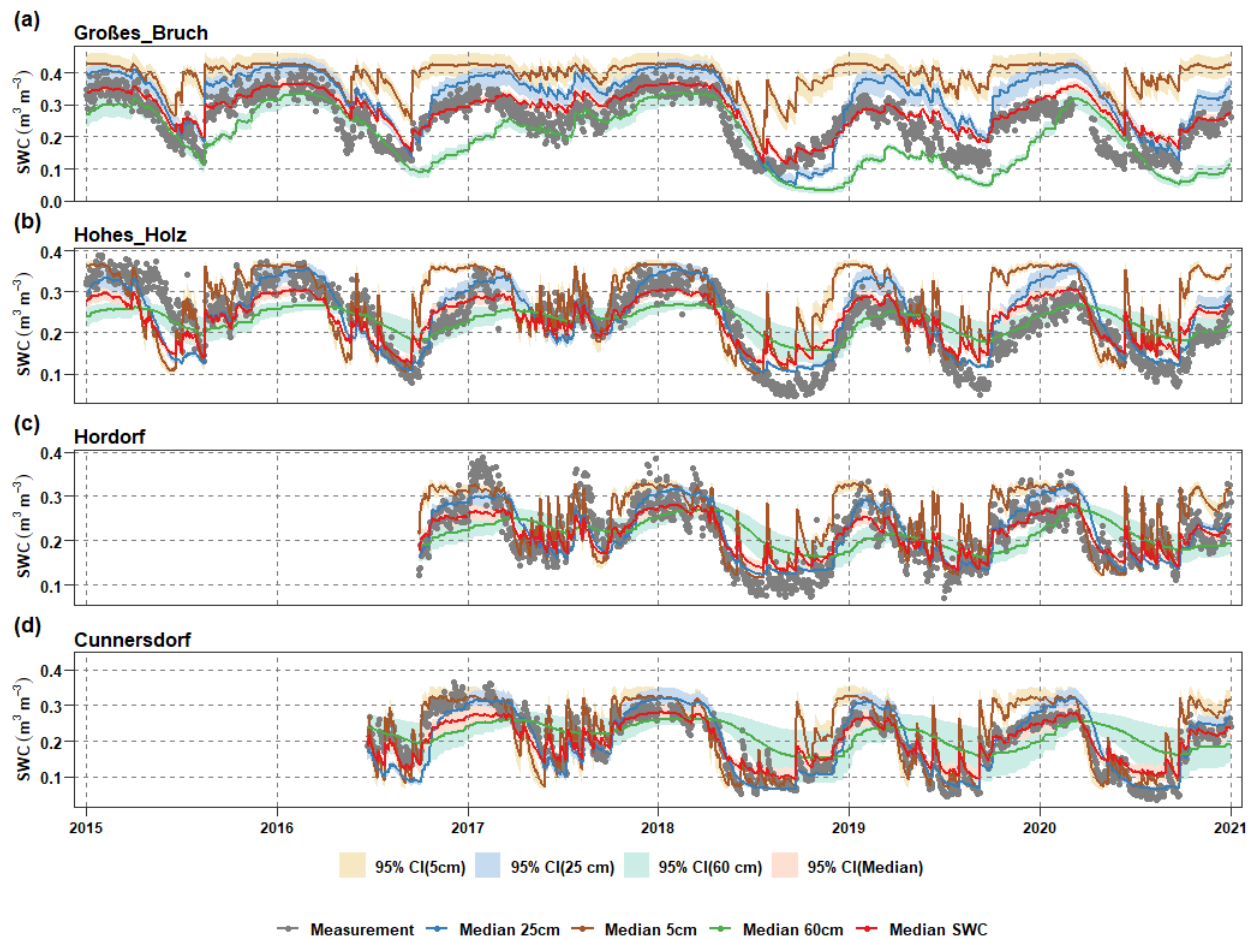
Figure S1. Soil Water content Soil water content at different land cover sites measured by the sensor network (dotted grey), simulated mHM with different depths (0–5 cm) in brown, (0–25 cm) in blue, (0–60 cm) in green, and the median value is shown with red.
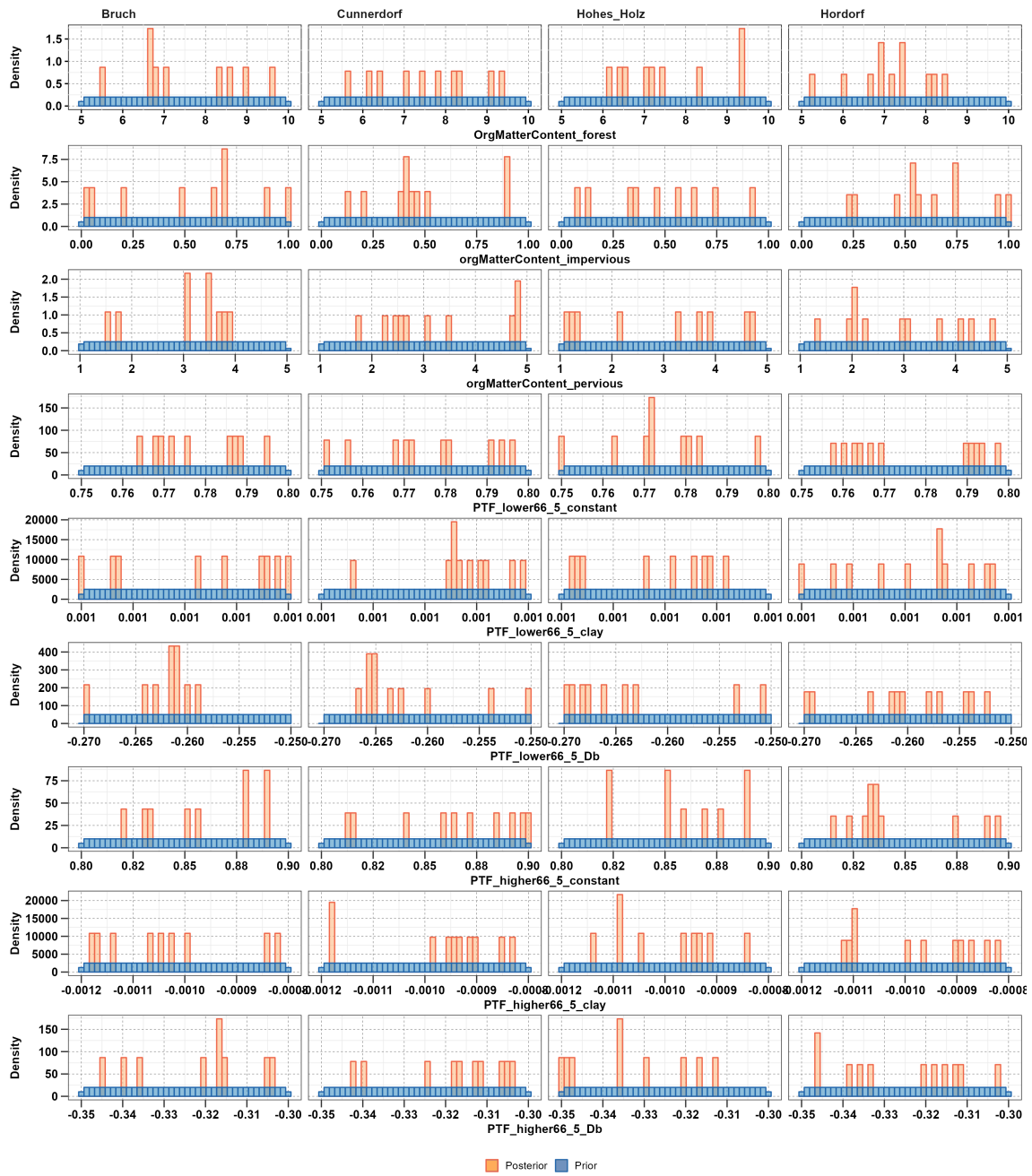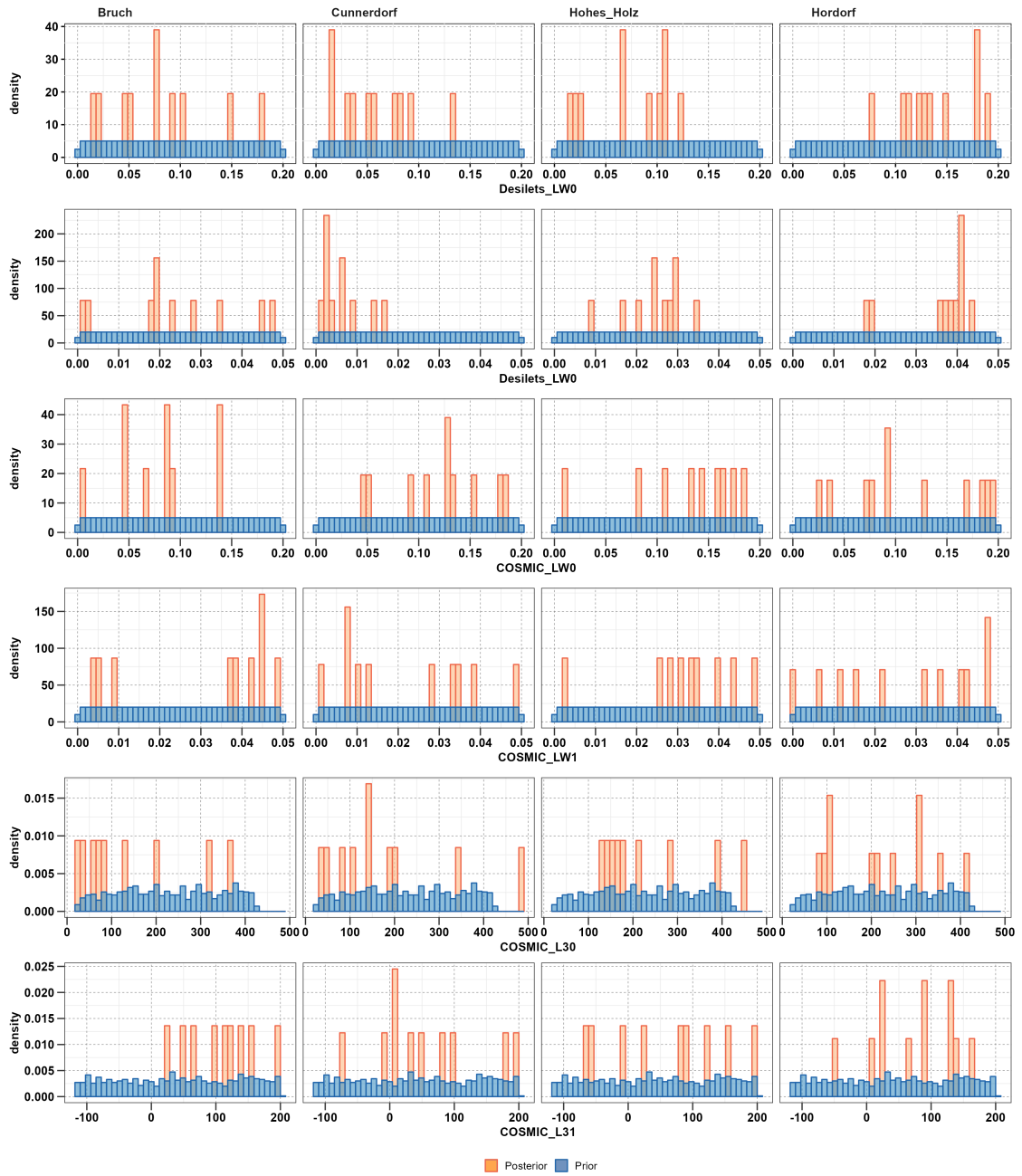
Figure S2. Soil Water content of nine parameter sets with LHS 100,000 in blue and LHS10 in Orange.
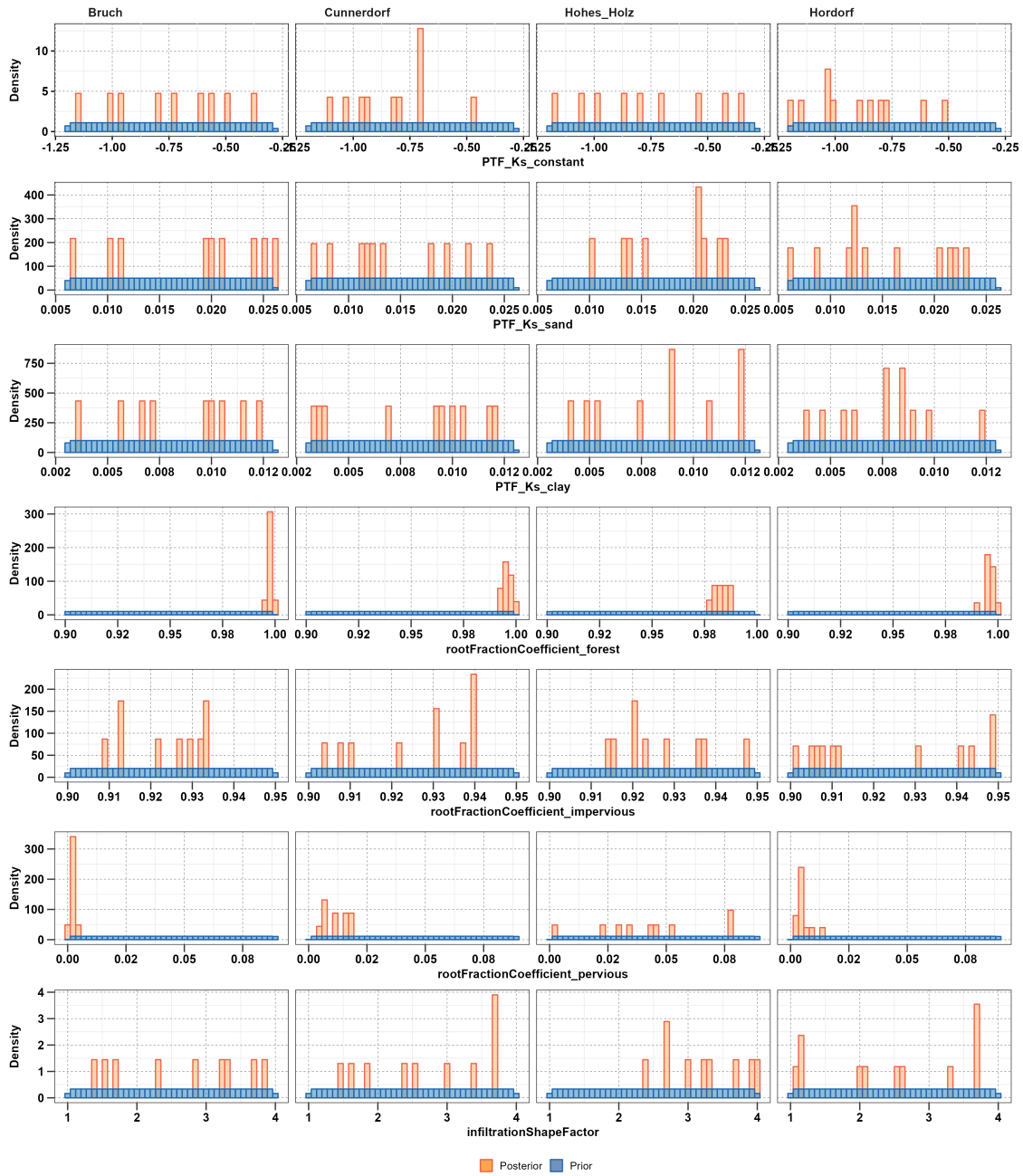
Figure S3. Soil Water content of seven parameter sets with LHS 100,000 in blue and LHS10 in Orange.
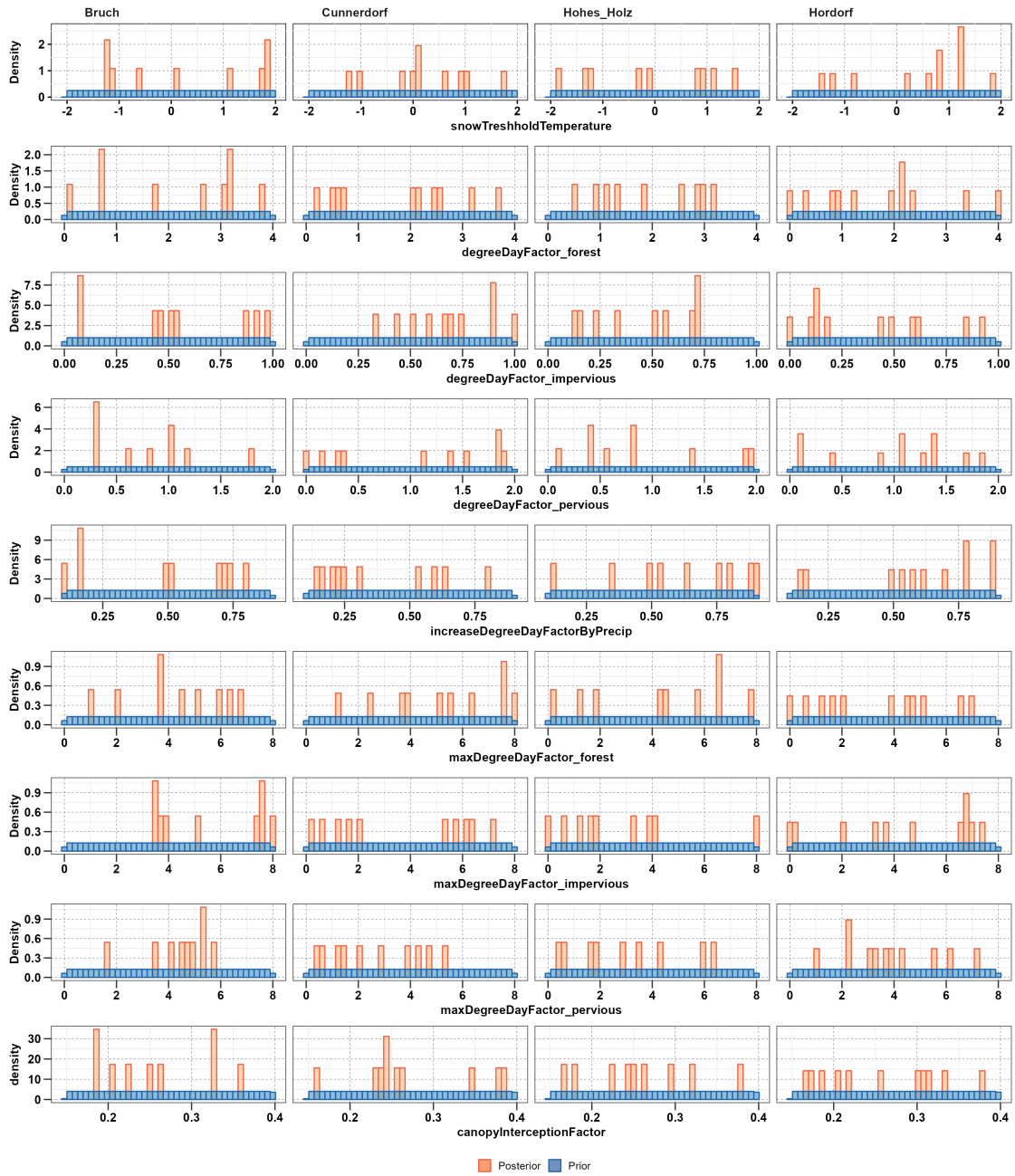
Figure S4. Snow parameter sets of nine parameter sets with LHS 100,000 in blue and LHS10 in Orange.

Figure S5. Neutron counts parameter sets of Six parameter sets with LHS 100,000 in blue and LHS10 in Orange.

Table S1. Description of the mHM Model Parameters ranges used in this Study.

Parameter	Description	Prior Range
Interceptiont		
canintfact	canopyInterceptionFactor	0.15-0.4
Snow		
tsnow	Threshold temperature for snow/rain (°C)	-2.0-2.0
degreeDayFactor_forest		0.0001-4.0
degreeDayFactor_impervious		0.00-1.0
degreeDayFactor_pervious		0.0-2.0
increaseDegreeDayFactorByPrecip	degree-day factor per unit of precip (mm day^1 $°C^{-1}$)	0.1-0.9
maxDegreeDayFactor_forest		0.0-8.0
maxDegreeDayFactor_impervious		0.0-8.0
maxDegreeDayFactor_pervious		0.0-8.0
Soil moisture		
orgmatforest	Organic matter content for forest	5.0-10.0
orgmatimper	Organic matter content for impervious zone	0.0-1.0
orgmatperv	Organic matter content for pervious zone	1.0-5.0
ptflowconst	ptf saturated water content: constant	0.75-0.8
ptflowclay	ptf saturated water content: coefficient clay content	0.0008-0.0012
ptflowdb	ptf saturated water content: coefficient bulk density	-0.27 - -0.25
pfthighconst	ptf saturated water content: constant	0.8-0.9
ptfhighclay	Coefficient for clay content in pedo-transfer function	-0.35-0.30
pfthighdb	Coefficient for bulk density in pedo-transfer function for soils	-0.0012-0.00080
ptfksconst	Constant in pedo-transfer function for hydraulic conductivity of soils	-1.200-0.285
ptfkssand	ptf hydraulic conductivity: coefficient sand content	0.006-0.026
pftksclay	ptf hydraulic conductivity: coefficient clay content	0.003-0.013
ptfksslp	Coefficient for slope in pedo-transfer function	60.96 - 60.96
rotfcoffore	Root fraction for forest areas	0.9- 0.999
rotfcofimperv		0.9-0.095
rotfcofpervi	Threshold for	0.001-0.090
infshapef	Infiltration shape factor	1.0 - 4.0
neutron counts		
$N_{0(Des)}$	neutron intensity over dry soil under the same conditions (cph)	600 - 1500
$Desliets_{lw0}$	lattice water content gg^{-1}	0.0-0.2
$Desliets_{lw1}$	lattice water content gg^{-1}	0.0-0.05
$N_{0(COSMIC)}$	neutron intensity over dry soil under the same conditions (cph)	100-400
$COSMIC_{L30}$	calculated using mean soil bulk density g cm^{-2}	20.0-500.0
$COSMIC_{L31}$	calculated using mean soil bulk density g cm^{-2}	-120.0-200.0
$COSMIC_{lw0}$	lattice water content gg^{-1}	0.0-0.20
$COSMIC_{lw1}$	lattice water content gg^{-1}	0.0-0.05

Table S2. Description of the best parameter set values in mHM for each site and methods i.e., Grosses Bruch, Hohes Holz, Hordorf, and Cunnersdorf. To better assist the user we keep the model nomenclature name the same as that is there in the model code mHM.

Parameters	Grosses Bruch			Hohes Holz			Hordorf			Cunnersdorf		
Methods:	Des,U	Des,W	COSMIC	Des,U	Des,W	COSMIC	Des,U	Des,W	COSMIC	Des,U	Des,W	COSMIC
Interceptiont												
canintfact	0.217	0.297	0.226	0.370	0.20	0.242	0.323	0.312	0.184	0.395	0.334	0.377
Snow												
tsnow	-1.491	1.642	1.171	-0.149	0.705	-0.261	-0.753	1.285	-1.264	1.228	1.601	-0.189
degreeDayFactor_forest	3.896	2.676	3.215	1.915	2.17	2.524	0.824	3.87	0.286	1.1181	3.013	0.163
degreeDayFactor_impervious	0.942	0.259	0.433	0.558	0.57	0.729	0.895	0.449	0.004	0.501	0.542	0.660
degreeDayFactor_pervious	0.648	1.342	1.049	0.158	1.336	0.094	1.063	1.191	0.881	1.371	0.402	1.917
increaseDegreeDayFactorByPrecip	0.505	0.557	0.496	0.768	0.350	0.803	0.859	0.60	0.137	0.397	0.79	0.534
maxDegreeDayFactor_forest	2.984	2.761	1.111	7.328	5.885	4.301	5.55	7.767	0.057	2.238	1.872	5.045
maxDegreeDayFactor_impervious	1.681	5.367	5.187	0.803	5.371	3.992	4.68	4.483	0.250	2.674	0.459	1.234
maxDegreeDayFactor_pervious	3.291	1.493	3.497	4.586	5.459	6.368	2.849	5.247	2.205	7.252	6.857	0.344
Soil moisture												
orgmatforest	8.4456	6.51	5.551	9.324	7.362	8.365	5.718	9.733	6.9698	6.296	9.145	8.234
orgmatimper	0.124	0.615	0.690	0.180	0.8162	0.329	0.024	0.202	0.752	0.387	0.098	0.433
orgmatperv	2.307	1.219	3.769	1.314	2.643	4.696	4.778	4.466	2.227	4.8759	4.328	3.059
ptflowconst	0.794	0.7505	0.768	0.752	0.793	0.783	0.765	0.774	0.796	0.766	0.774	0.755
ptflowclay	0.00099	0.001	0.00087	0.001	0.0009	0.001	0.0009	0.0009	0.0008	0.0009	0.0008	0.0008
ptflowdb	-0.263	-0.265	-0.261	-0.266	-0.262	-0.267	-0.267	-0.258	-0.269	-0.262	-0.265	-0.265
pfthighconst	0.893	0.891	0.8792	0.836	0.827	0.851	0.8363	0.889	0.835	0.855	0.8165	0.839
ptfhighclay	-0.0011	-0.0008	-0.0010	-0.0009	-0.0009	-0.001	-0.0008	-0.001	-0.001	-0.0009	-0.0011	-0.0011
pfthighdb	-0.335	-0.349	-0.304	-0.345	-0.322	-0.330	-0.308	-0.308	-0.311	-0.328	-0.345	-0.305
ptfksconst	-1.084	-0.715	-1.158	-0.549	-0.971	-0.345	-0.362	-0.978	-1.015	-1.045	-0.842	-0.792
ptfkssand	0.015	0.022	0.0194	0.014	0.021	0.023	0.009	0.0219	0.021	0.025	0.0195	0.0214
pftksclay	0.011	0.011	0.007	0.0067	0.008	0.012	0.009	0.0096	0.007	0.006	0.003	0.0093
ptfksslp	60.96	60.96	60.96	60.96	60.96	60.96	60.96	60.96	60.96	60.96	60.96	60.96
rotfcoffore	0.995	0.997	0.998	0.9546	0.937	0.985	0.968	0.934	0.99	0.989	0.939	0.998
rotfcofimperv	0.918	0.904	0.922	0.939	0.934	0.920	0.922	0.936	0.910	0.932	0.939	0.939
rotfcofpervi	0.0072	0.0039	0.0054	0.011	0.087	0.051	0.027	0.015	0.004	0.039	0.939	0.017
infshapef	2.898	3.610	3.838	1.383	2.811	2.381	3.620	2.182	2.598	2.725	3.005	1.488
neutron counts												
$N_{0(Des)}$	888.01	879.63		854.76	909.08		1121.9	1169.53		1270.64	1234.69	
$Desliets_{lw0}$	0.0916	0.174		0.026	0.105		0.128	0.151		0.0048	0.0843	
$Desliets_{lw1}$	0.0184	0.00197		8.675	0.009		0.0061	0.0033		0.0033	0.0059	
$N_{0(COSMIC)}$			245.11			233.89			303			317.24
$COSMIC_{L30}$			130.79			285.37			88.70			34.83
$COSMIC_{L31}$			192.14			90.72			128.01			50.12
$COSMIC_{lw0}$			0.137			0.186			0.036			0.151
$COSMIC_{lw1}$			0.0086			0.030			0.047			0.033

Table S3. Site-specific values of lattice water ($cm^3 cm^{-3}$), clay content (%), mean bulk density ($g cm^{-3}$), and L_3 ($g\ cm^{-2}$) is from the COSMIC method, mean and standard deviation obtained by the best 10 ensemble members from the three methods i.e., $N_{\text{Des,U}}$,$N_{\text{Des,W}}$ and $N_{\text{Des,COSMIC}}$ of four different sites.

Sites	Symbol	Grosses Bruch		Hohes Holz		Hordorf		Cunnersdorf	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lattice Water ($cm^3 cm^{-3}$)	θ_{lw}	0.04	0.02	0.04	0.02	0.03	0.02	0.02	0.02
Clay (%)	C	2.5	-	14.0	-	21.0	-	14.5	-
Mean Bulk density ($g cm^{-3}$)	ϱ	1.30	0.04	1.03	0.04	1.14	0.09	1.25	0.04
L_3 ($g\ cm^{-2}$)	L_3	289.02	246.29	232.46	154.0	295.48	177.8	123.0	168.32