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Supplement of

The evolution of root-zone moisture capacities after deforestation: a step towards hydrological predictions under change?

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Supplementary Material

S1. Protocol

Experiment: The evolution of root zone moisture capacities after land use change

Partners: SMHI, Bristol

Lead: TUD

Formal protocol

Execution

i. Data requirements and formatting

   Required data: Long-term hydrological data (i.e. daily precipitation, runoff and potential evaporation) for at least 20 years for at least one and temporally well documented, land use change (ideally deforestation). Selected catchments are Hubbard Brook WS2 and WS5, and HJ Andrews WS1.

ii. Experiment execution steps

   a. TUD: Determine time series of root zone moisture capacity based on water-balance.

   b. SMHI, Bristol, TUD: Randomly run models with a moving time window of 2 years. Compute Kling-Gupta Efficiency, log Kling-Gupta Efficiency and Volume Error for each model run.

   c. TUD: Adjust model with a more dynamic formulation of the root zone storage capacity. Randomly run adjusted model and original model for a longer time series including deforestation. Compute hydrological signatures.

iii. Result reporting

   a. Mat-files with the used parameter combinations and performance metrics for each window.

Analysis

i. Trend analysis for the water balance derived root zone storage capacities

ii. Derive posterior distributions for window-based model runs for the root zone storage capacity or the equivalent parameter for each model.

iii. Calculate probability of improvement and ranked probability score for each hydrological signature for the adjusted model with time-varying root zone storage capacity and the original model.

iv. Analyse/interpret findings.

S2. Model descriptions

2.1 FLEX

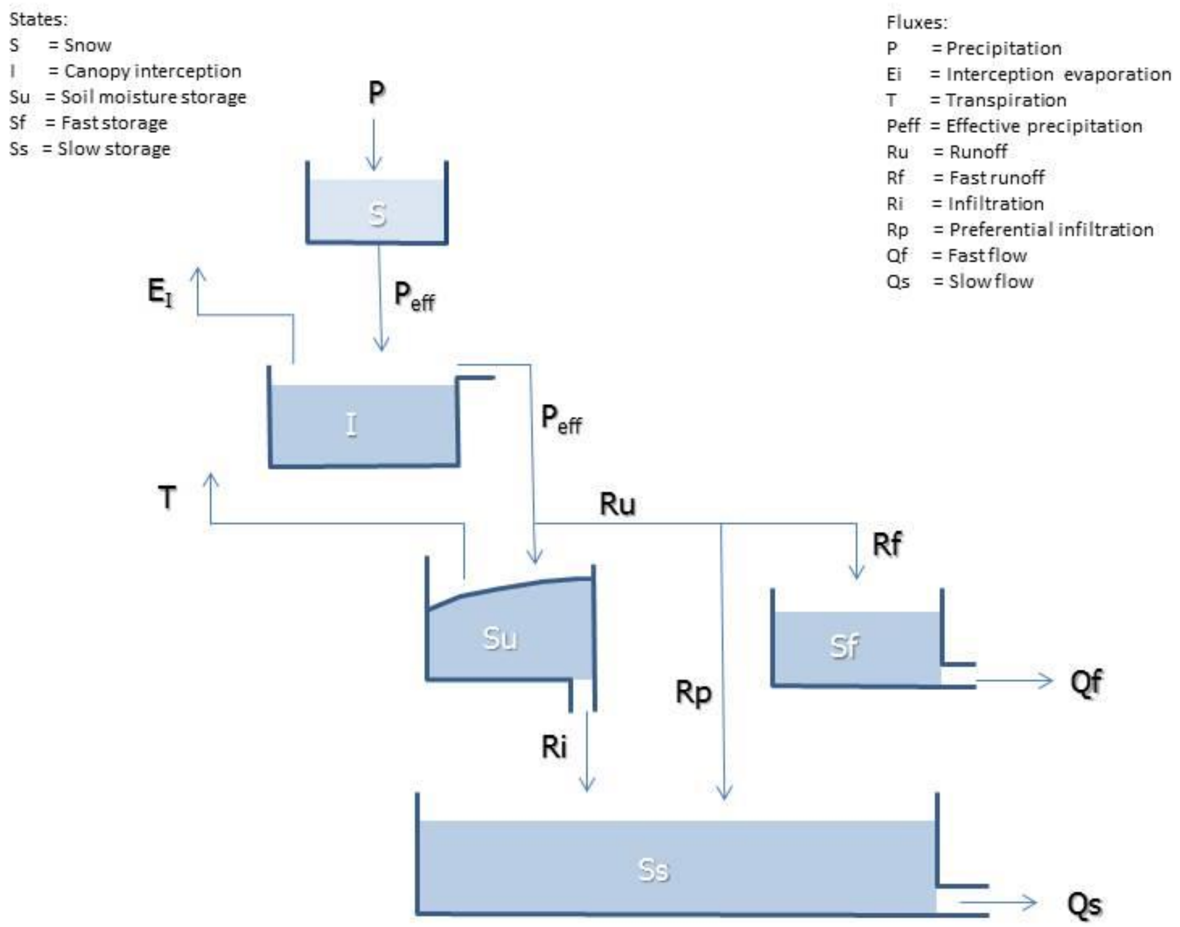

Figure S1. FLEX model structure.

Table S1. Parameters with descriptions and prior ranges for the FLEX model

Parameters	**Unit**	**Min**	**Max**	**Description**
Meltfactor	mm/ ^{o}C	4	5	Water released with a degree change temperature
Tthresh	^{o}C	-1	0	Threshold temperature to separate rain from snow
Imax	mm	0.0	5	Maximum interception capacity
Sumax	mm	1.0	1000	Maximum soil moisture storage
Beta	-	0.01	3	Shape factor soil moisture function
Kf	days	1	10	Recession coefficient fast reservoir
Ks	days	60	65	Recession coefficient slow reservoir
D	-	0.0	1.0	Partition of runoff that preferentially percolates to the groundwater
Pmax	mm/d	0.0	10	Maximum percolation to the groundwater

Table S2. Water balance and constitutive relations applied in the FLEX model

Reservoir	**Water balance equation**	**Constitutive relation**
Snow	$\frac{dS_{Snow}}{dt} = P - M$	$P_{e,s} = \begin{cases} Meltfactor * (T_a - T_{thresh}) & if\ T_a > T_{thresh} \\ 0 & if\ T_a \leq T_{thresh} \end{cases}$
Interception	$\frac{dS_I}{dt} = P_{e,s} - E_i - P_{eff}$	$P_{eff} = \max(0, S_i + P_{e,s} - I_{\max})$ $E_i = \min(E_p, \quad S_i - P_{eff})$ $S_{i,new} = S_{i,old} + P_{e,s} - P_{eff} - E_i$
Soil moisture	$\frac{dS_u}{dt} = P_{eff} - E_t - R - P$	$S_{u,m} = (1+\beta)\, S_{u,max} \left(1 - \left(1 - \frac{S_u}{S_{u,max}}\right)^{1/(1+\beta)}\right)$ $R = P_{eff} - S_{u,max} + S_u + S_{u,max} * \left(1 - \frac{P_{eff} + S_{u,m}}{(1+\beta)\, S_{u,max}}\right)^{1+}$ $E_t = \begin{cases} E_p \frac{S_u}{0.5 * S_{u,max}} & if\ S_u \leq 0.5 * S_{u,max} \\ \min(E_p, \quad S_u) & if\ S_u > 0.5 * S_{u,max} \end{cases}$ $P = P_{max} \frac{S_u}{S_{u,max}}$ $S_{u,new} = S_{u,old} + P_{eff} - R - E_t - P$
Fast reservoir	$\frac{dS_f}{dt} = (1-D) * R - Q_f$	$Q_f = K * S_f$ $S_{f,new} = S_{f,old} + (1-D) * R - Q_f$

Slow reservoir	$\frac{dS_s}{dt} = D * R + P - Q_s$	$Q_s = K * S_s$ $S_{s,new} = S_{s,old} + D * R - Q_s$

2.2 HYPE

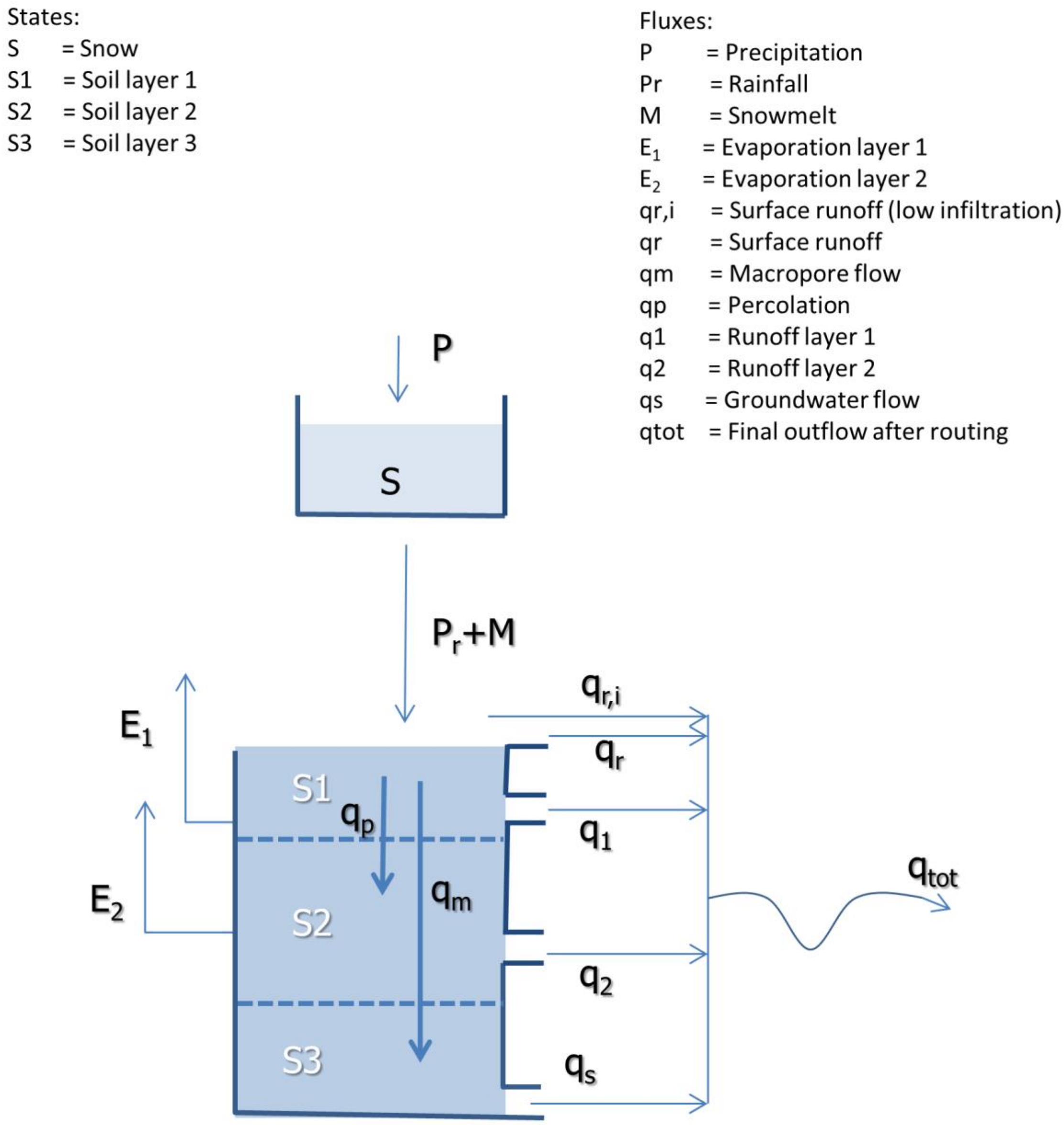

Figure S2. HYPE model structure.

Table S2. Parameters with descriptions and prior ranges for the HYPE model

Parameters	**Unit**	**Min**	**Max**	**Description**
wcfc	-	0.05	0.35	fraction of soil available for evapotranspiration but not for runoff, same for all soil layers
wcep	-	0.05	0.4	effective porosity as a fraction, same for all soil layers
wcwp	-	0.05	0.5	wilting point as a fraction, same for all soil layers
rrcs1	-	0.05	0.6	recession coefficient for uppermost soil layer
rrcs2	-	0.05	0.6	recession coefficient for lowest soil layer
mperc1	-	5	100	maximum percolation capacity from soil layer 1 to soil layer 2
mperc2	-	5	100	maximum percolation capacity from soil layer 2 to soil layer 3
mactrsm	-	0.2	0.9	threshold soil water for macro-pore flow and surface runoff
macrate	-	0.1	0.5	fraction for macro-pore flow
mactrinf	mm/d	10	45	threshold for macro-pore flow
srrcs	-	0.01	0.2	recession coefficient for surface runoff
cmlt	mm/^{o}/d	2	5	melting parameter for snow
ttmp	^{o}C	0	1	threshold temperature for snow melt and evapotranspiration
lp	-	0.7	1	limit for potential evapotranspiration

rivvel	m/s	0.5	2	celerity of flood in watercourse

2.3 TUW

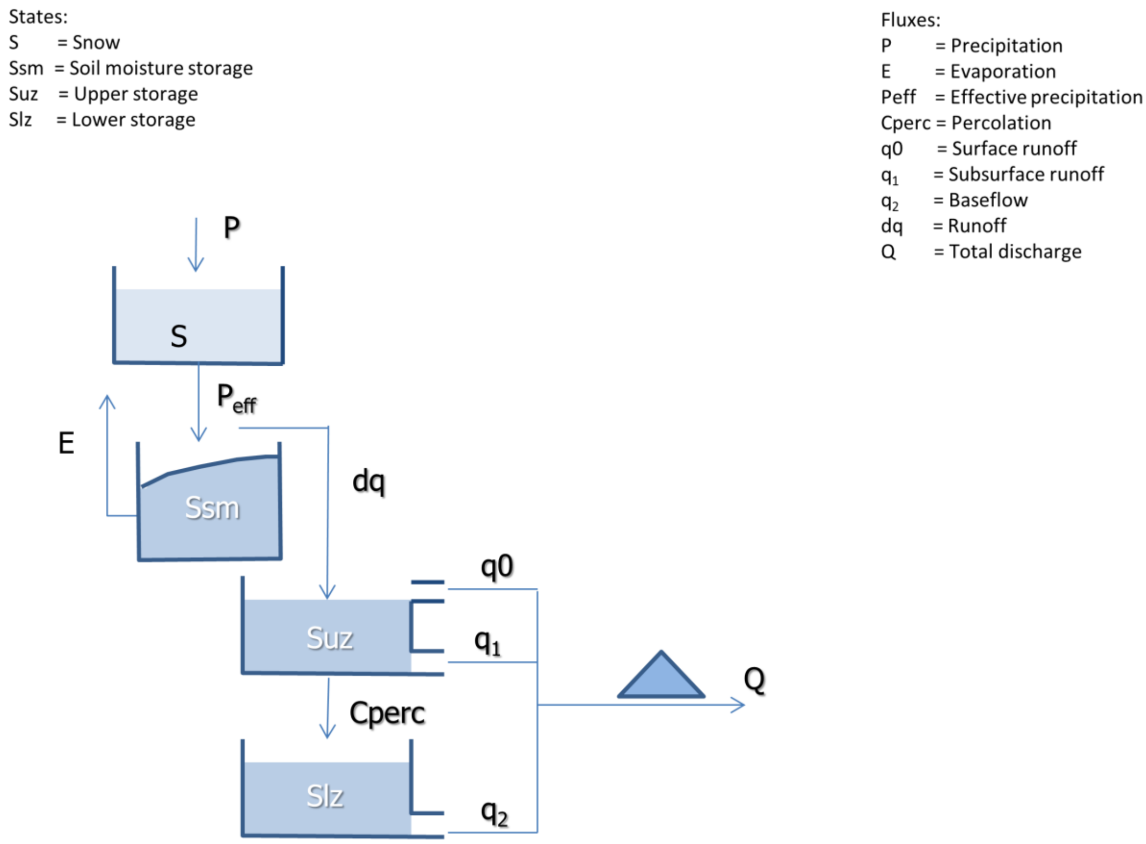

Figure S3. TUW model structure.

Table S3. Parameters with descriptions and prior ranges for the TUW model

Parameters	**Unit**	**Min**	**Max**	**Description**
SCF	-	0.9	1.5	Snow correction factor
DDF	Mm/^{o}C /d	0	6	Degree day factor
Tr	mm	1.0	3.0	Threshold temperature above which precipitation is rain
Ts	mm	-3.0	1	Threshold temperature below which precipitation is snow
Tm	-	-2.0	2	Threshold temperature above which melt starts
LPrat	days	0	1	Parameter related to the limit for potential evaporation
FC	mm	0.0	1000	field capacity, i.e., max soil moisture storage
Beta	-	0.0	20.0	the non linear parameter for runoff production
k0	days	0.0	2	storage coefficient for very fast response
k1	days	2.0	5	storage coefficient for fast response
k2	days	5.0	30	storage coefficient for slow response
lsuz	mm	1.0	100.0	threshold storage state, i.e., the very fast response start if exceeded
Cperc	mm/d	0.0	8.0	constant percolation rate
bmax	days	0.0	10.0	maximum base at low flows
croute	day2/mm	0.0	50.0	free scaling parameter

2.4 HYMOD

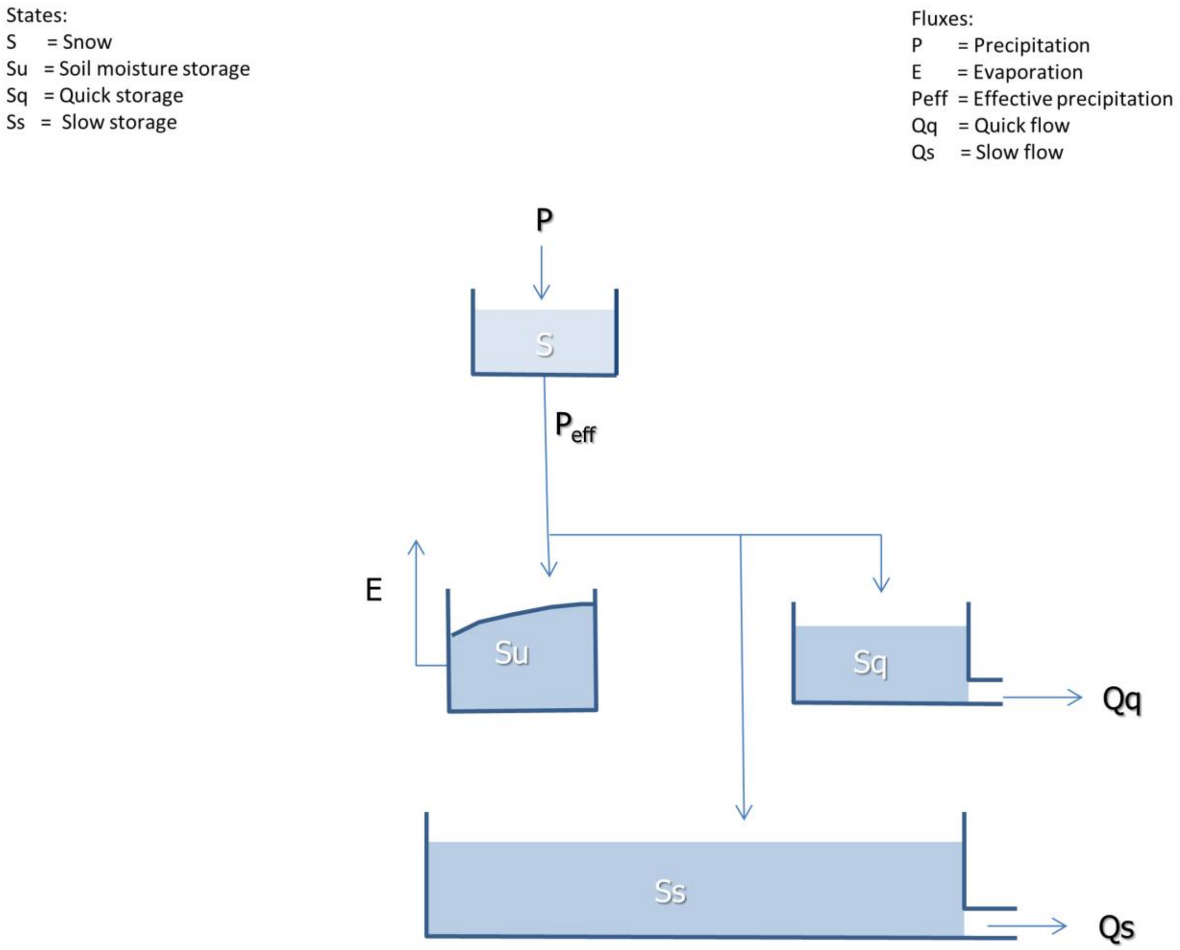

Figure S4. HYMOD model structure.

Table S4. Parameters with descriptions and prior ranges for the HYMOD model

Parameters	**Unit**	**Min**	**Max**	**Description**
DDF	Mm/^{o}C /d	0	6	Degree day factor
Tb	^{o}C	-3.0	3.0	Threshold temperature above which precipitation is rain
Tth	^{o}C	-2.0	2	Threshold temperature below which precipitation is snow
alpha	-	0.0	1	Parameter determining separation between fast and slow runoff
Cmax	Mm	0	1000	max soil moisture storage
Beta	-	0.01	3.0	the non linear parameter for runoff production
Kq	Days	1.0	3.0	storage coefficient for fast response
Ks	Days	1.0	20	storage coefficient for slow response

S3. Calibration results

Table S5. Feasible number of model runs for HJ Andrews WS1

HJ Andrews	FLEX	TUW	HYPE	HYMOD
Window 1	653	18448	9017	23809
Window 2	4146	17692	9419	46291
Window 3	1433	6129	9663	9334
Window 4	7023	30599	9609	46917
Window 5	252	15862	9922	26773
Window 6	6	843	9990	1356
Window 7	100	12194	9876	27186
Window 8	116	13415	10000	24778
Window 9	8	1437	9969	1965
Window 10	35	12626	9367	12073
Window 11	3	5242	9996	3158
Window 12	149	30344	9597	30321
Window 13	54	20485	9427	19171
Window 14	47	12567	9625	15843

Table S6. Feasible number of model runs for Hubbard Brook WS2

Hubbard Brook WS2	FLEX	TUW	HYPE	HYMOD
Window 1	48	38741	19977	9765
Window 2	2717	5798	15678	4456
Window 3	7258	8295	19961	11825
Window 4	1031	5184	19445	8276
Window 5	3496	51959	19940	21003
Window 6	247	18393	17674	6683
Window 7	137	11248	19999	4491
Window 8	18	22928	19708	1665
Window 9	108	37971	19914	18884
Window 10	25	35596	19961	3085
Window 11	19	33985	19997	11258
Window 12	107	21985	19604	2749
Window 13	34	31767	19999	7932
Window 14	26	6450	19938	6999
Window 15	66	31713	19999	9296
Window 16	77	37002	19999	11879
Window 17	29	14256	19940	6031
Window 18	162	32063	19841	10672
Window 19	67	45893	19995	8326
Window 20	19	27436	20000	10652
Window 21	49	7872	19978	4943
Window 22	37	11060	19994	6304
Window 23	1289	48703	19910	23705

Table S7. Feasible number of model runs for Hubbard Brook WS5

Hubbard Brook WS5	FLEX	TUW	HYPE	HYMOD
Window 1	103		99980	
Window 2	194		99980	
Window 3	161	33592	99980	16819
Window 4	204	28342	99980	9658
Window 5	686	27978	99980	6893
Window 6	32	2262	99980	972
Window 7	123	22632	99980	10496
Window 8	86	40841	99980	9029
Window 9	162	36043	99980	17378
Window 10	70	35020	99980	6351
Window 11	86	6415	99980	4034
Window 12	140	6054	99970	466
Window 13	311	44640	99980	17834
Window 14	469	34557	99980	16863
Window 15	40	2934	99980	1215
Window 16	249	26178	99980	9073
Window 17	85	11782	99980	4428
Window 18	190	23955	99980	7983
Window 19	242	44971	99980	13454
Window 20	215	39199	99980	16568
Window 21	59	7734	99980	4164
Window 22	33	6020	99980	3958
Window 23	1873	50668	99980	23343

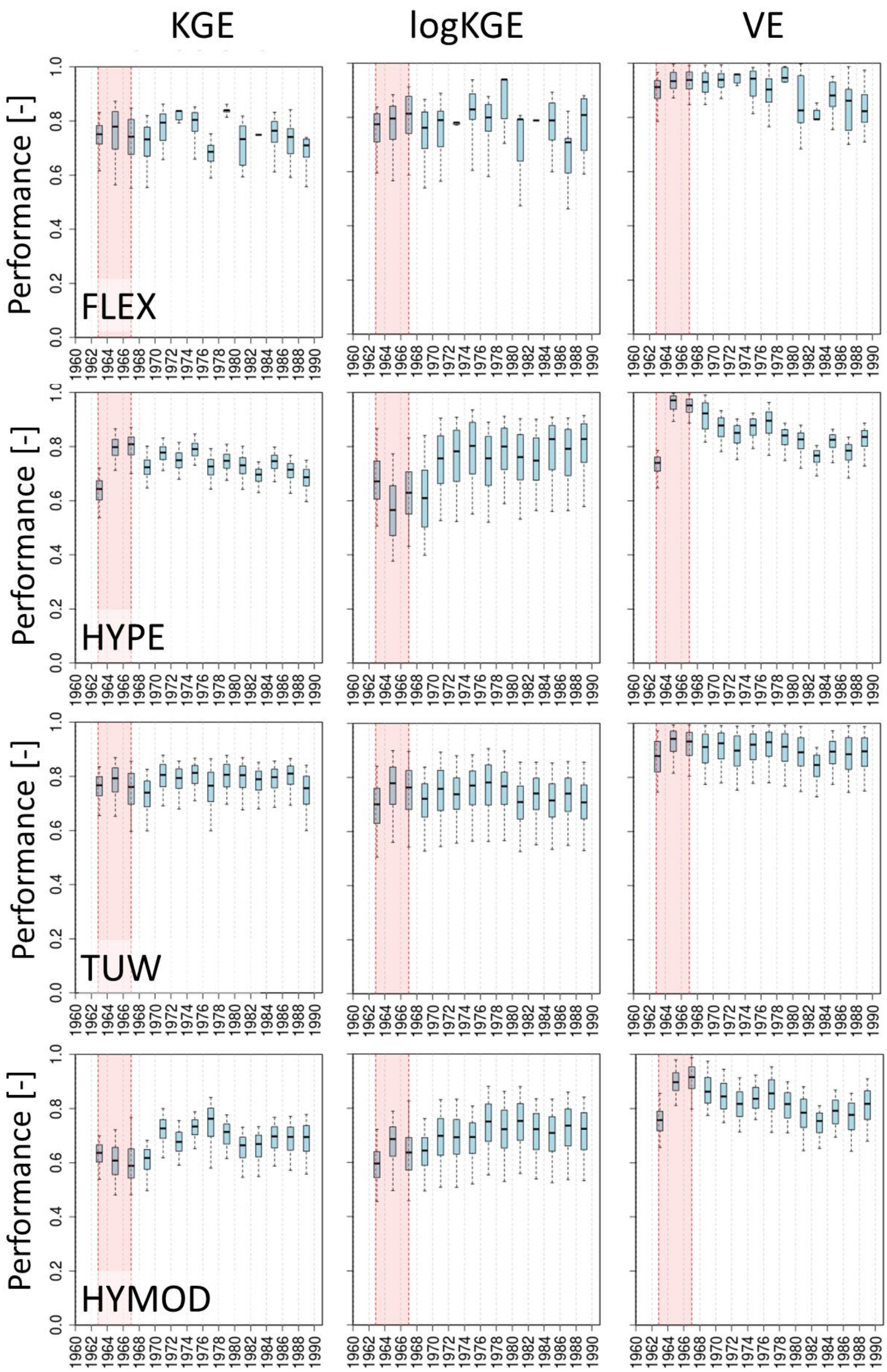

Figure S5. Objective function values of Kling-Gupta Efficiency (KGE), log Kling-Gupta Efficiency (logKGE) and volume error (VE) for HJ Andrews WS1 resulting from the calibration for each time window.

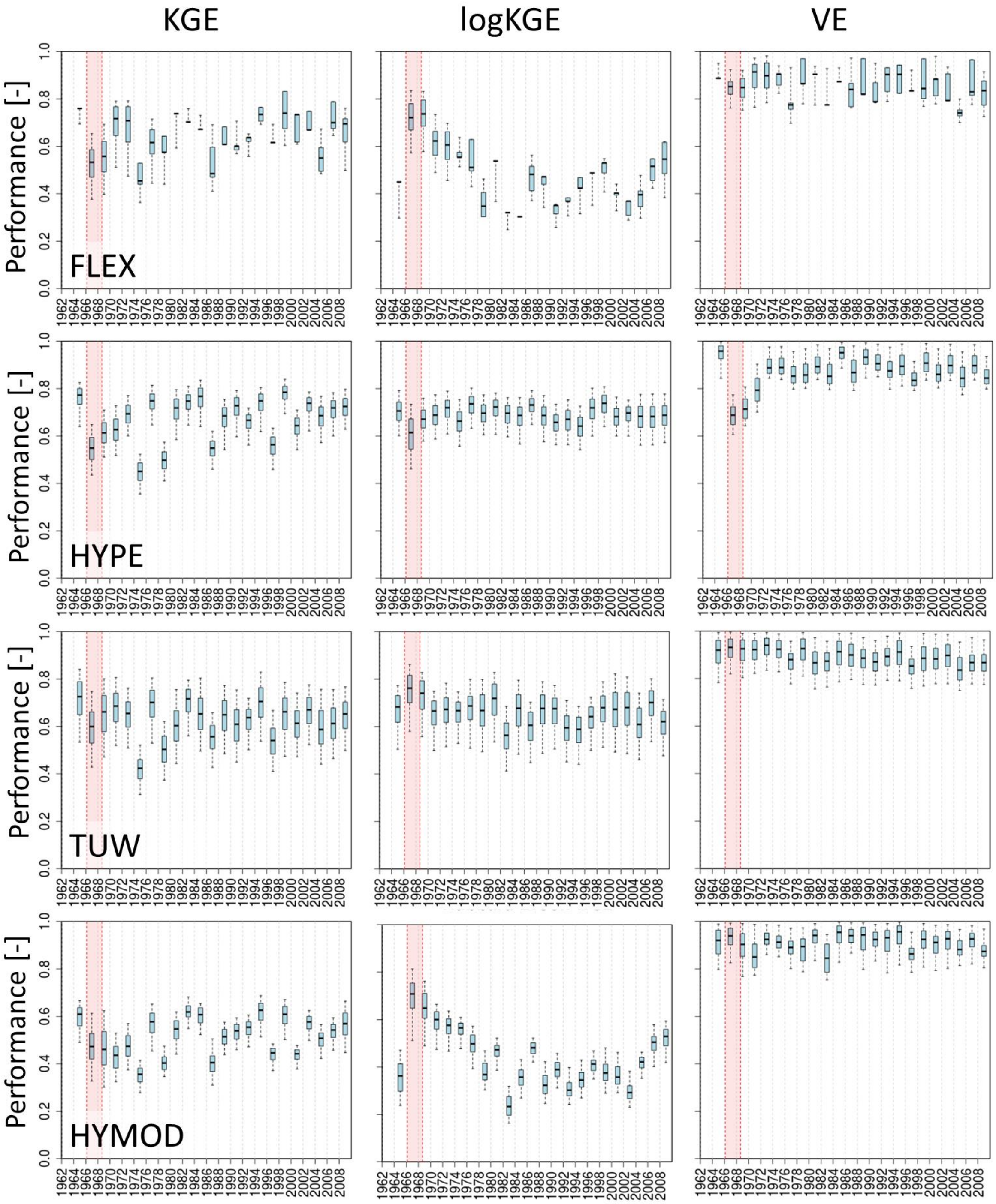

Figure S6. Objective function values of Kling-Gupta Efficiency (KGE), log Kling-Gupta Efficiency (logKGE) and volume error (VE) for Hubbard Brook WS2 resulting from the calibration for each time window.

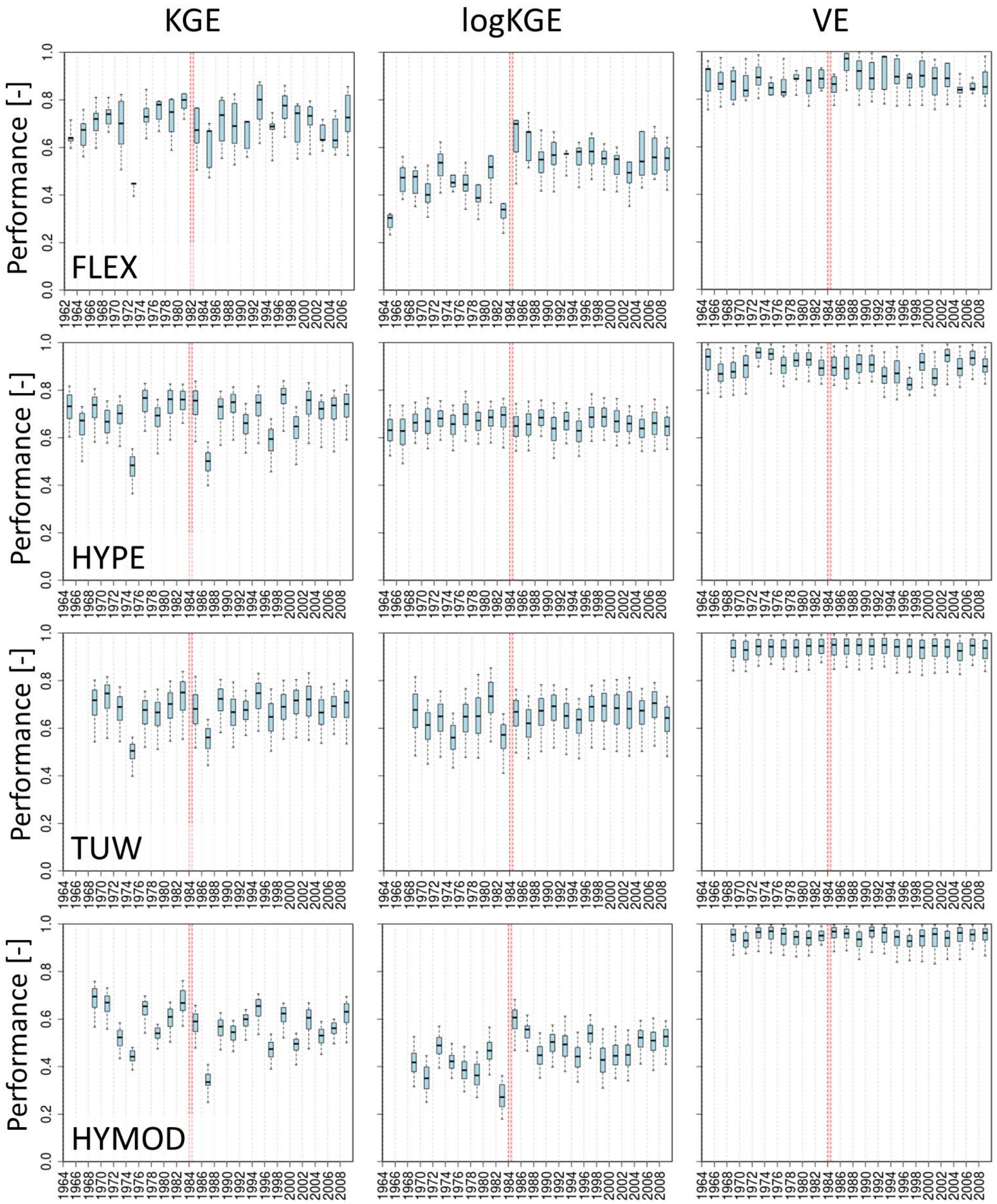

Figure S7. Objective function values of Kling-Gupta Efficiency (KGE), log Kling-Gupta Efficiency (logKGE) and volume error (VE) for Hubbard Brook WS5 resulting from the calibration for each time window.

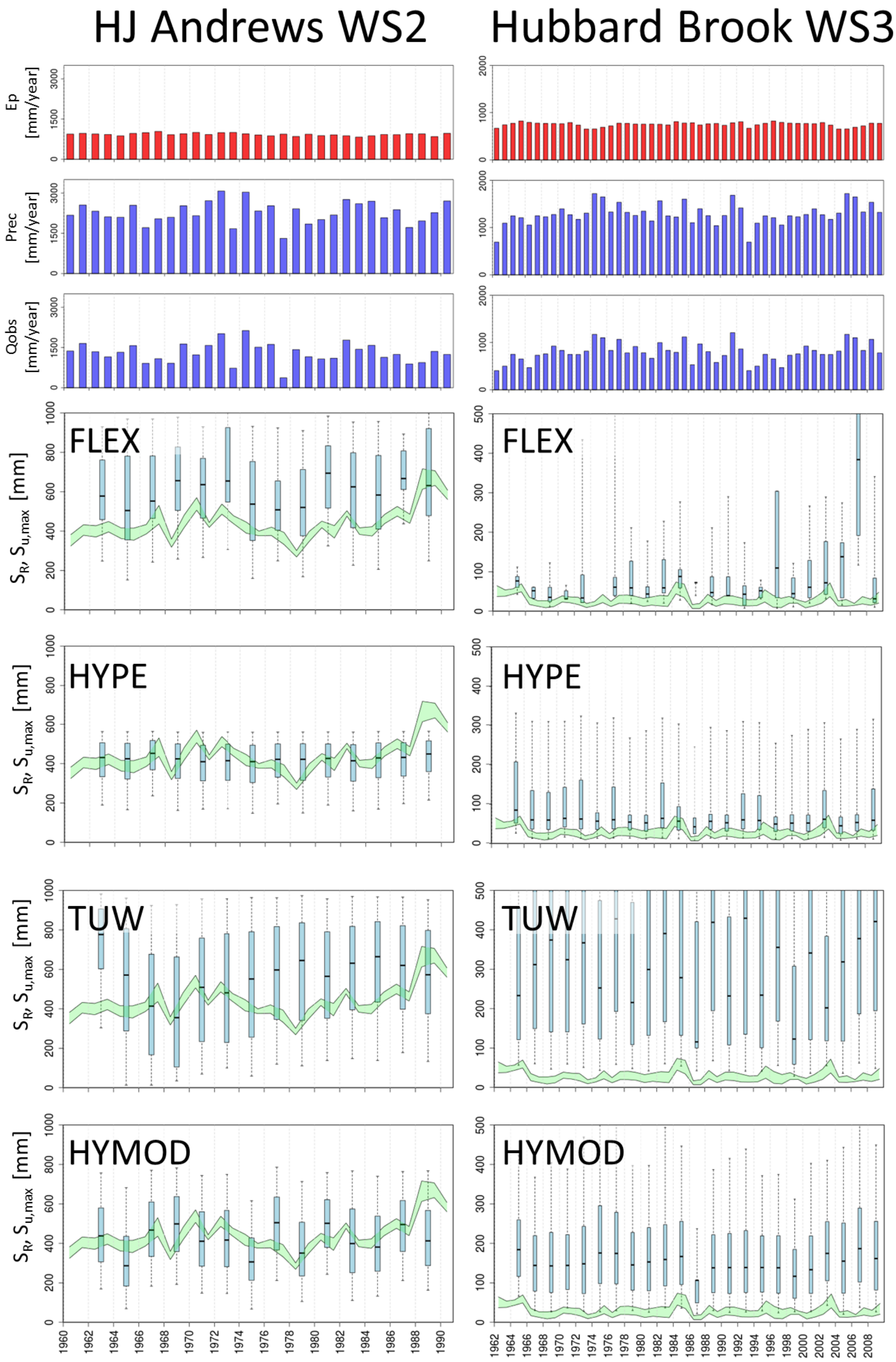

Figure S8. Evolution of root zone storage capacity $S_{R,1yr}$ from water balance-based estimation (green shaded area, a range of solutions due to the sampling of the unknown interception capacity) compared with $S_{u,max,2yr}$ estimates obtained from the calibration of four models (FLEX, HYPE, TUW, HYMOD; blue boxplots) for a) HJ Andrews WS2, b) Hubbard Brook WS3.

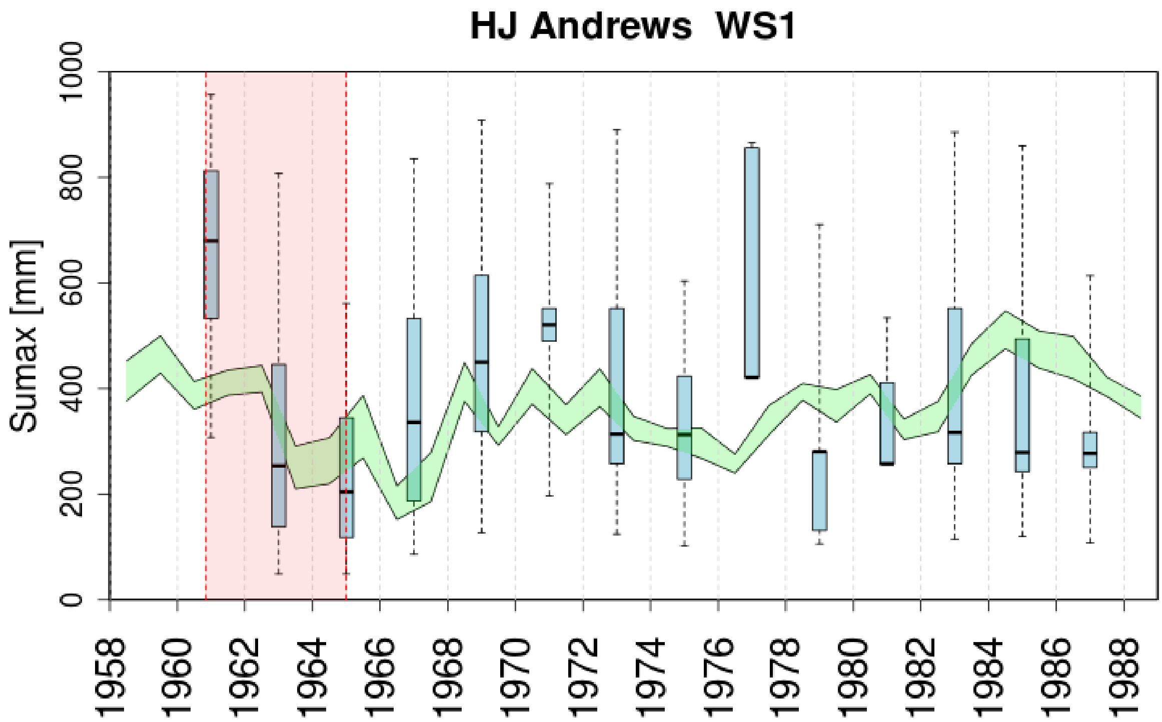

Figure 9. Evolution of root zone storage capacity $S_{R,1yr}$ from a 5 year water balance-based estimation (green shaded area, a range of solutions due to the sampling of the unknown interception capacity) compared with $S_{u,max,2yr}$ estimates obtained from the calibration of the FLEX model.

S4. Posterior parameter distributions

4.1 FLEX

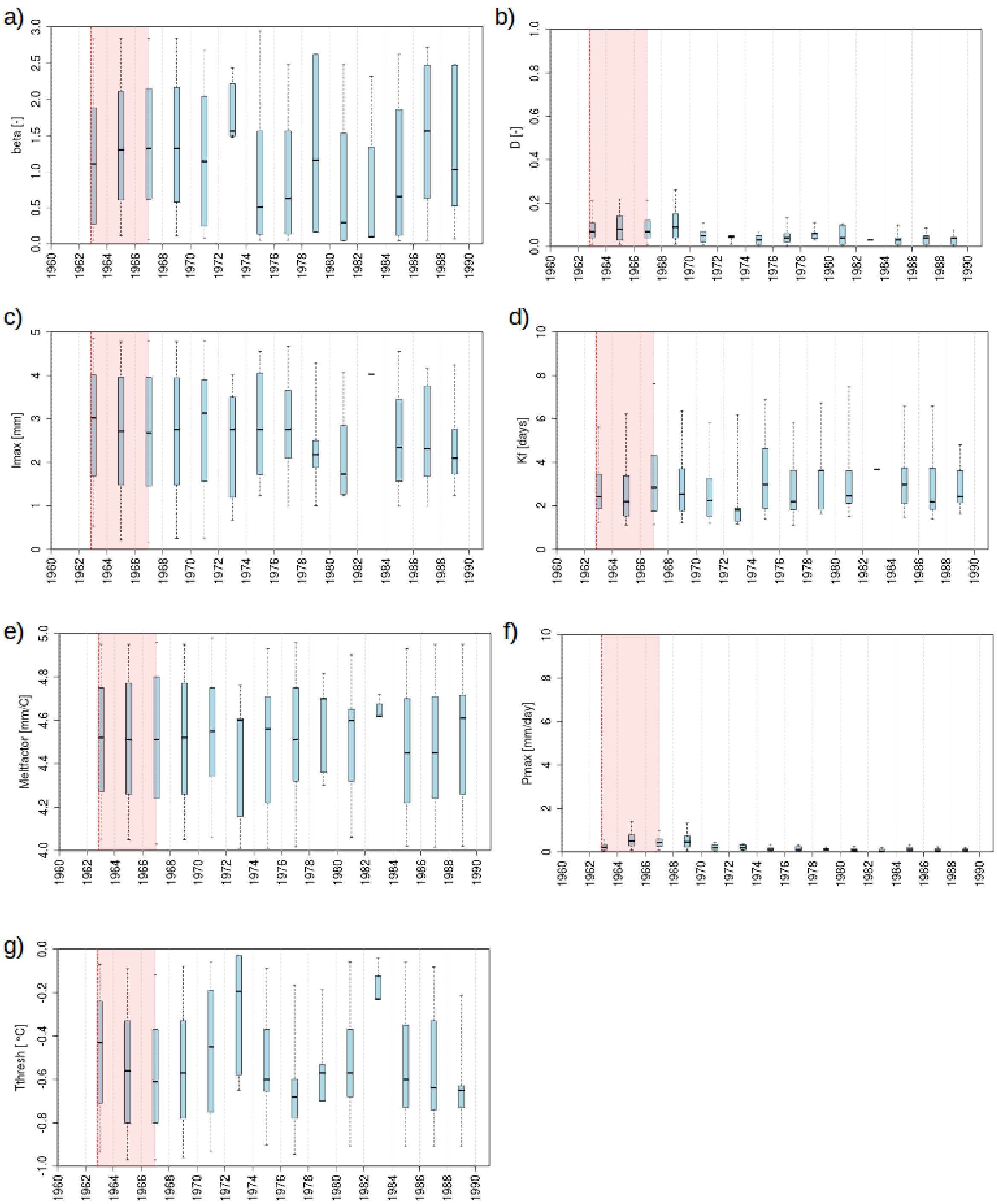

Figure S10. Posterior parameter distributions for the FLEX model in HJ Andrews WS1.

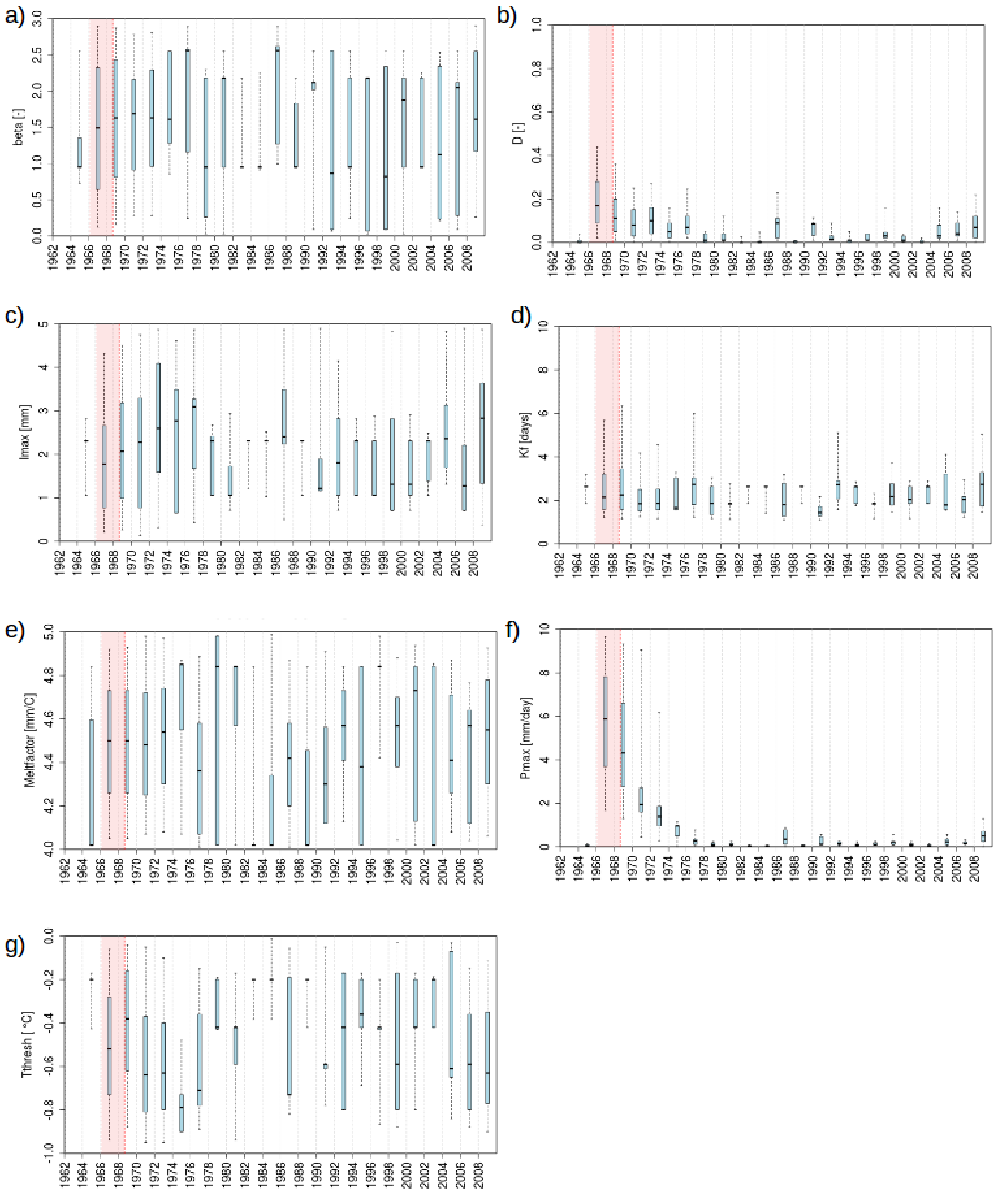

Figure S11. Posterior parameter distributions for the FLEX model in Hubbard Brook WS2.

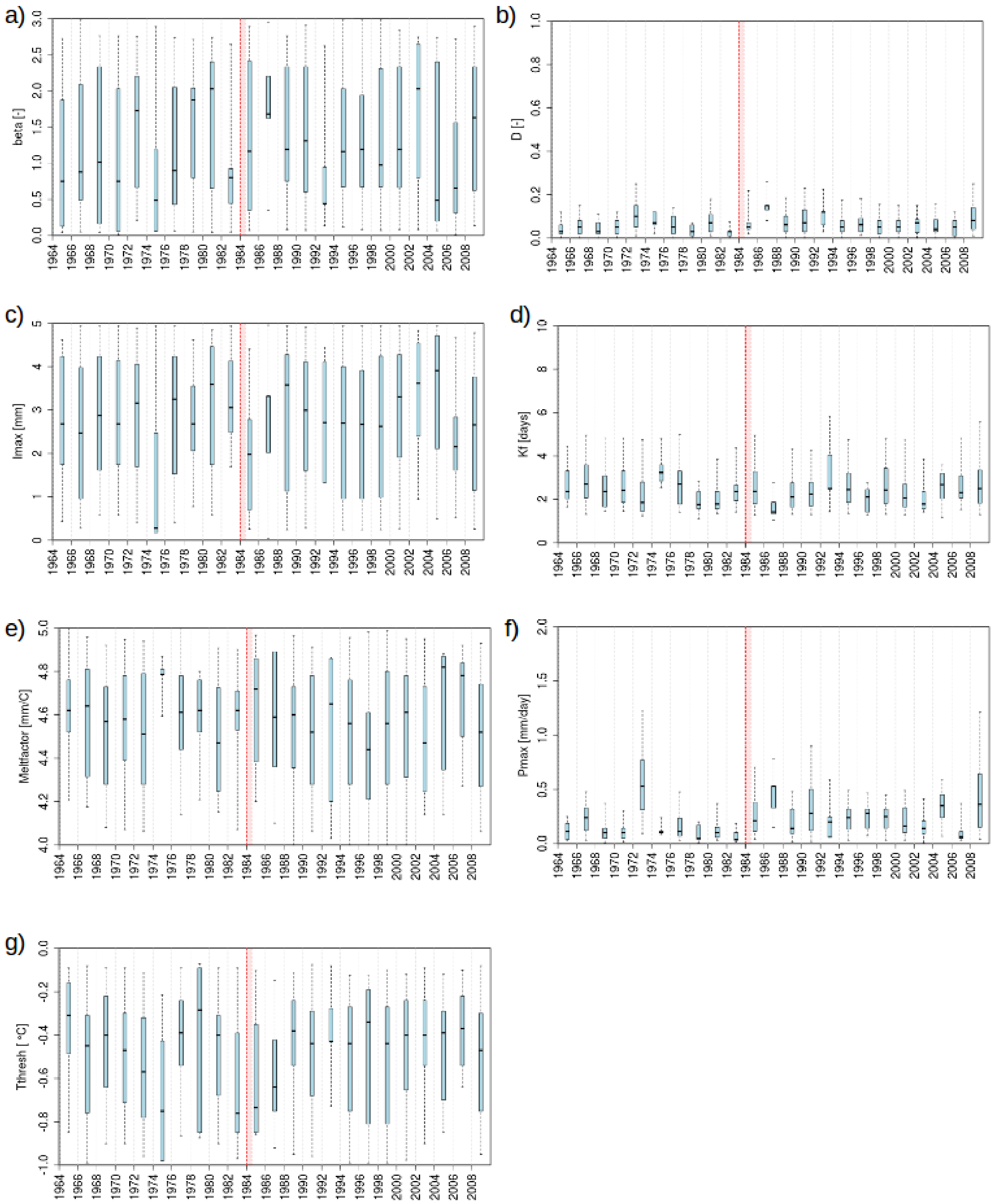

Figure S12. Posterior parameter distributions for the FLEX model in Hubbard Brook WS5.

4.2 HYPE

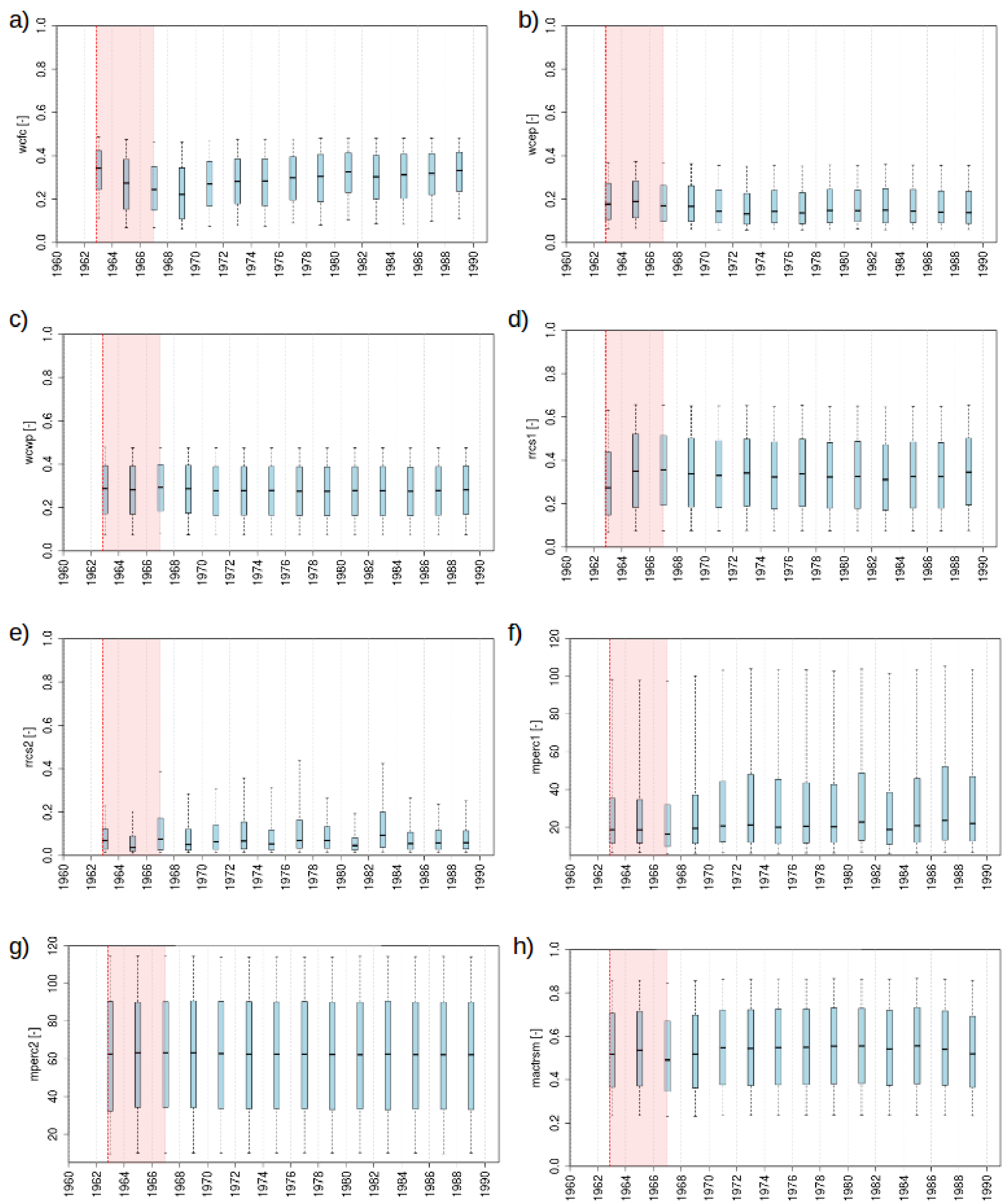

Figure S13. Posterior parameter distributions for the HYPE model in HJ Andrews WS1.

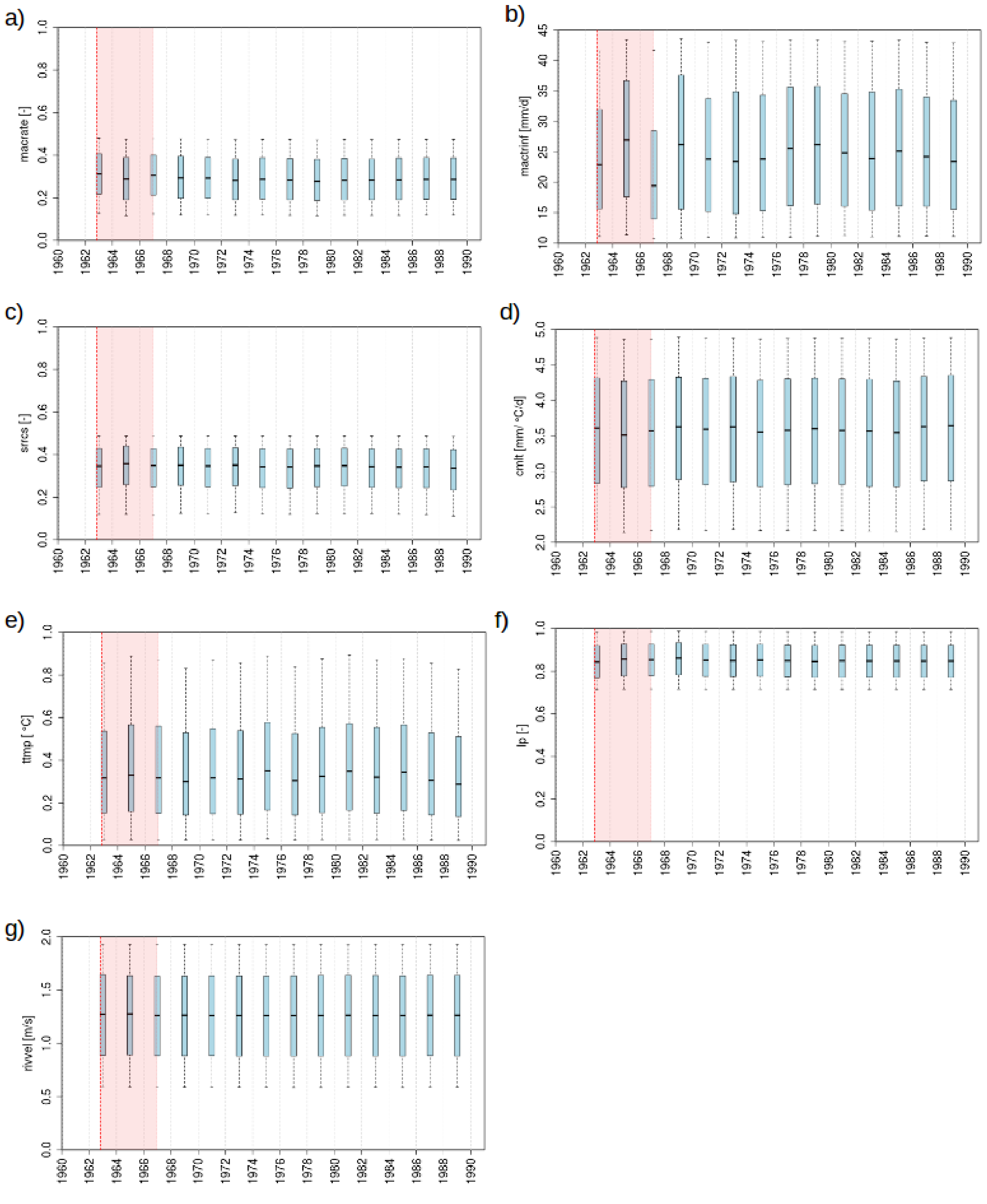

Figure S14. Continued posterior parameter distributions for the HYPE model in HJ Andrews WS1.

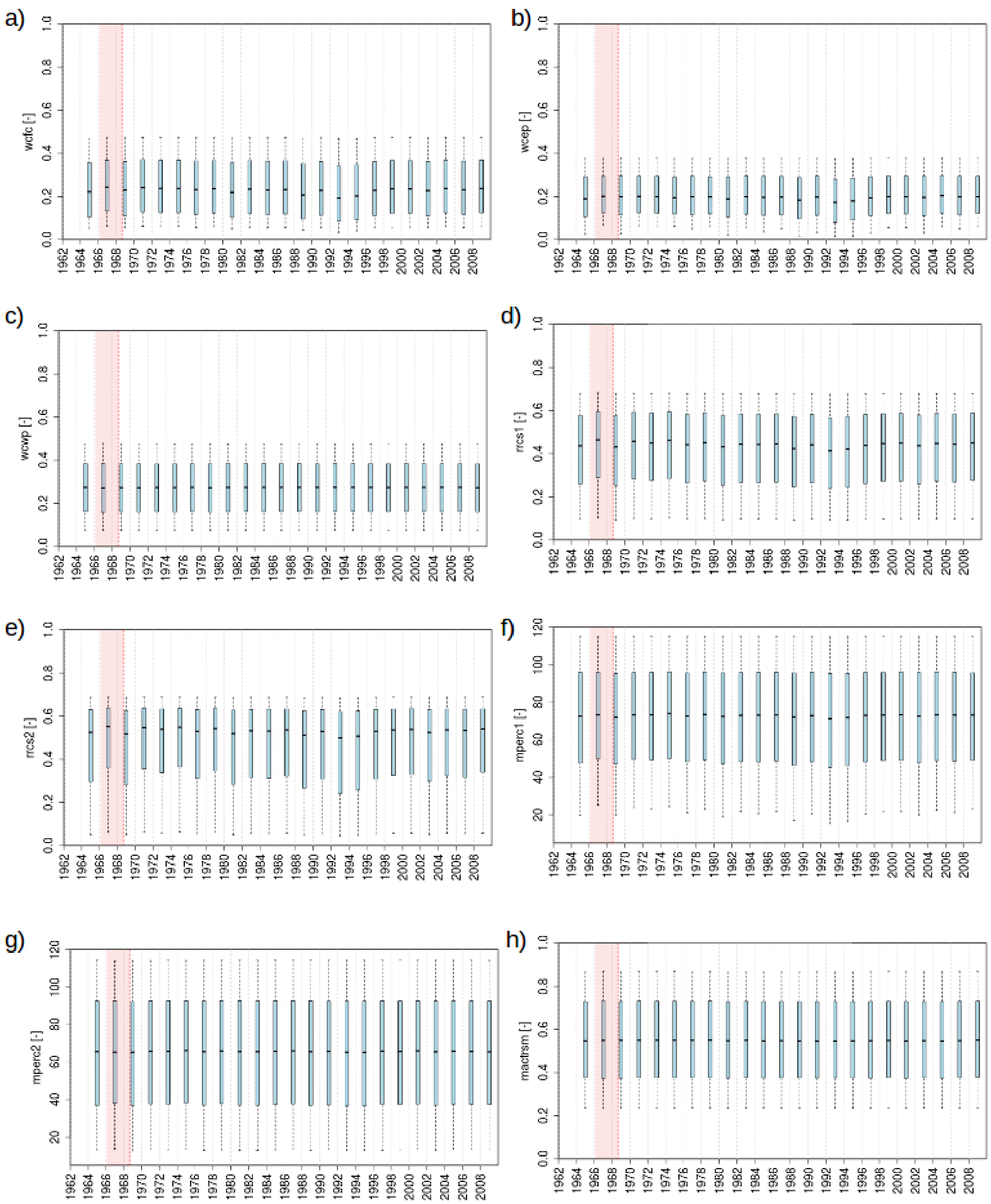

Figure S15. Posterior parameter distributions for the HYPE model in Hubbard Brook WS2.

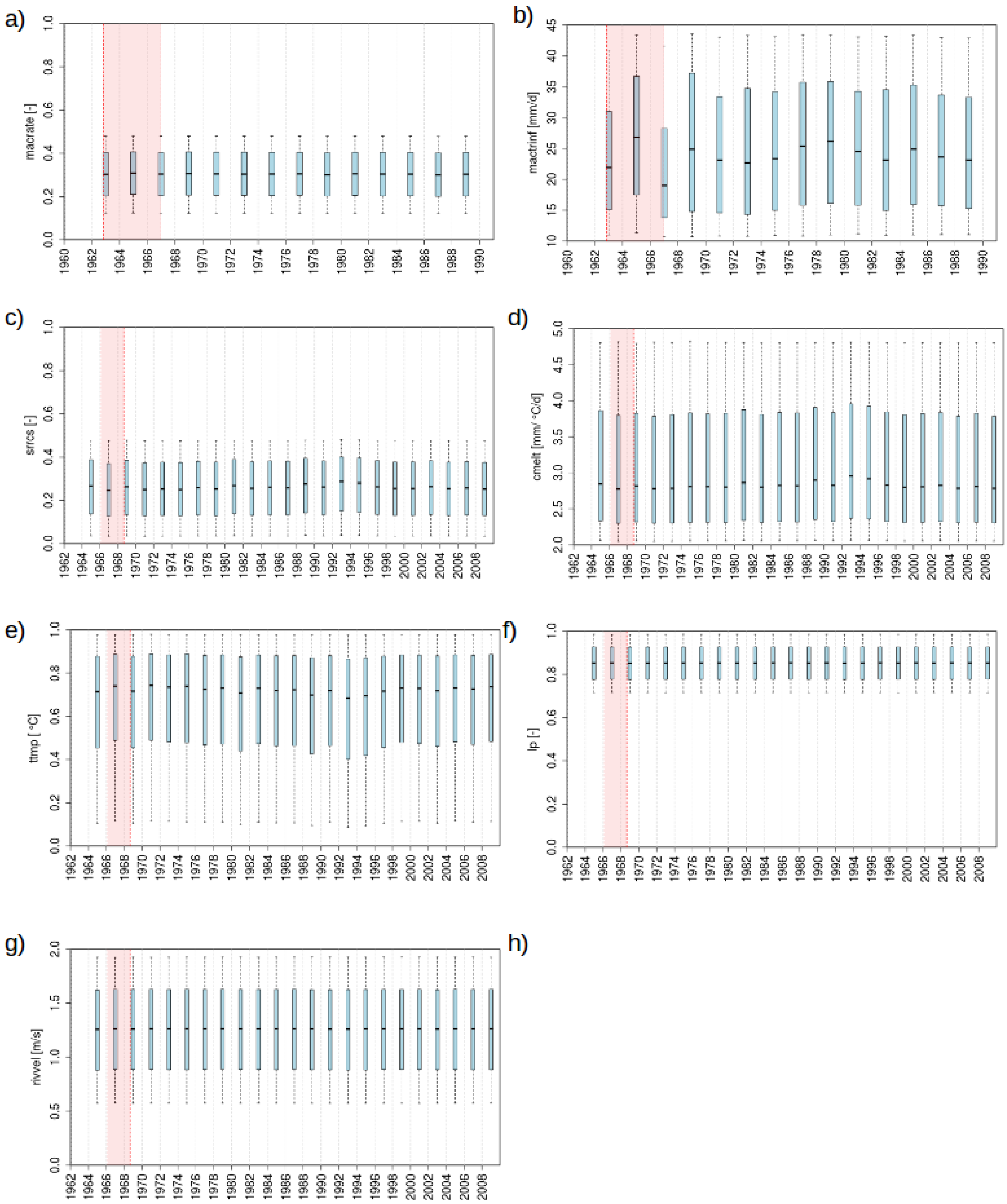

Figure S16. Continued posterior parameter distributions for the HYPE model in Hubbard Brook WS2.

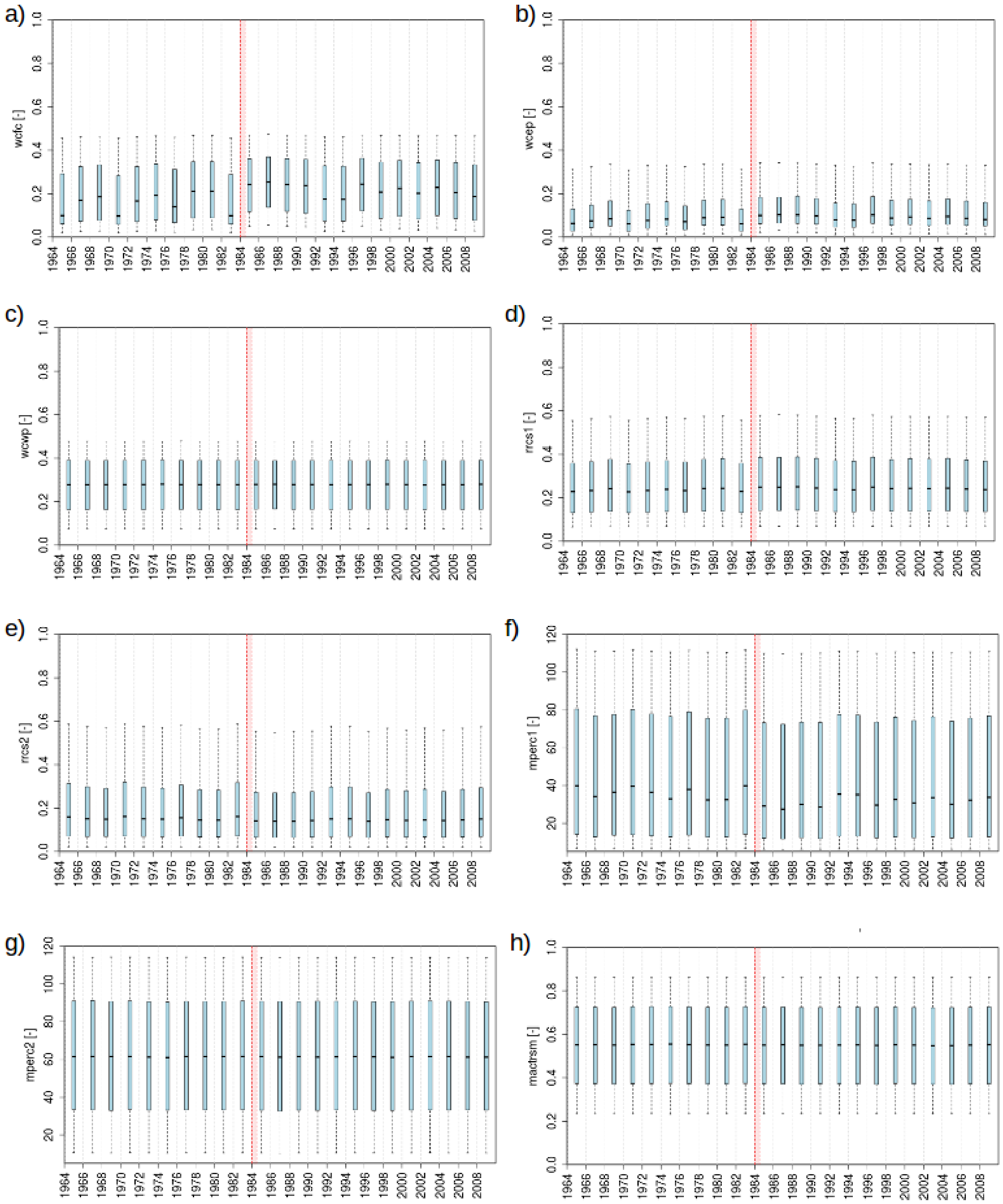

Figure S17. Posterior parameter distributions for the HYPE model in Hubbard Brook WS5.

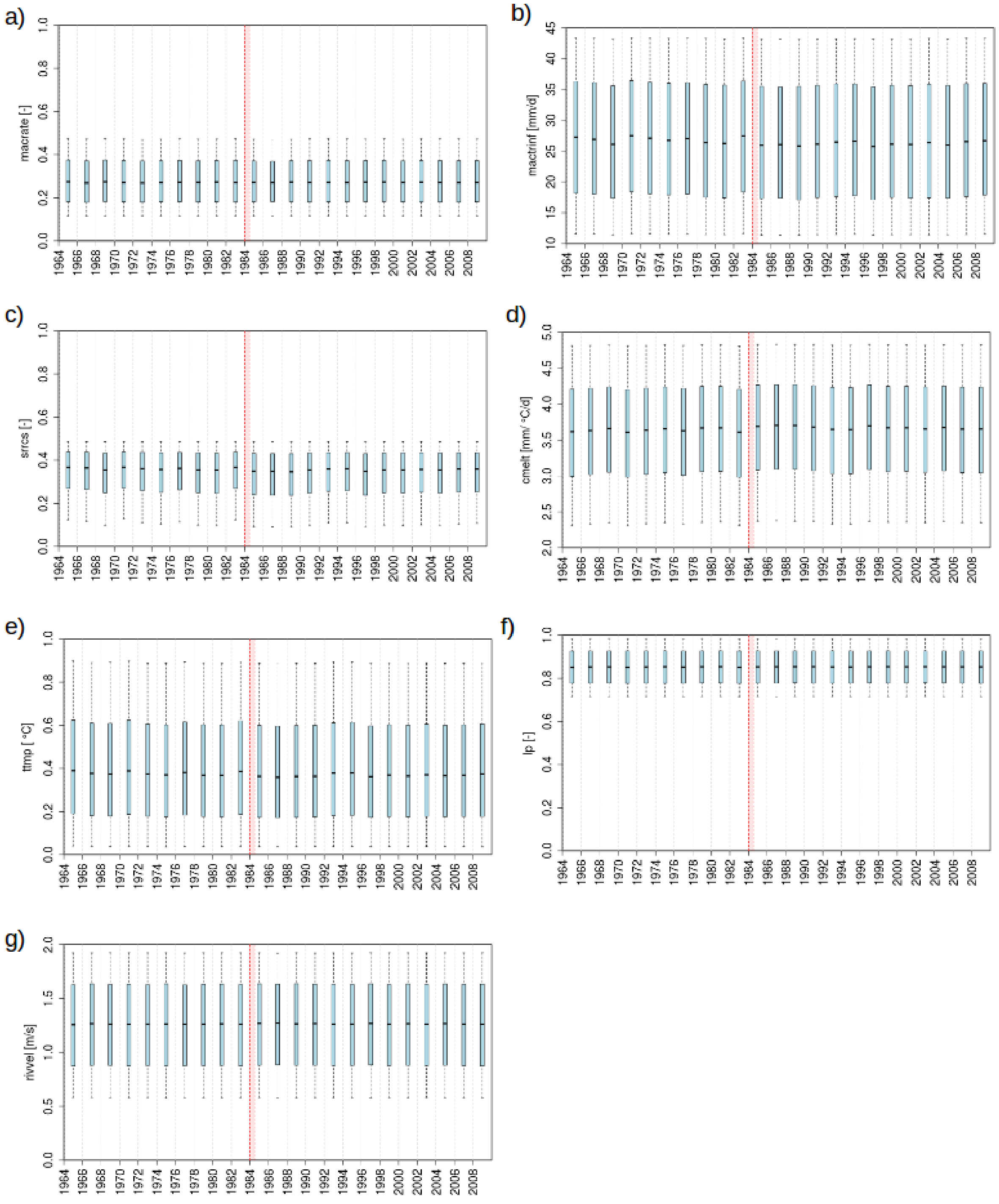

Figure S18. Continued posterior parameter distributions for the HYPE model in Hubbard Brook WS5.

4.3 HYMOD

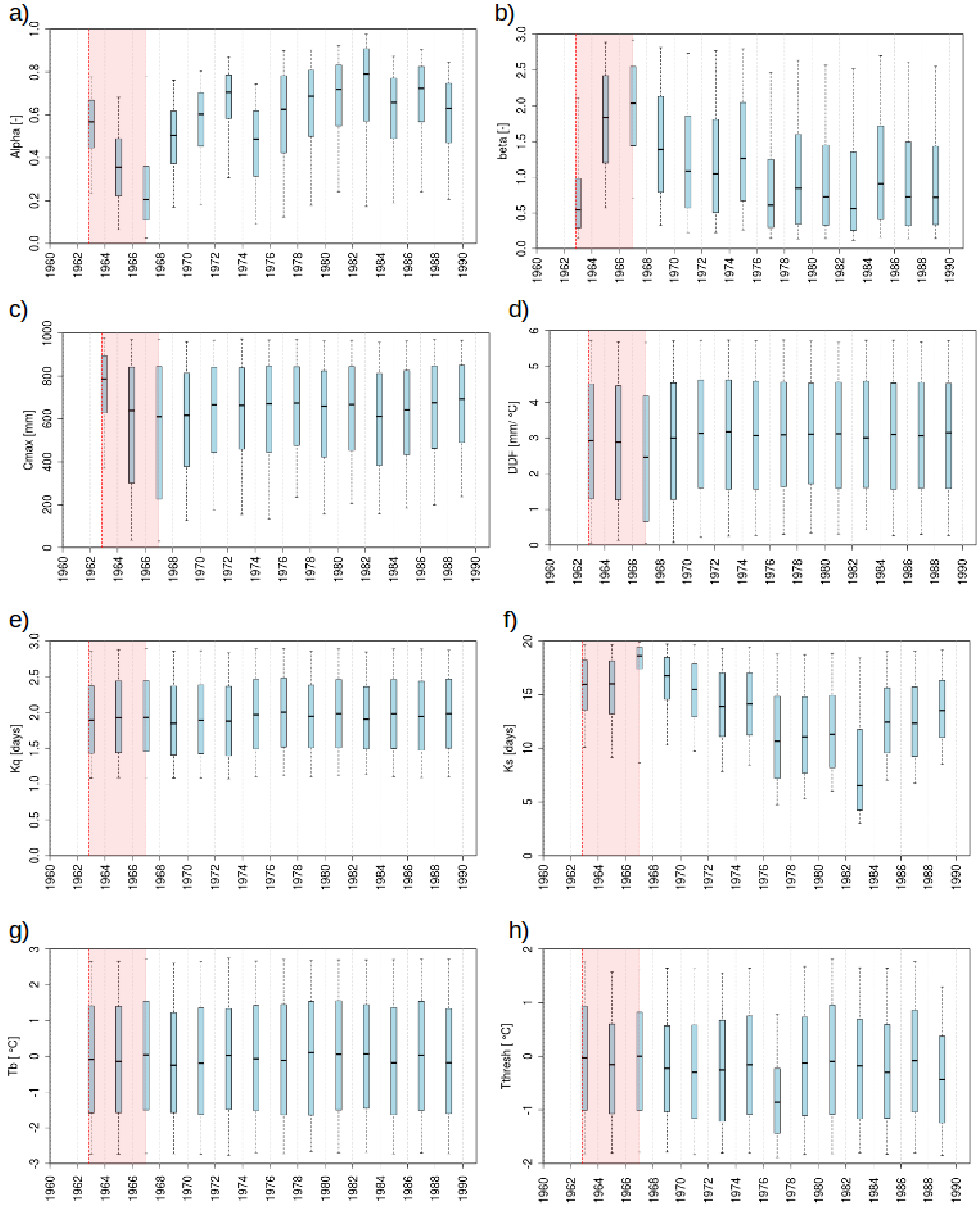

Figure S19. Posterior parameter distributions for the HYMOD model in HJ Andrews WS1.

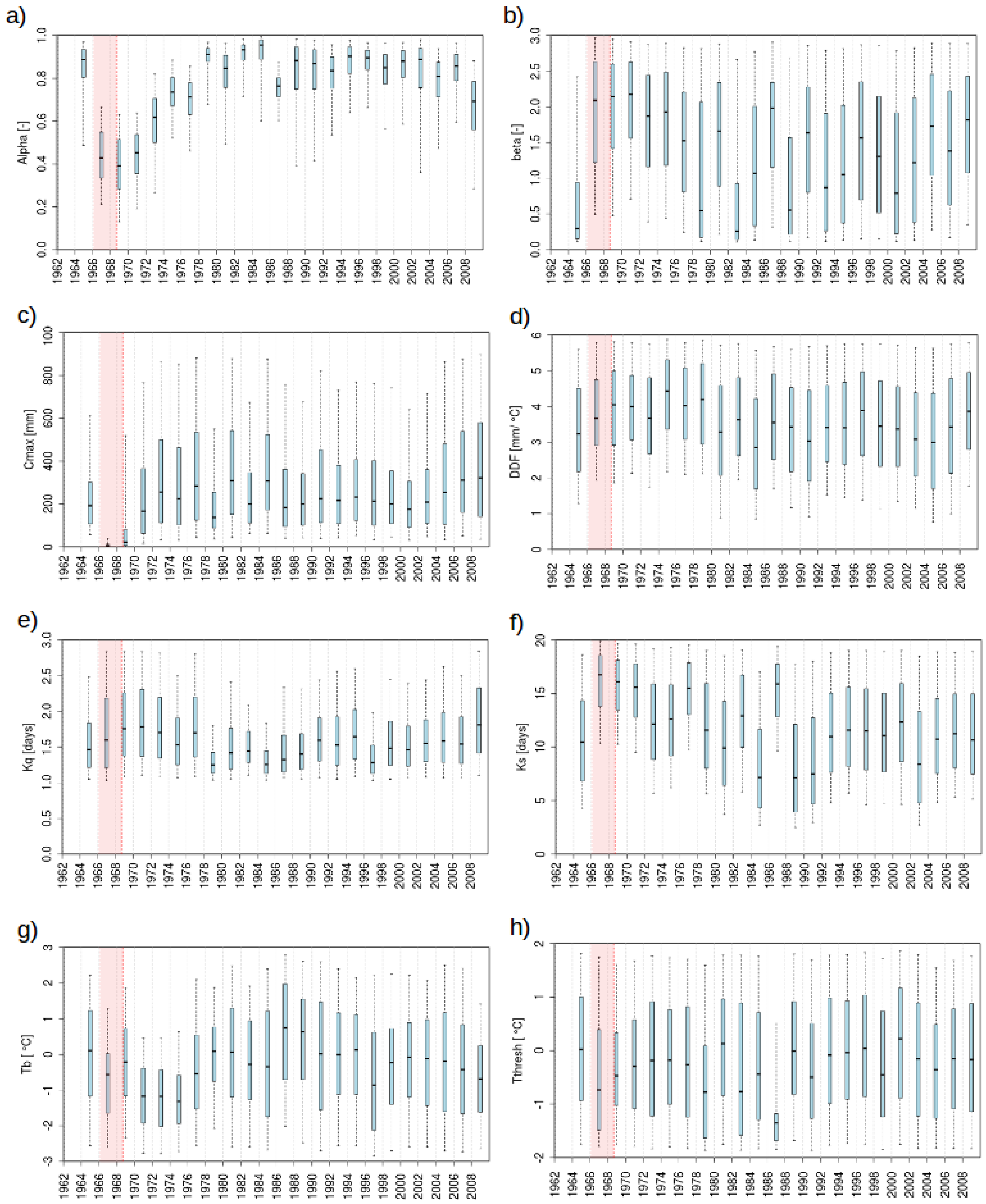

Figure S20. Posterior parameter distributions for the HYMOD model in Hubbard Brook WS2.

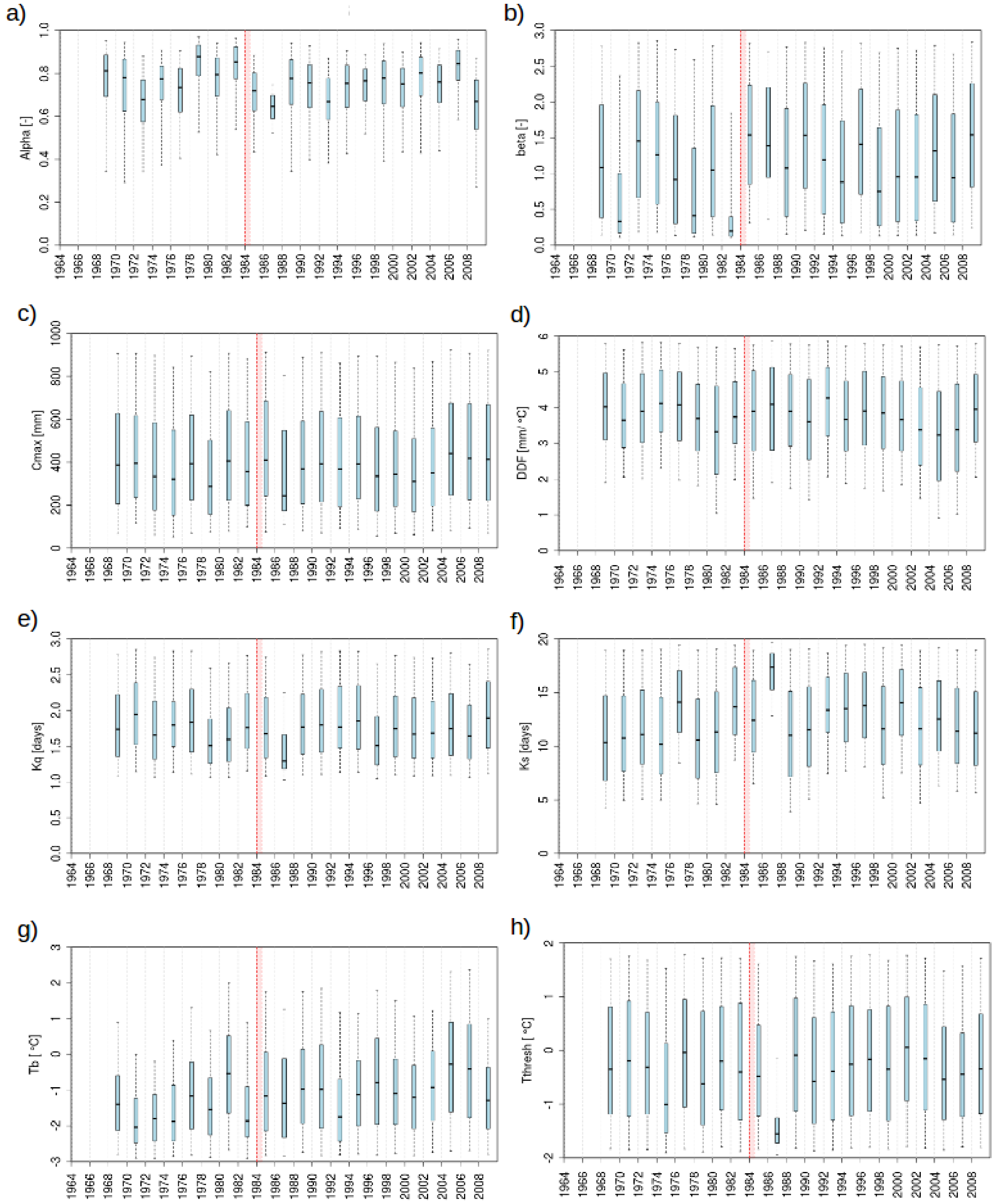

Figure S21. Posterior parameter distributions for the HYMOD model in Hubbard Brook WS5.

4.4 TUW

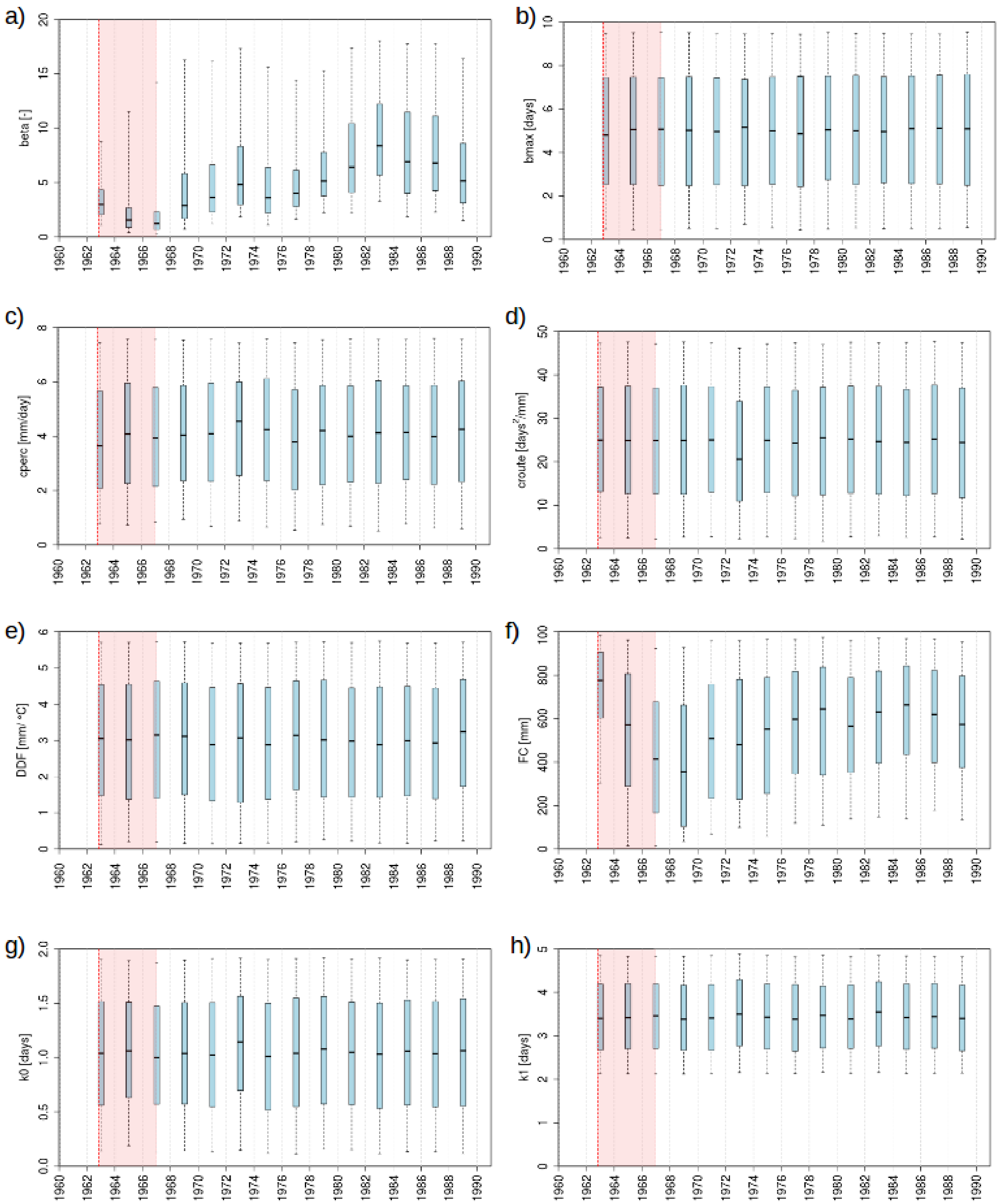

Figure S22. Posterior parameter distributions for the TUW model in HJ Andrews WS1.

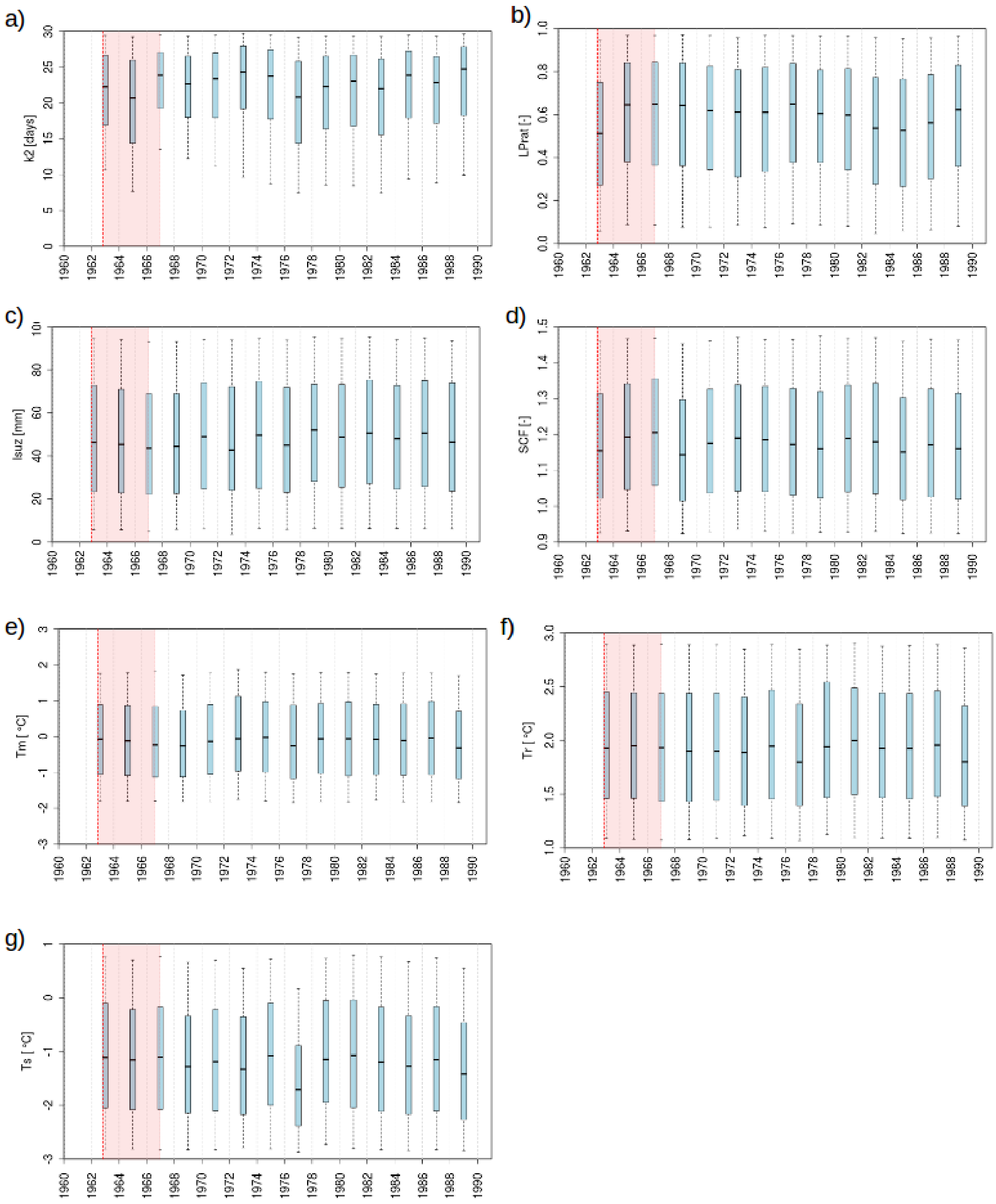

Figure S23. Continued posterior parameter distributions for the TUW model in HJ Andrews WS1.

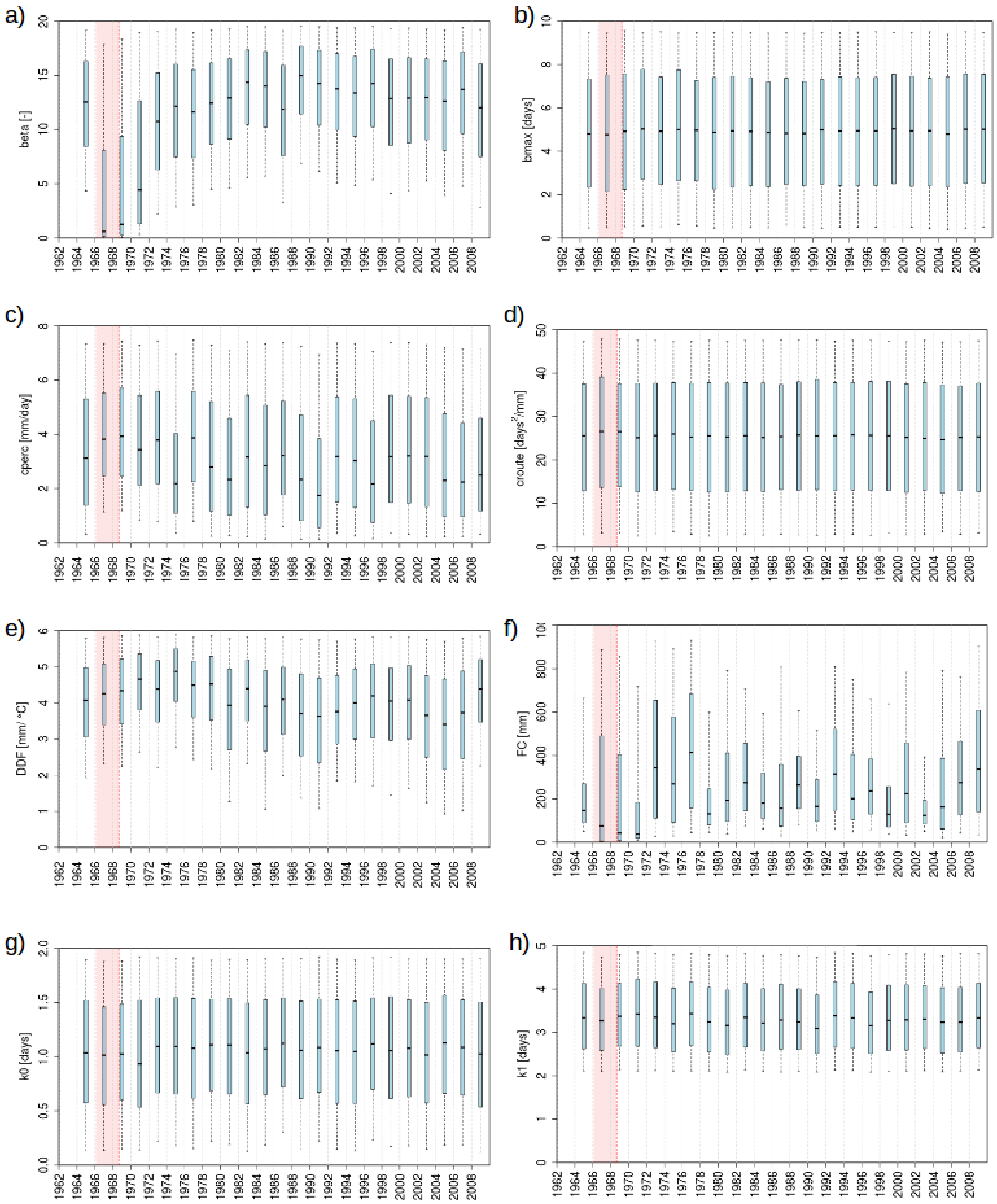

Figure S24. Posterior parameter distributions for the TUW model in Hubbard Brook WS2.

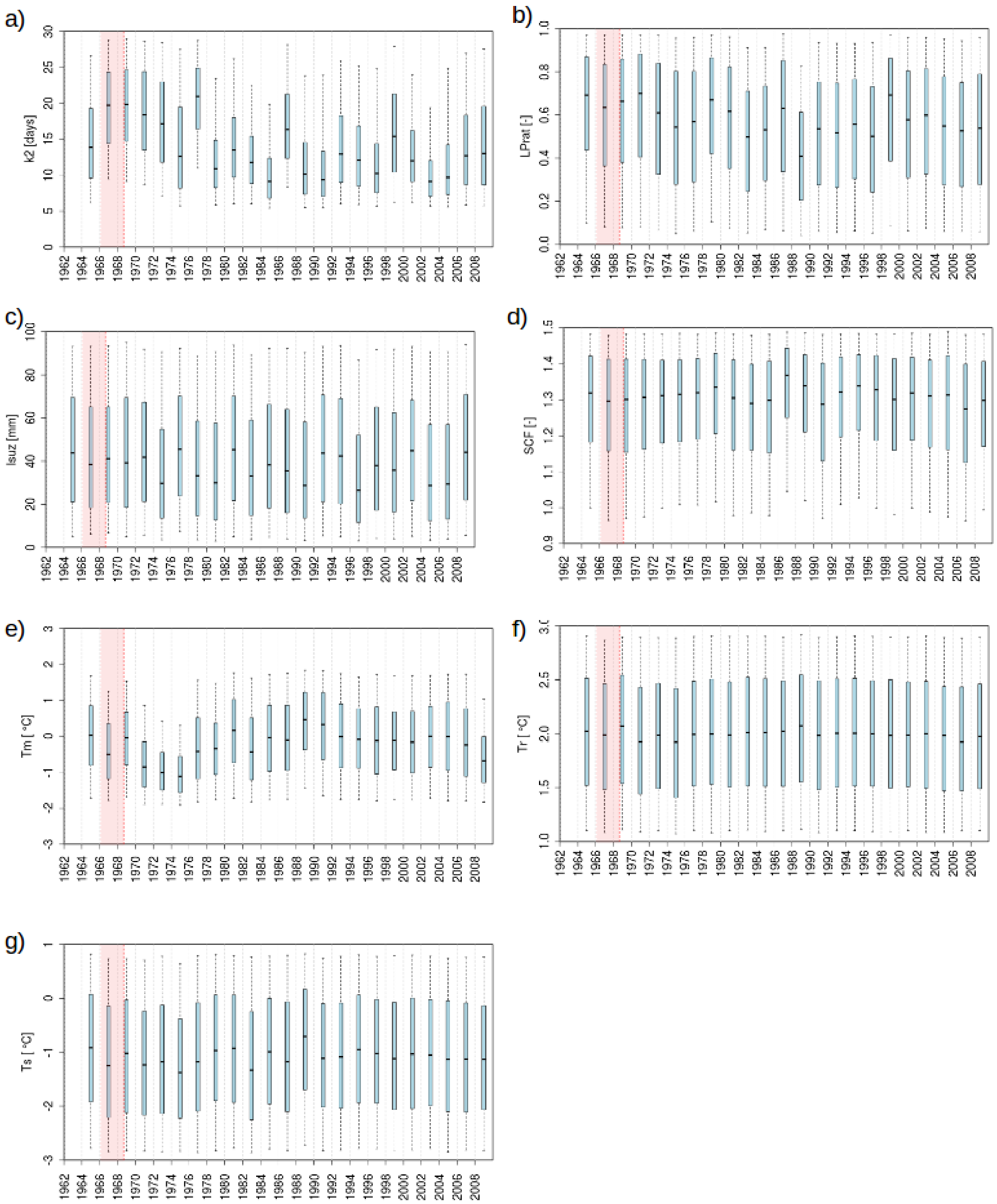

Figure S25. Continued posterior parameter distributions for the TUW model in Hubbard Brook WS2.

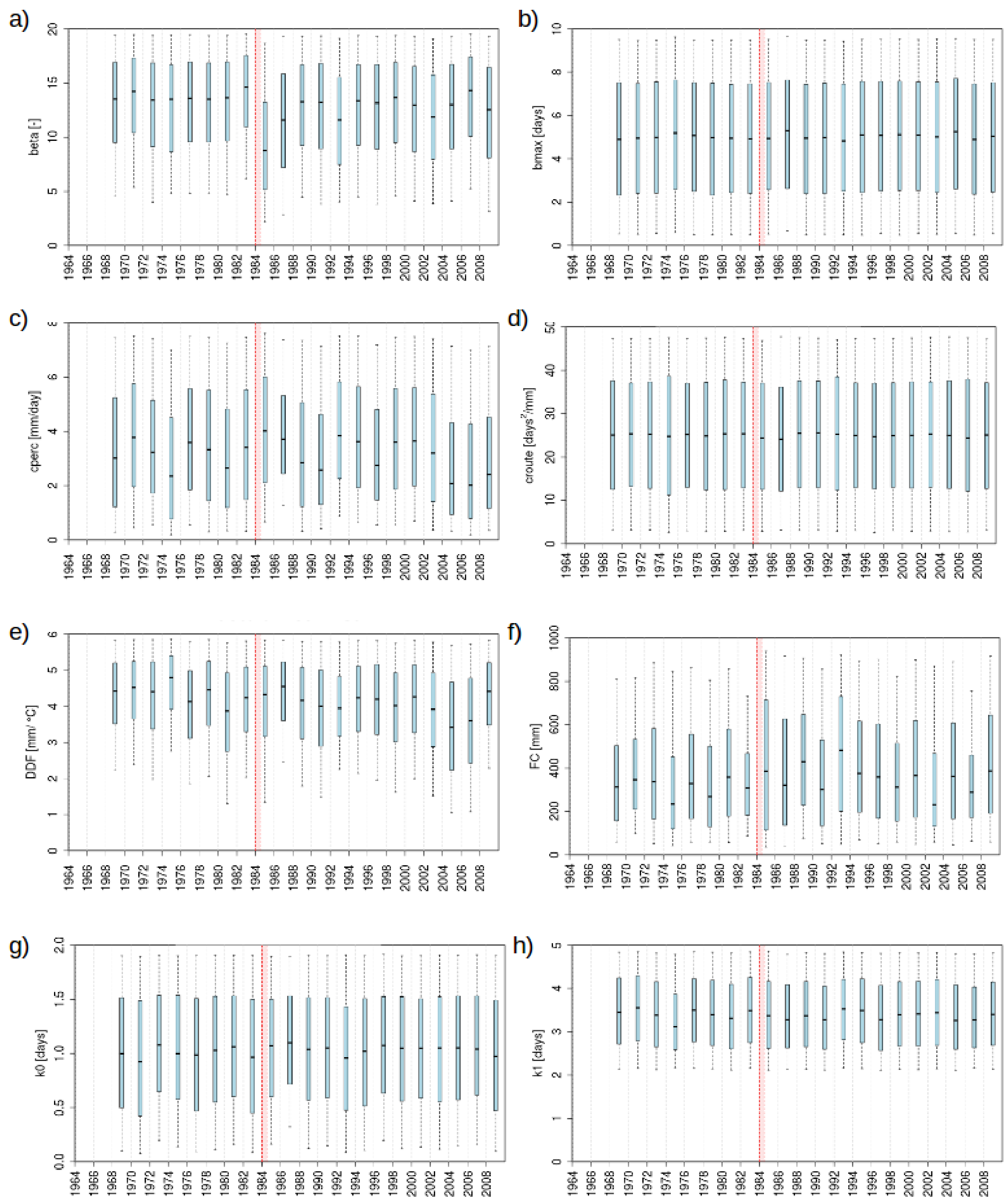

Figure S26. Posterior parameter distributions for the TUW model in Hubbard Brook WS5.

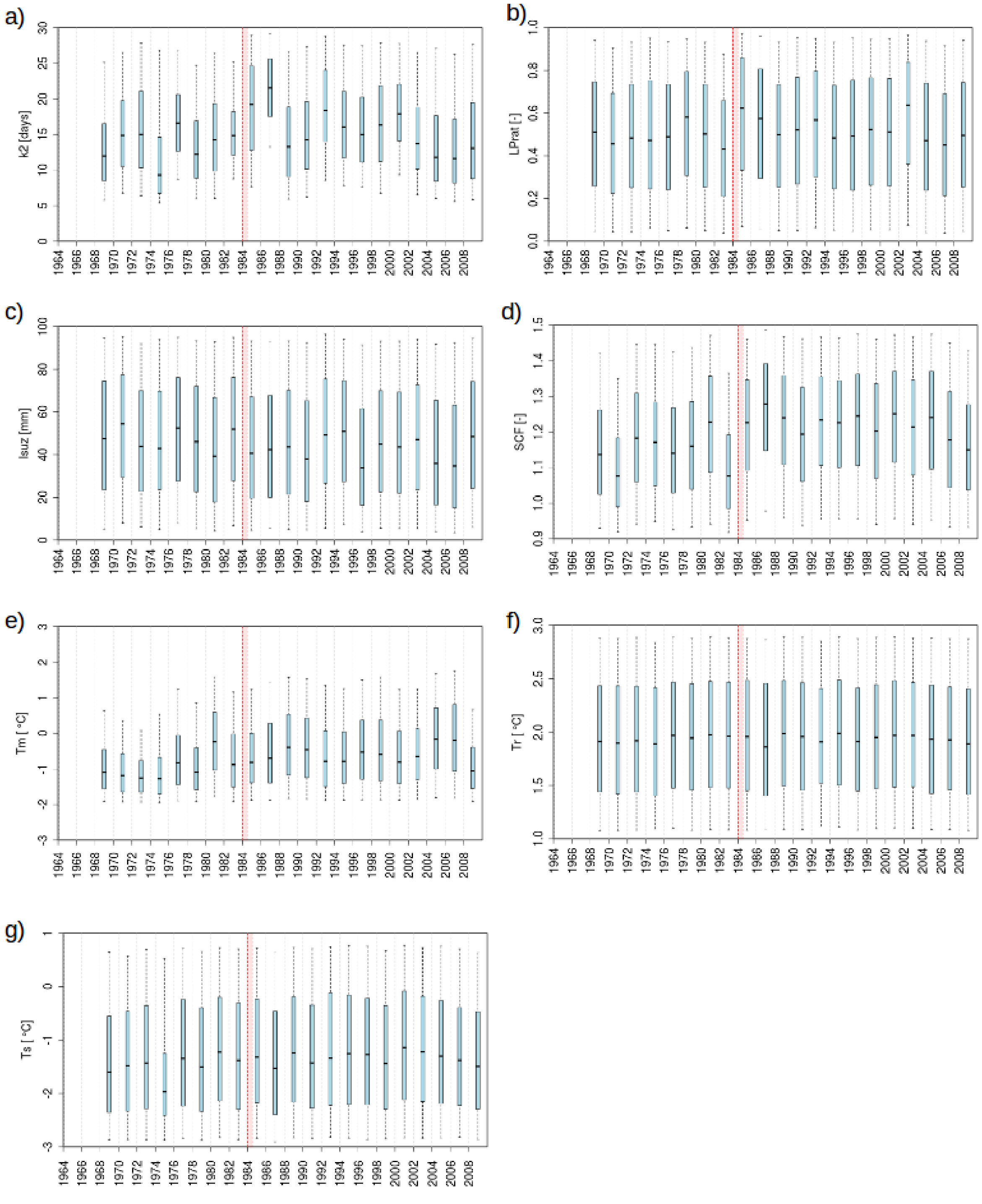

Figure S27. Continued posterior parameter distributions for the TUW model in Hubbard Brook WS5.