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Supplementary Information

Assessing uncertainty and complexity in regional-scale crop model simulations

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Table S1 GLAM parameters and values adopted for the simulations of the present study

Parameter[1]	Symbol[2]	Suggested range	Value adopted[3]	Units
Growth and development[4]				
FSWSOW	C_{sow}	0.1 – 0.9	0.5	
DLDTMX	$\left(\partial L / \partial t\right)_{\max}$	0.01 – 0.1	OP	day^{-1}
SWF_THRESH	S_{cr}	0.5 – 1.0	OP	
DLDLAI	$\partial l_v\left(z=0\right) / \partial L$	0.5 – 5.0	OP	$km \cdot cm^{-1} \cdot m^{-2}$
EFV	V_{EF}	1 – 2	OP	$cm \cdot day^{-1}$
RLVEF	$l_v(z=z_{ef})$	0.18 – 0.42	OP	$km/cm \cdot m^2$
TE	E_T	1.3 – 4.5	OP	Pa
TEN_MAX	$E_{TN,max}$	1.5 – 5	OP	$g \cdot kg^{-1}$
RSPARE3	R_{UE}	0.5 – 2.5		
DHDT	$\partial H_I / \partial t$	0.0042 – 0.0098	OP	day^{-1}
IEMDAY	t_{em}	3 – 13	8	day
TB	T_b	8 – 12	8	ºC
TO	T_o	28 – 37	28	ºC
TM	T_m	40 – 50	40	ºC
GCPLFL	t_{TT0}	350 – 400	OP	ºC day
GCFLPF	t_{TT1}	310 – 400	OP	ºC day
GCPFLM	t_{TT2}	200 – 300	OP	ºC day
GCLMHA	t_{TT3}	500 – 750	OP	ºC day
Evaporation and transpiration				
CRIT_LAI_T	L_{cr}	0.6 – 1.2	OP	
P_TRANS_MAX	TT_{max}	0.15 – 0.40	OP	$cm \cdot day^{-1}$
PT_CONST	α_0	NA	1.26	
VPD_REF	V_{ref}	0.6 – 1.4	OP	kPa
ALBEDO	A	0.12 – 0.28	OP	
SHF_CTE	C_G	0.22 – 0.51	OP	
EXTC	k	0.2 – 0.8	OP	
R_THRESH	P_{cr}	0 – 1	0.1	cm
UPDIFC	k_{DIF}	0.19 – 0.30	OP	$cm^2 \cdot day^{-1}$
UPCTE	C_θ	0.3 – 0.7	0.5	
Soil sub-model and miscellaneous				
ZSMAX	z_{max}	NA	210	cm
NSL	N_{SL}	NA	25	
D1	C_{d1}	NA	2.96	day^{-1}
D2	C_{d2}	NA	-2.62	day^{-1}
D3	C_{d3}	0.75 – 0.95	0.85	day^{-1}
RKCTE	K_{ks}	19 – 74	37	$cm \cdot day^{-1}$
ASWS	θs	0 – 1	θ_{ll}	
E_DEPTH	z_{ed}	8.4 – 84	16.8	cm
VPD_CTE	C_V	0.42 – 0.98	OP	kPa
YGP	C_{YG}	0.01 – 1.00	OP	
RLL	θ_{ll}	0 – 1	Soil data	
DLL	θ_{dul}	0 – 1	Soil data	
SAT	θ_{sat}	0 – 1	Soil data	

Table S1 (Continued)

Parameter[1]	Symbol	Suggested range	Value adopted[3]	Units
High temperature stress				
TCSLOPE	S_c	0.0 – 0.7	OP	ºC·day^{-1}
TLSLOPE	S_l	1.0 – 2.5	OP	ºC·day^{-1}
TCRITMIN	$T_{cr}^{\min}$	36 – 42	OP	ºC
TLINT	T_{ia}	50 – 60	OP	ºC
PPCRIT	P_{cr}	0.0 – 1.0	OP	
FDOFFSET	$OFFSET$	-0.2 – 0.5	OP	
FDWIDTH	$WIDTH$	3.0 – 10.0	OP	
IDURMAX	--	NA	6	day
IBAMAX	--	NA	6	day
IAAMAX	--	NA	12	day
Other stresses				
RSPARE2	F_{SW}	0 – 1	OP	
RSPARE1	$H_I^{\min}$	0.0 – 0.1	OP	
TETR1	T_{ETR1}	NA	35	ºC
TETR2	T_{ETR2}	NA	47	ºC
SWFF_THR	S_{cr}	0.2 – 0.4	0.2	
CO_2 response and specific leaf area (SLA) control				
TENFAC	$TENFAC$	0 – 1	NA	
B_TEN_MAX	$E_{TNc,\max}$	1.5 – 5.0	NA	g·kg^{-1}
B_TE	E_{Tc}	1.3 – 4.5	NA	Pa
NDSLA	N_D	1 – 10	5	day
SLA_INI	$SLA_{\max}$	250 – 300	300	g·cm^{-2}

[1]Name given in GLAM parameter file
[2]See Table S2 for parameter descriptions.
[3]Where "NA" appears as the adopted value means that the process was switched off or the parameter was irrelevant for this study. Where "OP" appears means that the parameters were optimised within the suggested ranges.
[4]Grey shading indicates parameters that were optimised. C_{YG} appears indicated in orange.

Table S2 Description of GLAM parameters and associated symbols

Parameter	Symbol	Description
FSWSOW	C_{sow}	Fractional soil moisture at sowing
DLDTMX	$(\partial L / \partial t)_{\max}$	Maximum rate of change in the leaf area
SWF_THRESH	S_{cr}	Threshold of soil water factor for reduced LAI growth
DLDLAI	$\partial l_v (z=0) / \partial L$	Rate of root length density increase at surface per unit LAI
EFV	V_{EF}	Extraction front velocity
RLVEF	$l_v(z=z_{ef})$	Root length density at the extraction front
TE	E_T	Normalised transpiration efficiency
TEN_MAX	$E_{TN,max}$	Maximum transpiration efficiency
RSPARE3	R_{UE}	Radiation use efficiency at optimum light conditions
DHDT	$\partial H_I / \partial t$	Rate of change in the harvest index
IEMDAY	t_{em}	Day of emergence
TB	T_b	Base temperature for development
TO	T_o	Optimum temperature for development
TM	T_m	Maximum temperature for development
GCPLFL	t_{TT0}	Thermal time requirement from planting to flowering
GCFLPF	t_{TT1}	Thermal time requirement from flowering to start of pod-filling
GCPFLM	t_{TT2}	Thermal time requirement from start of pod-filling to maximum LAI
GCLMHA	t_{TT3}	Thermal time requirement from maximum LAI to harvest
CRIT_LAI_T	L_{cr}	Critical LAI value for reduced transpiration
P_TRANS_MAX	TT_{max}	Maximum value of physiologically limited transpiration
PT_CONST	α_0	Priestley-Taylor constant
VPD_REF	V_{ref}	Priestley-Taylor equation parameter
ALBEDO	A	Surface albedo
SHF_CTE	C_G	Constant for calculation of soil heat flux
EXTC	k	Light extinction coefficient
R_THRESH	P_{cr}	Threshold for rain registration
UPDIFC	k_{DIF}	Uptake diffusion coefficient
UPCTE	C_θ	Constant for calculation of water uptake
ZSMAX	z_{max}	Maximum soil depth
NSL	N_{SL}	Number of soil layers
D1	C_{d1}	Constant for calculation of soil drainage
D2	C_{d2}	Constant for calculation of soil drainage
D3	C_{d3}	Constant for calculation of soil drainage
RKCTE	K_{ks}	Constant to calculate saturated hydraulic conductivity
ASWS	θs	Initial available soil water
E_DEPTH	z_{ed}	Depth of soil over which evaporation occurs
VPD_CTE	C_V	Constant used to compute *VPD*
YGP	C_{YG}	Yield gap parameter
RLL	θ_{ll}	Volumetric lower soil moisture limit (permanent wilting point)
DLL	θ_{dul}	Volumetric upper soil moisture limit (field capacity)
SAT	θ_{sat}	Volumetric soil moisture at saturation
TCSLOPE	S_c	For calculating heat stress around flowering
TLSLOPE	S_l	For calculating heat stress around flowering
TCRITMIN	$T_{cr}^{\min}$	Critical temperature at which heat has an impact on flowering
TLINT	T_{ia}	For calculating heat stress around flowering

Table S2 (Continued)

Parameter	Symbol	Description
PPCRIT	P_{cr}	Critical value of pod-set below which harvest index is reduced
FDOFFSET	*OFFSET*	Offset parameter for the flowering distribution (normal dist.)
FDWIDTH	*WIDTH*	Width parameter for the flowering distribution (normal dist.)
IDURMAX	--	Duration of heat event for impact on flowering
IBAMAX	--	Time before anthesis that heat has an impact
IAAMAX	--	Time after anthesis that heat has an impact
RSPARE2	F_{SW}	Soil moisture threshold for terminal drought stress
RSPARE1	$H_I^{\min}$	Minimum harvest index for terminal drought stress
TETR1	T_{ETR1}	Temperature at which high temperature reduces transpiration efficiency
TETR2	T_{ETR2}	Temperature at which transpiration efficiency is zero
SWFF_THR	S_{cr}	Soil moisture content below which drought has an impact on flowering
TENFAC	*TENFAC*	Factor to control assimilation in high CO_2 and high moisture (low *VPD*) conditions
B_TEN_MAX	$E_{TNc,\max}$	Non-CO_2 stimulated (i.e. baseline) value of maximum transpiration efficiency
B_TE	E_{Tc}	Non-CO_2 stimulated (i.e. baseline) value of transpiration efficiency
NDSLA	N_D	Number of days during which SLA control acts on biomass
SLA_INI	$SLA_{\max}$	Maximum value of SLA for use of SLA-control

Table S3 Differences in skill as measured by mean *RMSE* (in kg ha^{-1}) and *RMSE* normalised by mean observed yield (in %) between simulated yield with two input weather datasets, for each model version and groundnut growing zone.

Zone ID	Zone name	Model	RMSE			Normalised RMSE		
			WTH-A	WTH-B	Diff. (%)	WTH-A	WTH-B	Diff. (%)
1	North	GLAM-TE	168.3	156.9	6.8	37.0	34.7	6.2
2	West		314.1	318.9	1.5	49.7	51.0	2.6
3	Centre		182.0	182.7	0.4	32.9	33.0	0.3
4	East		394.5	250.1	36.6	49.2	30.1	38.8
5	South		175.0	163.6	6.5	24.5	22.4	8.6
1	North	GLAM-RUE	178.8	156.1	12.7	39.1	34.6	11.4
2	West		312.5	322.0	3.0	49.5	51.4	3.7
3	Centre		179.8	187.9	4.5	32.5	34.0	4.5
4	East		397.7	240.0	39.7	49.6	28.8	41.9
5	South		175.0	167.6	4.2	24.6	23.0	6.5

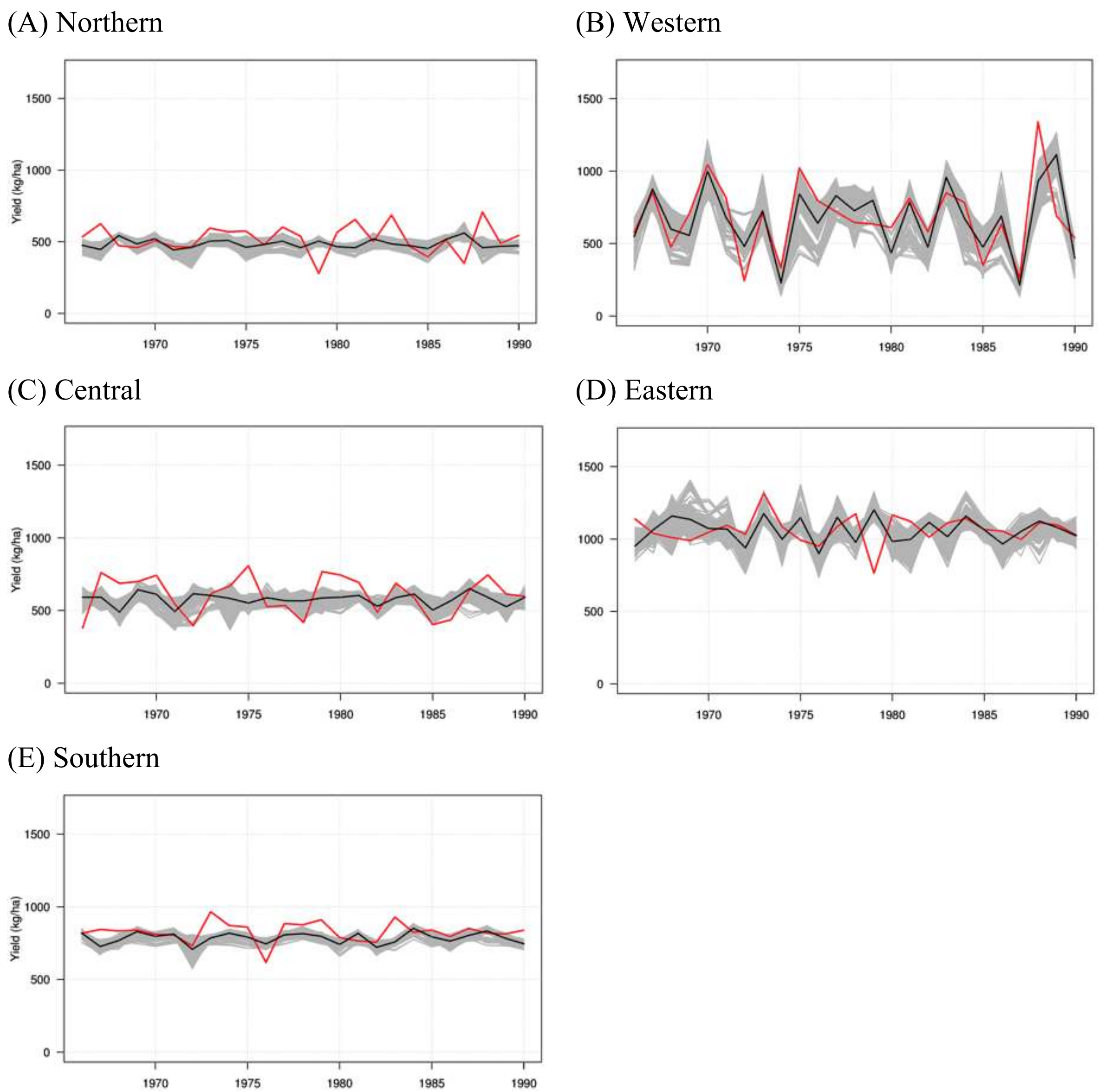

Figure S1 Simulated mean regional yield (black line) for each of the five groundnut growing regions for the parameter ensembles of GLAM-RUE and WTH-B (grey lines). Simulations of GLAM-TE for both weather datasets, and of GLAM-RUE for WTH-A show similar behaviour. The red line is the mean regional observed yield.

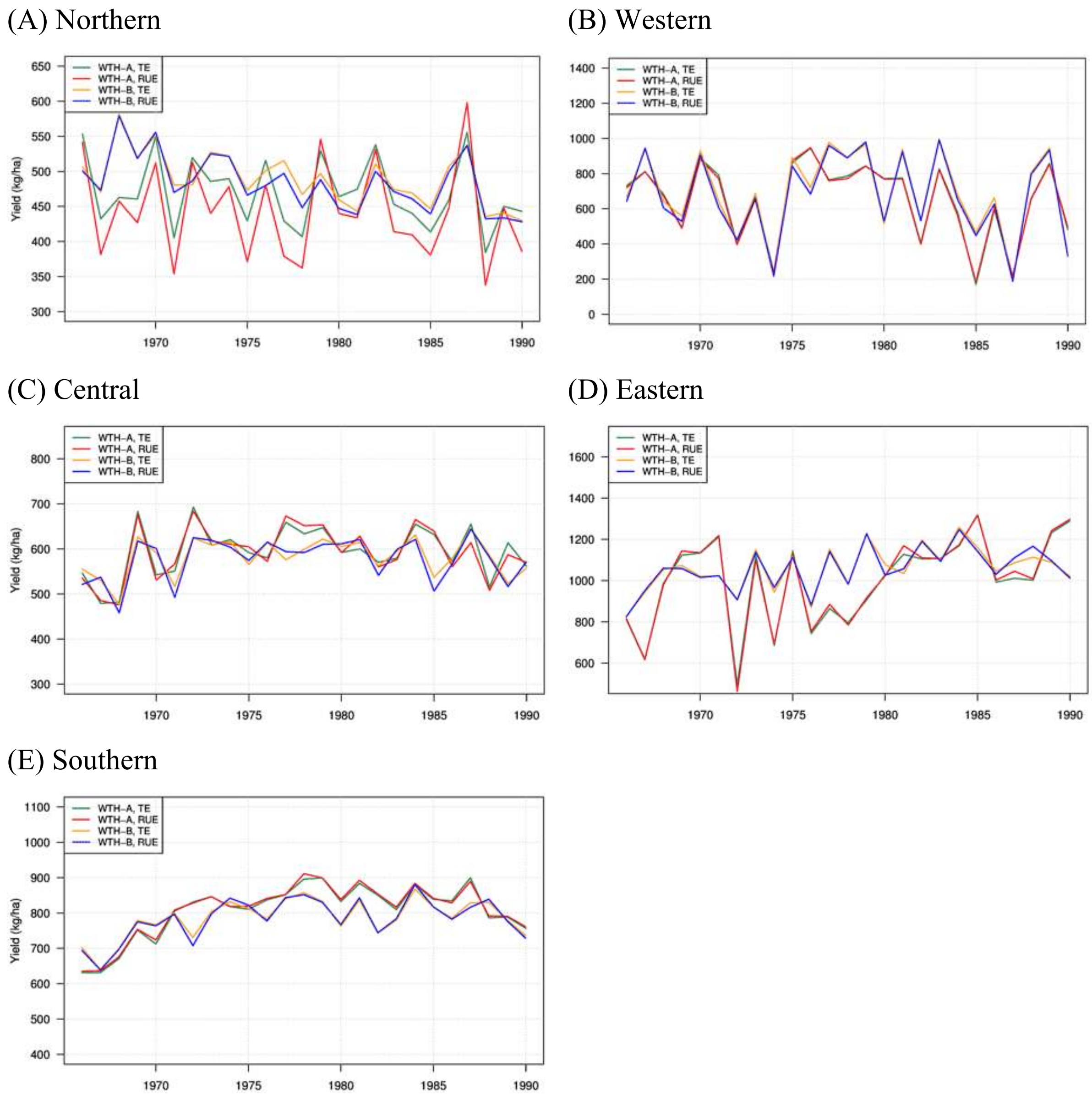

Figure S2 Simulated mean regional yield for each of the five groundnut growing regions, each input weather type and GLAM version (TE, RUE). Note the differences in *y*-axis scale, deliberately chosen to highlight differences between simulations within a zone. Note that no time de-trending has been done on these simulations, and hence observed temporal trends are likely a result of changes in climate.

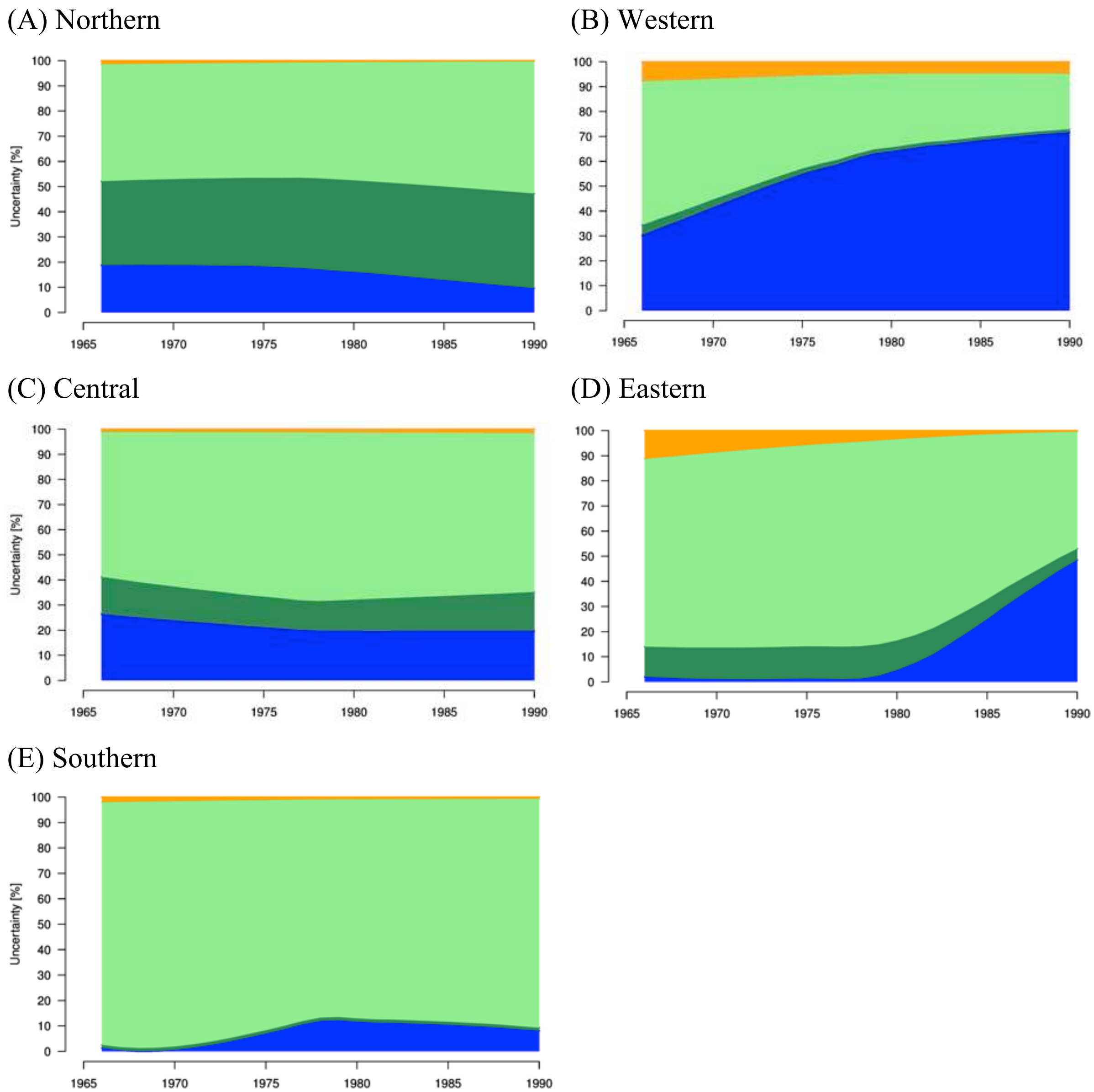

Figure S3 Fractional uncertainty in regional total crop biomass during the period 1966-1990, decomposed by source. Shown is the contribution of four different sources to total biomass variance, namely, weather inputs (blue), GLAM structure (dark green), parameter sets (light green), and natural variability (orange).

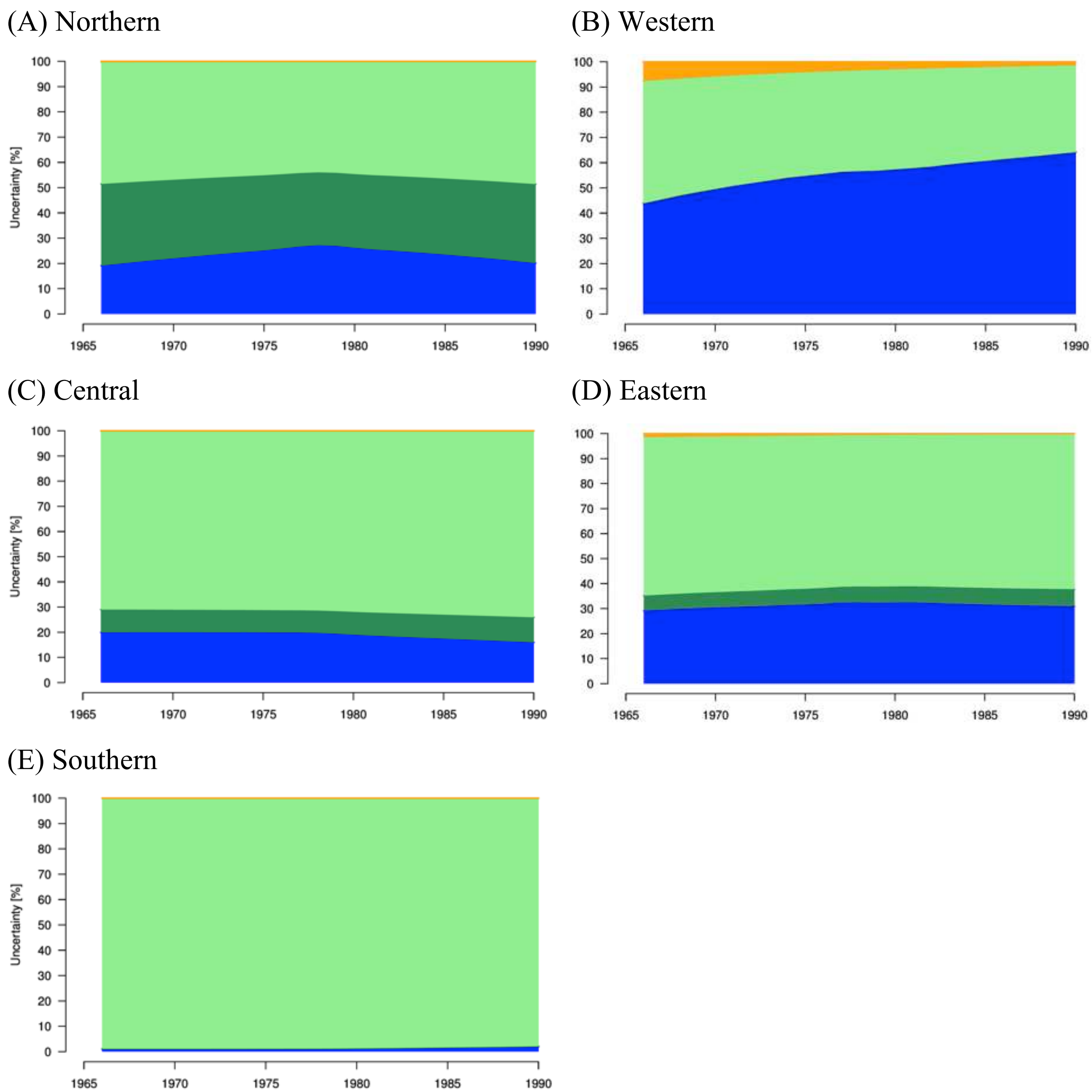

Figure S4 Fractional uncertainty in regional mean harvest index (H_I) during the period 1966-1990, decomposed by source. Shown is the contribution of four different sources to total H_I variance, namely, weather inputs (blue), GLAM structure (dark green), parameter sets (light green), and natural variability (orange).

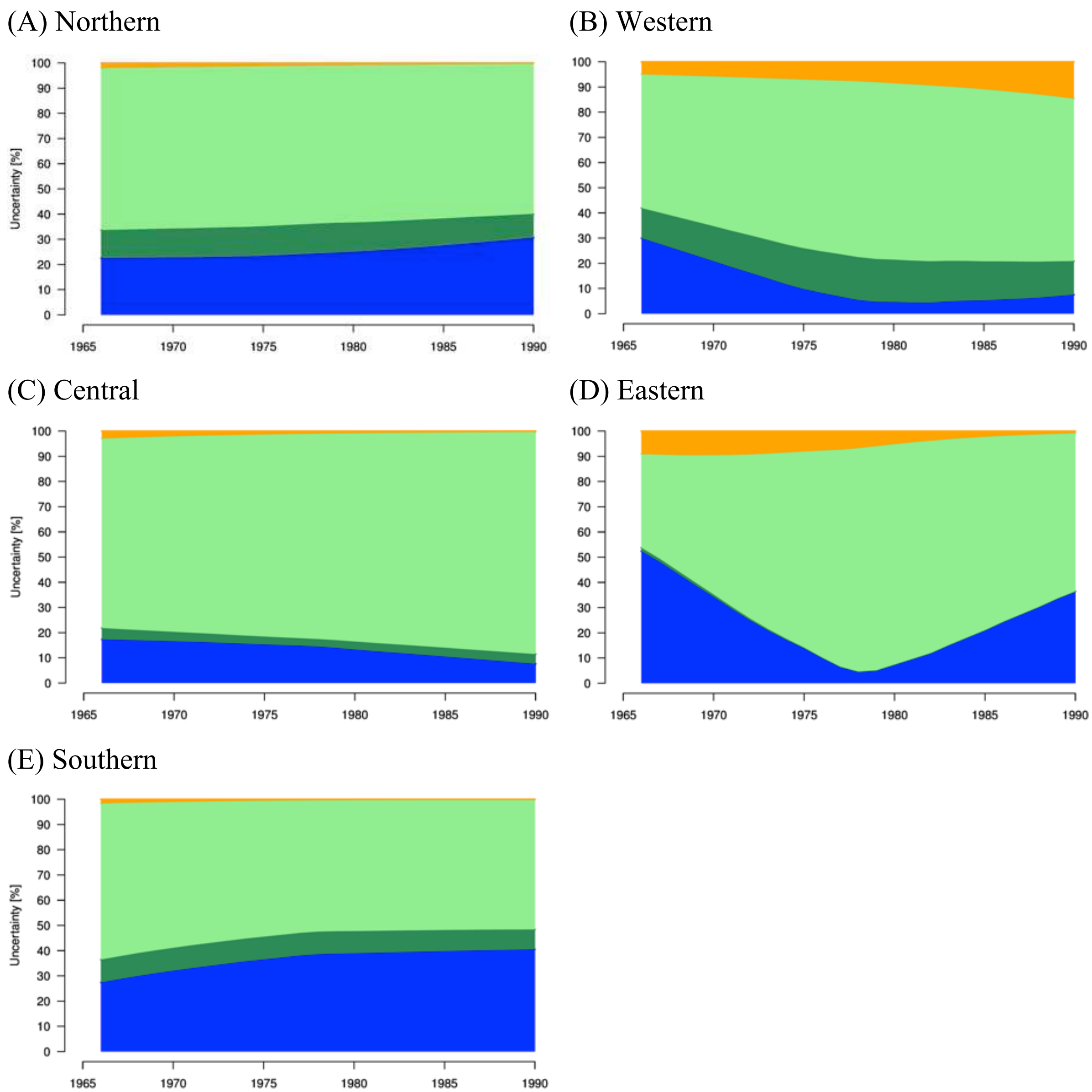

Figure S5 Fractional uncertainty in regional mean leaf area index (LAI) during the period 1966-1990, decomposed by source. Shown is the contribution of four different sources to total LAI variance, namely, weather inputs (blue), GLAM structure (dark green), parameter sets (light green), and natural variability (orange).

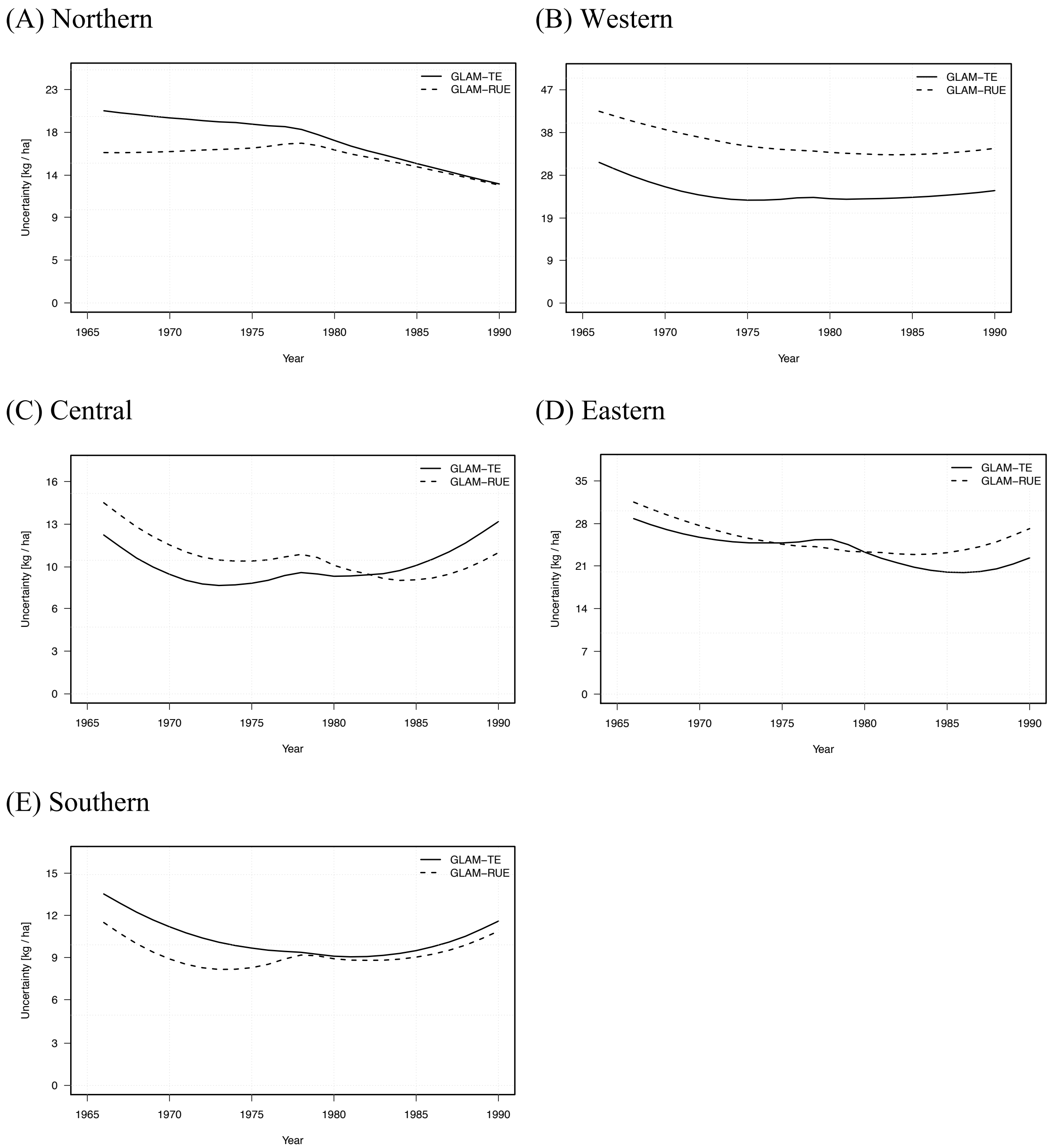

Figure S6 Absolute parametric uncertainty (standard deviation, kg ha^{-1}) in regional mean yield during the period 1966-1990.