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Supplement of

Improving the representation of major Indian crops in the Community Land Model version 5.0 (CLM5) using site-scale crop data

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TEXT S1:

The code added to the module CNPhenologyMod.F90 starts at line 2001:

```
Line no.
2001    if (cphase(p) == 4._r8) then
2002       if (idop(p) > jday) then
2003             cropplant(p) = .false.
2004             idop(p) = NOT_PLANTED
2005       else
2006             cropplant(p) = .true.
2007       end if
2008    else
2009    end if
```

where cphase = crop phenology phase, idop = day of planting, and jday = Julian day of the year.

TEXT S2:

- The pft number of wheat in CLM5 is 19 (rainfed) and 20 (irrigated). The pft number of rice in CLM5 is 61 (rainfed) and 62 (irrigated).
- Code changes to the CropType.F90 to include the latitudinal variation in base temperature for rice is:

```
Line no.
597     do p = begp,endp
598        if (this%croplive_patch(p)) then ! relative to planting date
599           ivt = patch%itype(p)
600           if ( (trim(this%baset_mapping) == baset_map_latvary) .and. &
601              ((ivt == nswheat) .or. (ivt == nirrig_swheat) .or. &
602               (ivt == nrice) .or. (ivt == nirrig_rice) .or.&                    !!Line added here!!
603               (ivt == nsugarcane) .or. (ivt == nirrig_sugarcane)) ) then
604              rbufslp(p) = max(0._r8, min(pftcon%mxtmp(ivt), &
605              t_ref2m_patch(p)-(SHR_CONST_TKFRZ + this%latbaset_patch(p)))) &
606              * dtime/SHR_CONST_CDAY
607           else
608              rbufslp(p) = max(0._r8, min(pftcon%mxtmp(ivt), &
609              t_ref2m_patch(p)-(SHR_CONST_TKFRZ + pftcon%baset(ivt)))) &
610              * dtime/SHR_CONST_CDAY
611           end if
612           if (ivt == nwwheat .or. ivt == nirrig_wwheat) then
613              rbufslp(p) = rbufslp(p) * this%vf_patch(p)
614           end if
615        else
616           rbufslp(p) = accumResetVal
617        end if
618     end do
```

Table S1: Site scale data from Varma et al. (2024) used for base temperature sensitivity study (2000-2014)

Site name	Event IDs in PANGEA repository (Varma et al., 2024)	Latitude [ºN]	Longitude [ºE]	Altitude [m] (above sea level)
Anantapur	IND_RI_RED_2000, and IND_RI_RED_2001*	14.68	77.6	350
Cooch Behar	IND_SW_COB_2000, and IND_SW_COB_2001*	26.34	89.40	43
Faizabad	IND_SW_FAZ_2002, IND_SW_FAZ_2003, and IND_SW_FAZ_2004*	26.78	82.20	113
Hyderabad	IND_RI_HYD_2010	17.19	78.23	542

Jabalpur	IND_RI_JAB_2009, IND_RI_JAB_2010*, and IND_RI_JAB_2011*	24.49	80.58	412
Jobner	IND_SW_JOB_2013	26.08	75.34	427
Kaul	IND_RI_KAU_2008	29.51	76.41	241
Kuthulia	IND_RI_KUT_2013	24.30	80.15	366
Ludhiana	IND_SW_LUD_2011, and IND_SW_LUD_2012*	30.93	75.87	247
Meerut	IND_SW_MEE_2011, IND_SW_MEE_2012, and IND_SW_MEE_2013*	29.07	77.70	237
Nadia	IND_SW_NAD_2000, IND_SW_NAD_2001, IND_SW_NAD_2002, IND_SW_NAD_2008, IND_SW_NAD_2009*, and IND_SW_NAD_2013*	22.88	89.00	10
Pantnagar	IND_SW_PAN_2007, IND_SW_PAN_2008*, IND_RI_PAN_2011, and IND_RI_PAN_2012*	29.00	79.48	244
Parbhani	IND_SW_PAR_2001, IND_SW_PAR_2005, and IND_SW_PAR_2009*	19.27	76.78	409
Raipur	IND_RI_RAI_2009	21.40	81.39	293

* Site data used in validation. Remaining data is used in calibrating

Table S2: Sensitivity experiment values for CLM5_Mod1 case. The values in bold font are the best performing parameter values.

Parameter	Wheat		Rice	
	CLM5_Def	Tested values	CLM5_Def	Tested values
planting window [mmdd, mmdd]	[401, 615]	[1015, 1130]; [1101,1215]; **[1115,1231]**; [1130, 1231]	[101, 228]	[615, 731]; **[701,815]**; [715,831]; [731, 915]
grnfill	0.6	0.55, **0.6**, 0.65, 0.7, 0.75	0.4	0.45, 0.5, 0.55, 0.6, **0.65**, 0.7, 0.75
hybgdd	1700	1600, **1700**, 1800, 1900, 2000	2100	1900, 2000, **2100**, 2200, 2300

Table S3: Base temperature at lowest bias observed during the sensitivity studies for wheat and rice

Crop	**Site Name**	**Latitude [ºN]**	**Base temperature @ lowest bias [ºC]**
Wheat	Parbhani	19.16	8
	Nadia	22.95	7
	Faizabad	25.26	7
	Cooch Behar	26.19	7
	Jobner	26.51	5
	Pantnagar	29.02	5
	Meerut	29.40	5
	Ludhiana	30.54	6
Rice	Anantapur	14.68	12
	Hyderabad	17.19	11

Raipur	21.04	12
Jabalpur	23.90	9
Kuthulia	24.30	8
Pantnagar	29.02	9
Kaul	29.51	8

Table S4: Calibration and validation of wheat and rice simulated by CLM5 against site scale observations

Parameter	Stage of model evaluation	Evaluation Metrics	Wheat				Rice			
			Obs	CLM5_Def	CLM5_Mod1	CLM5_Mod2	Obs	CLM5_Def	CLM5_Mod1	CLM5_Mod2
LAI (m^2/m^2)	Calibration	Mean of max. LAI	4.13	2.35	2.67	3.45	5.41	1.74	4.59	4.64
		MAB	--	0.81	0.51	0.45	--	0.73	0.45	0.36
		RMSE	--	2.48	1.70	1.44	--	3.25	2.15	1.71
		r	--	-0.18	0.17	0.27	--	0.05	0.33	0.47**
	Validation	Mean of max. LAI	4.38	2.38	2.73	3.52	4.96	1.50	4.29	4.12
		MAB	--	0.83	0.52	0.40	--	0.71	0.25	0.32
		RMSE	--	2.68	1.85	1.37	--	3.10	1.35	1.59
		r	--	-0.28*	0.03**	0.35**	--	0.13	0.45	0.41
Yield (t/ha)	Calibration	Mean	3.87	2.92	3.60	3.50	4.57	2.66	3.69	3.47
		MAB	--	0.29	0.16	0.17	--	0.70	0.26	0.29
		RMSE	--	1.30	0.85	0.90	--	3.72	1.52	1.57
		r	--	0.28	0.33	0.30	--	-0.59	-0.07	-0.07
	Validation	Mean	3.92	3.24	3.83	4.00	4.56	2.56	3.30	3.39
		MAB	--	0.17	0.13	0.22	--	0.70	0.34	0.30
		RMSE	--	1.00	0.69	0.99	--	3.93	1.88	1.71
		r	--	0.31	0.51	0.33	--	-0.96	-0.01	0.30
Growing season length (days)	Calibration	Mean	128	69	125	135	120	117	125	123
		MAB	--	0.46	0.11	0.09	--	0.09	0.10	0.12
		RMSE	--	61.72	15.60	15.30	--	13.64	14.62	18.13
		r	--	0.39	0.66*	0.62*	--	0.04	0.09	-0.67
	Validation	Mean	131	69	128	138	115	112	121	119
		MAB	--	0.48	0.10	0.11	--	0.05	0.05	0.07
		RMSE	--	64.76	15.66	15.68	--	7.81	8.09	11.04
		r	--	0.44	0.66	0.62	--	0.48	0.80*	0.51
--	Calibration	Overall bias	--	0.51	0.26	0.24	--	0.51	0.27	0.26
	Validation	Overall bias	--	0.49	0.25	0.24	--	0.49	0.21	0.23

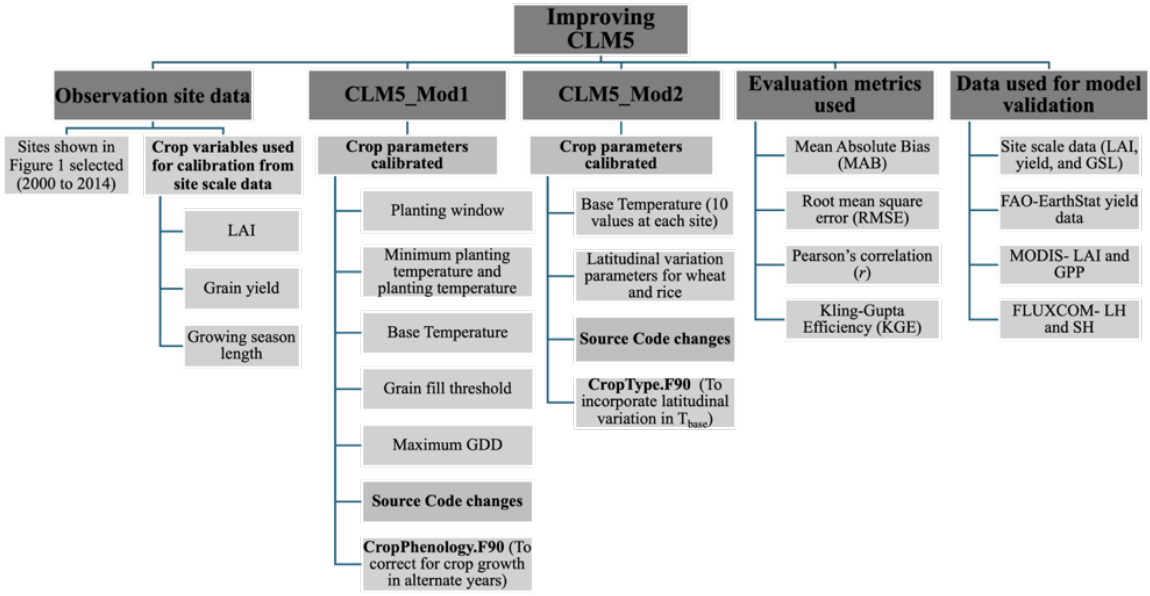

Figure S1: Flowchart showing the work flow of the CLM5 model development followed in this study.

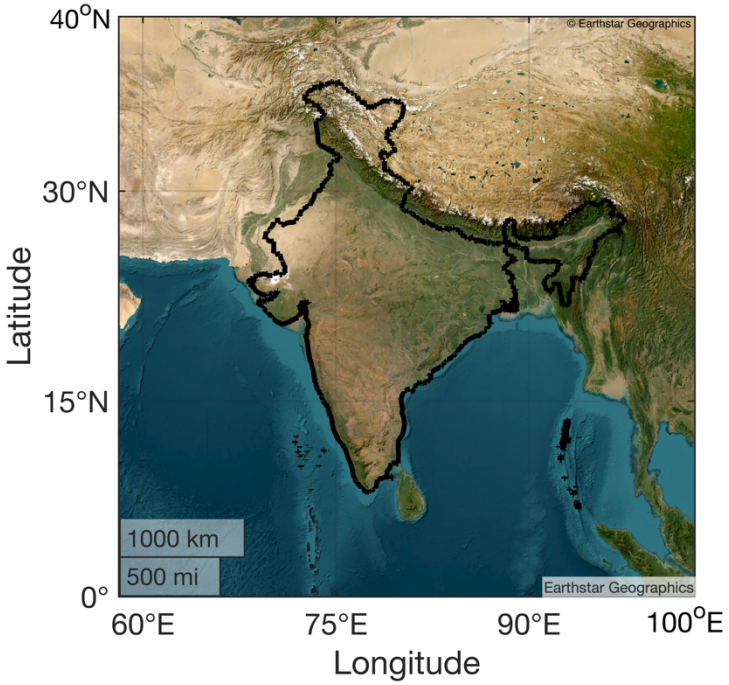

Figure S2: Domain used in simulations of CLM5 for regional experiments. © Earthstar Geographics.

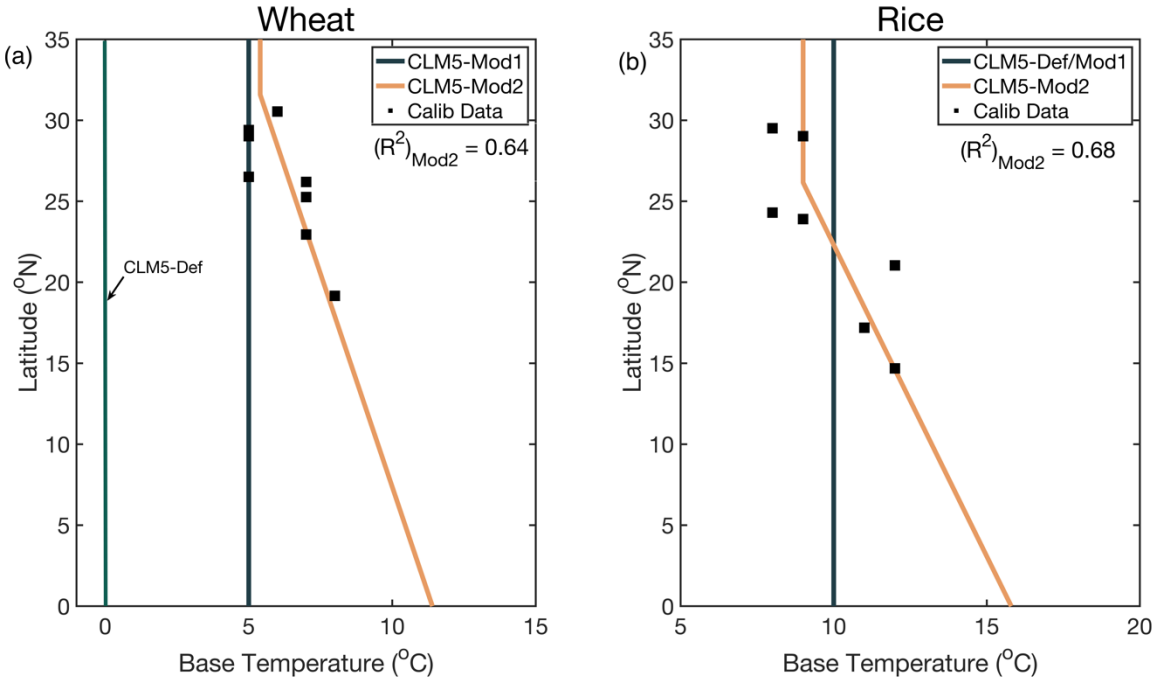

Figure S3: Latitudinal variation in base temperature calibration (a) Wheat, and (b) Rice

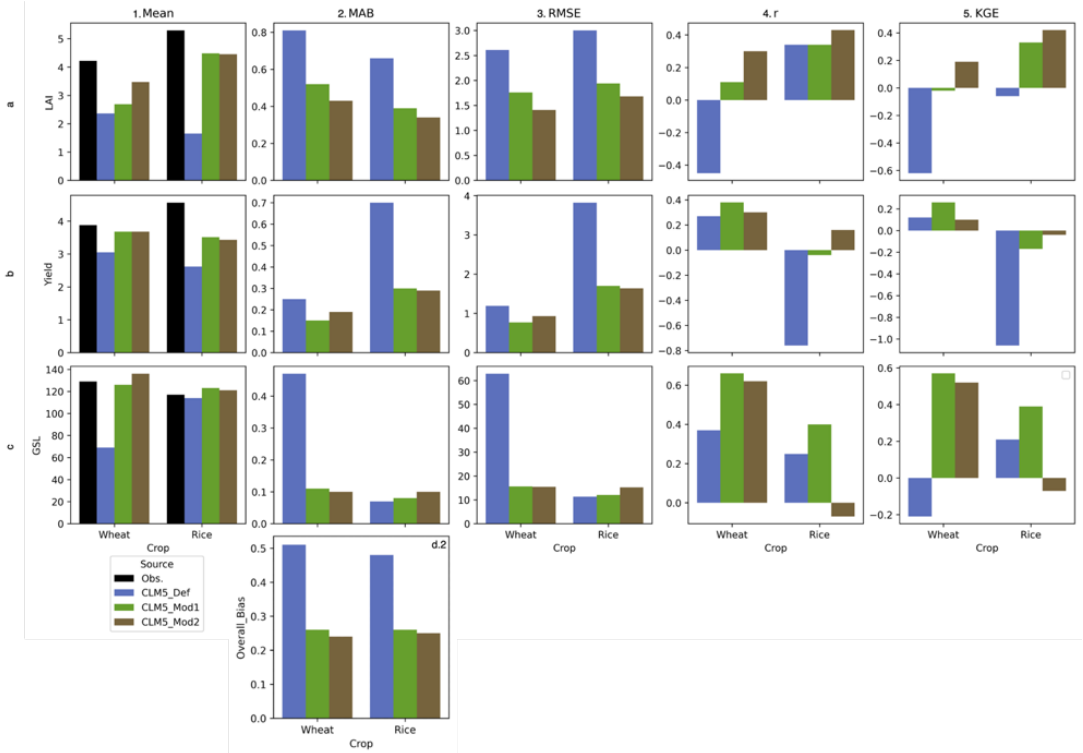

Figure S4: Bar plot of crop parameters (a) max. LAI, (b) Yield, and (c) growing season length and the evaluation metrics used in this study (1) Mean over all sites, (2) Mean Absolute Bias (MAB), (3) Root Mean Square Error (RMSE), (4) Pearsons r, and (5) Kling-Gupta Efficiency (KGE). The panel d.2 shows the overall bias of individual CLM5 model in simulating the crop parameters.

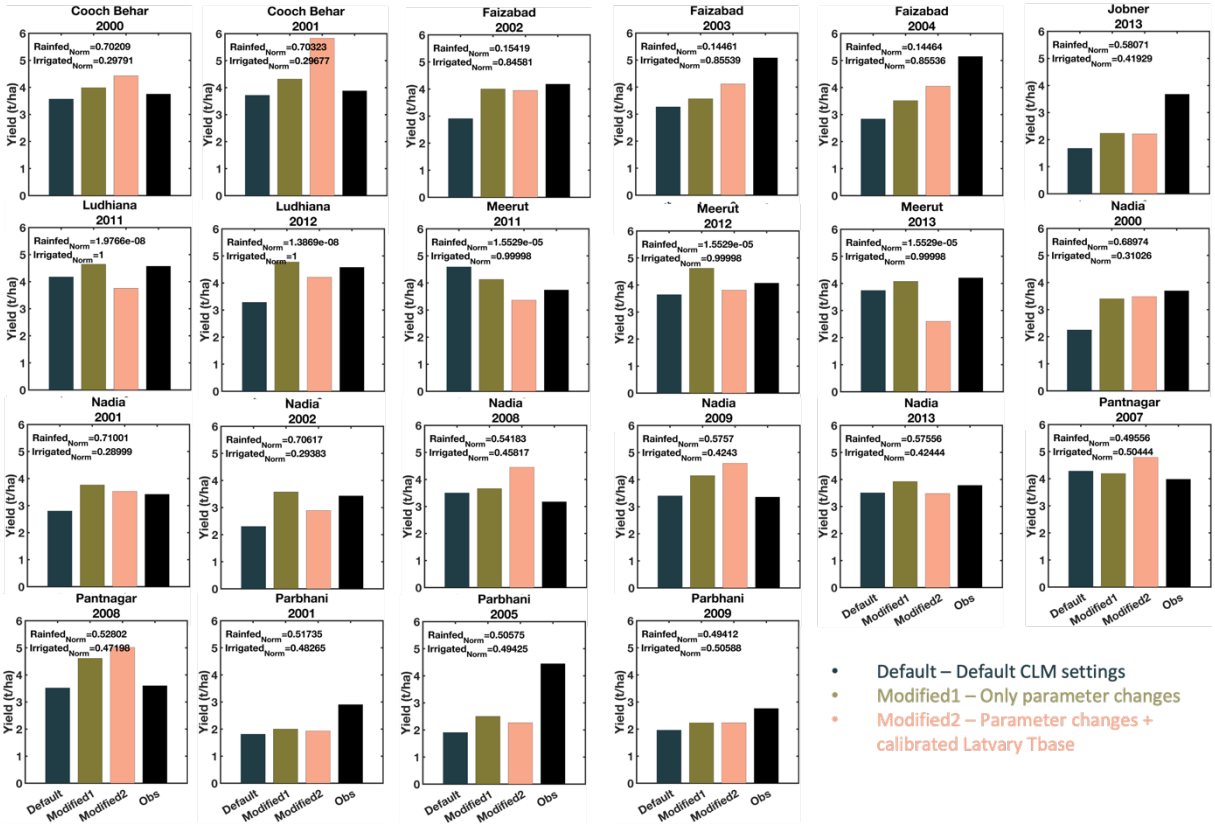

Figure S5: Comparing site scale yield of wheat simulated by CLM5 against the observations. Ranifed$_{Norm}$ and Irrigated$_{Norm}$ are the normalized crop areas covered at the site in CLM5.

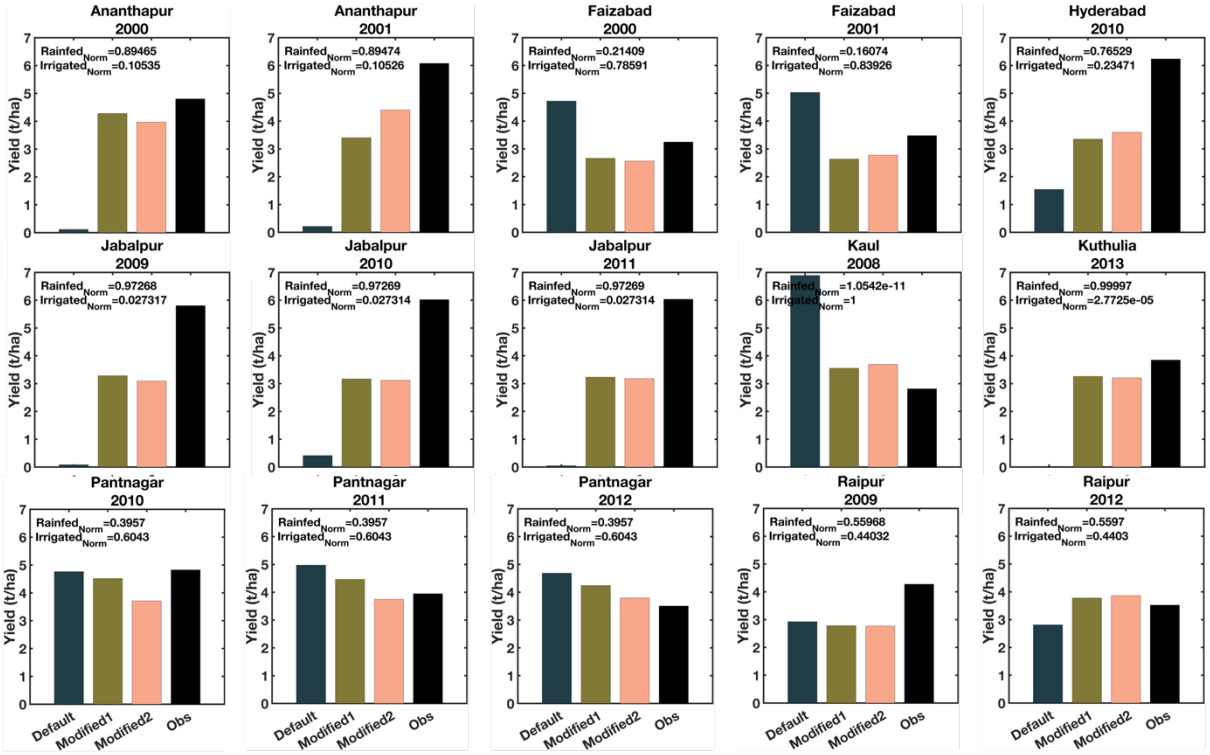

Figure S6: Comparing site scale yield of rice simulated by CLM5 against the observations. Ranifed$_{Norm}$ and Irrigated$_{Norm}$ are the normalized crop areas covered at the site in CLM5.

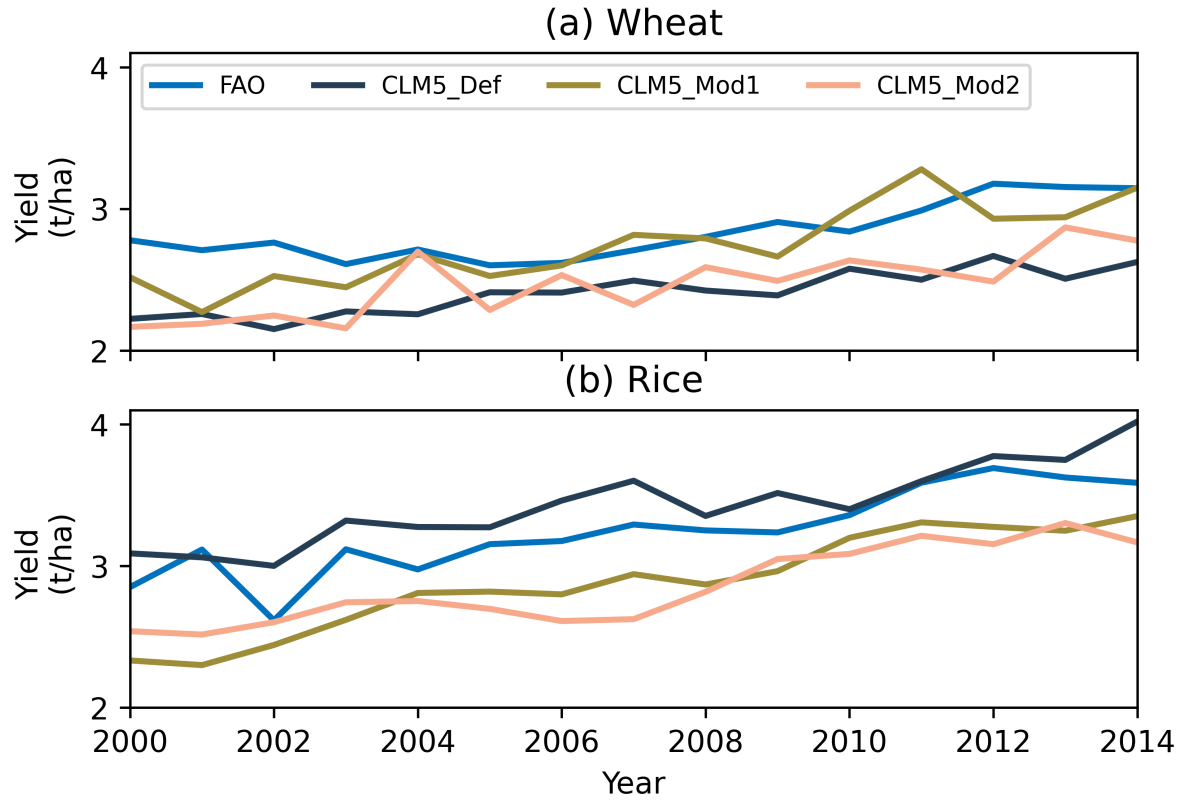

Figure S7: Comparing the total yield of (a) Wheat and (b) Rice against the FAO data from 2000 to 2014

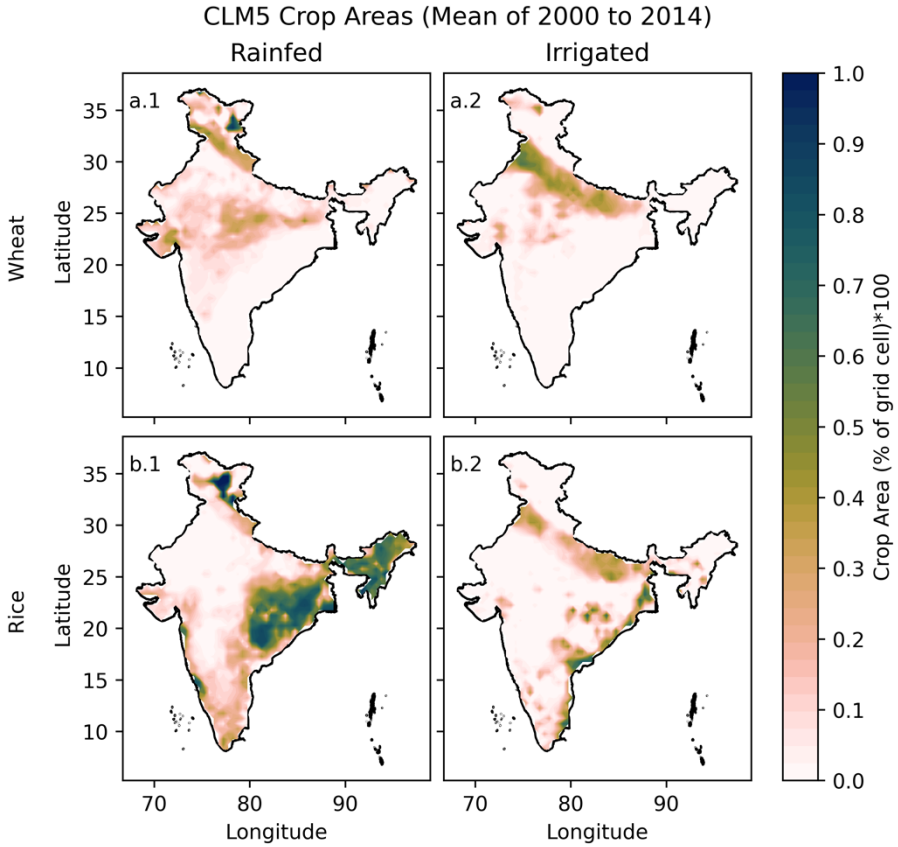

Figure S8: Crop areas of (a) wheat and (b) rice used in CLM5. The crops are further classified as (1) rainfed and (2) irrigated.

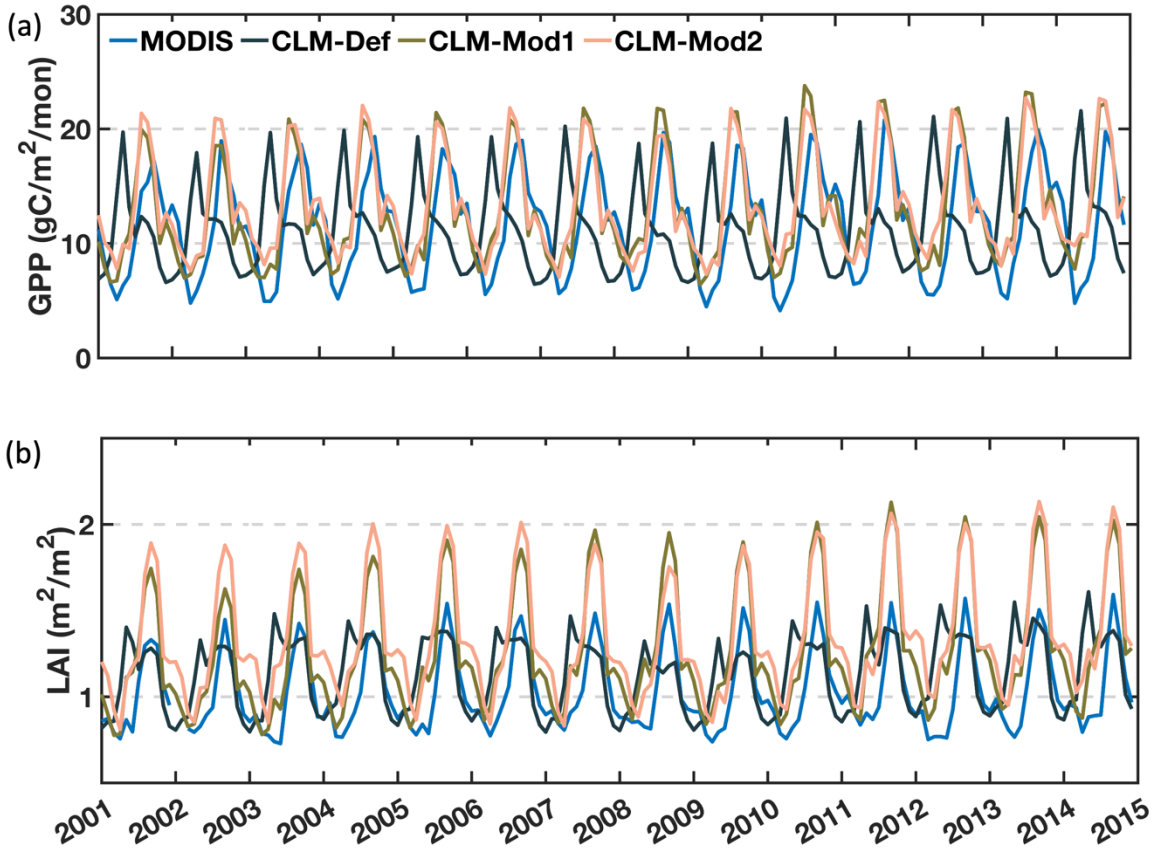

Figure S9: Comparison of MODIS (a) GPP and (b) LAI with CLM5 three setups over the period 2001 to 2014

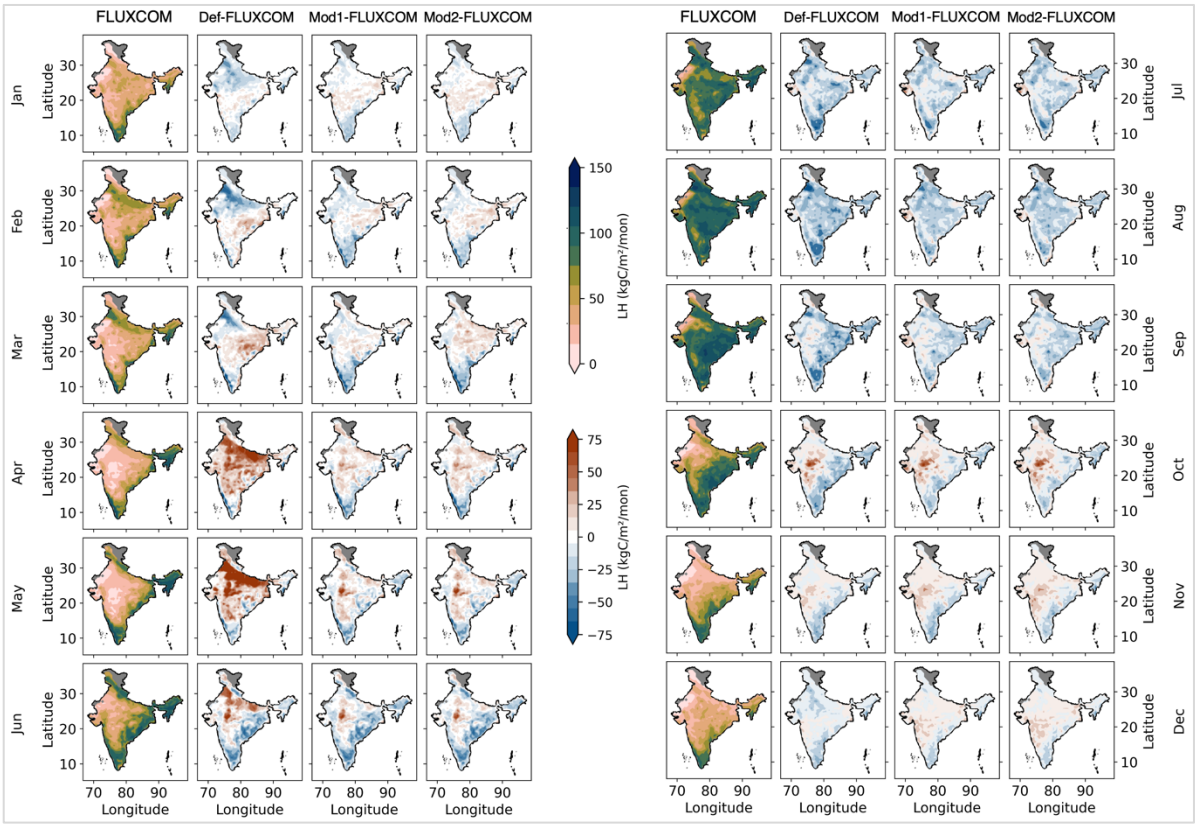

Figure S10: Comparison of FLUXCOM Latent Heat product against the three setups of CLM5. Data shown here is the monthly average taken over the period 2001 to 2014

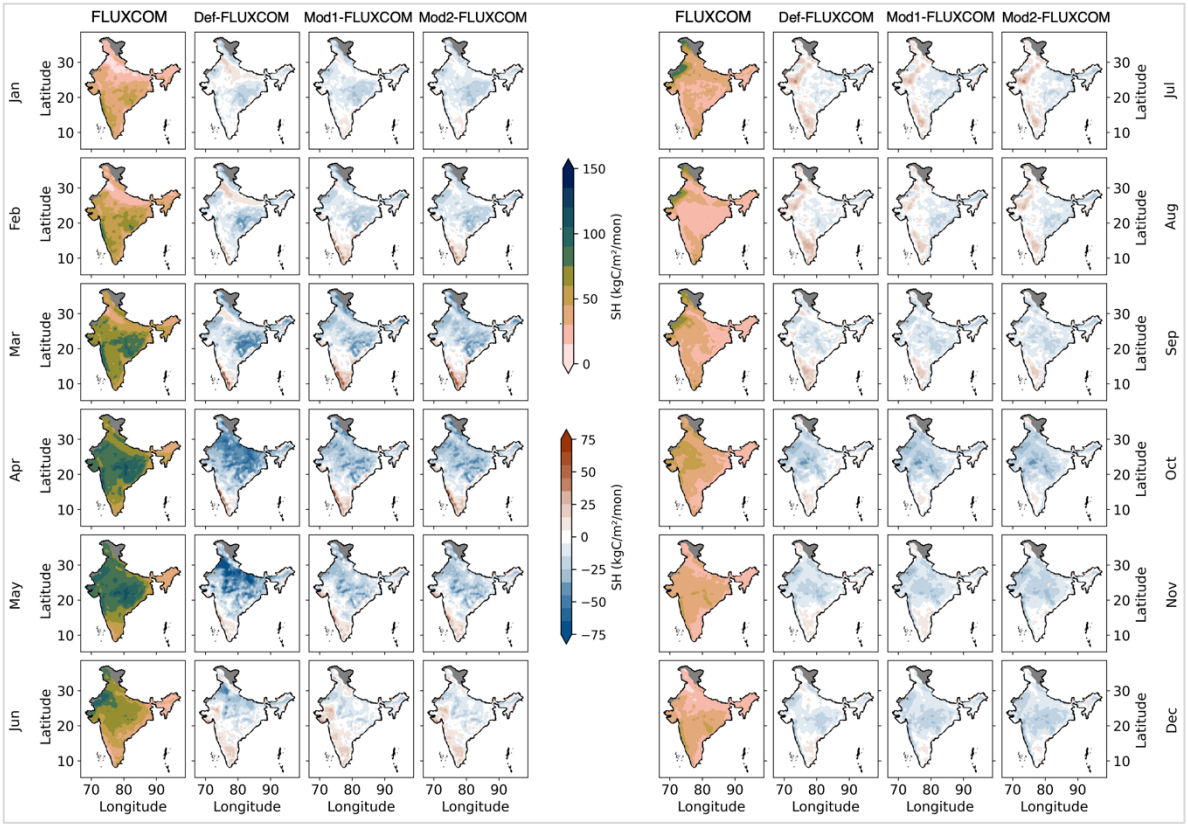

Figure S11: Comparison of FLUXCOM Sensible Heat product against the three setups of CLM5. Data shown here is the monthly average taken over the period 2001 to 2014

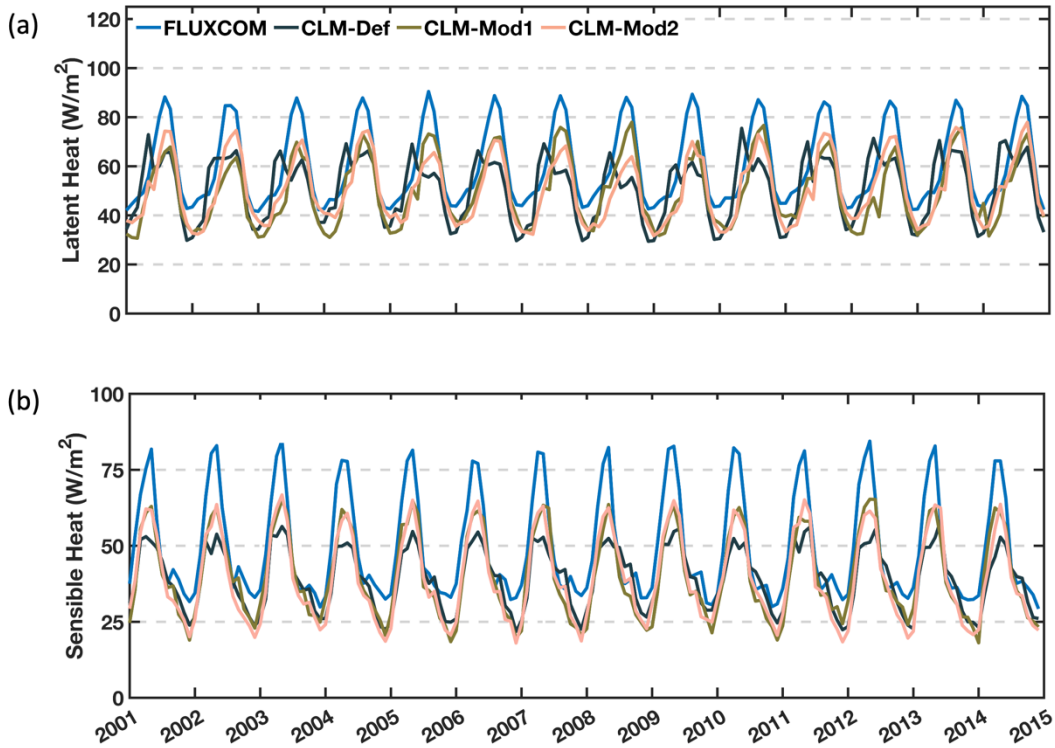

Figure S12: Comparison of (a) Latent Heat and (b) Sensible Heat from FLUXCOM against CLM5 three setups over the period 2001 to 2014.