vBG.7
EGU23-6395

Improving crop dynamics in CLM5 land surface model

(focusing on major Indian crops rice and wheat)

Authors:

K Narender Reddy*[1], Somnath Baidya Roy[1], Bimal K Bhattacharya[2], and G Venkateshwara Varma[1]

[1] Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi, 110016, India

[2] Space Applications Centre, Indian Space Research Organization, Ahmedabad, 380015, India

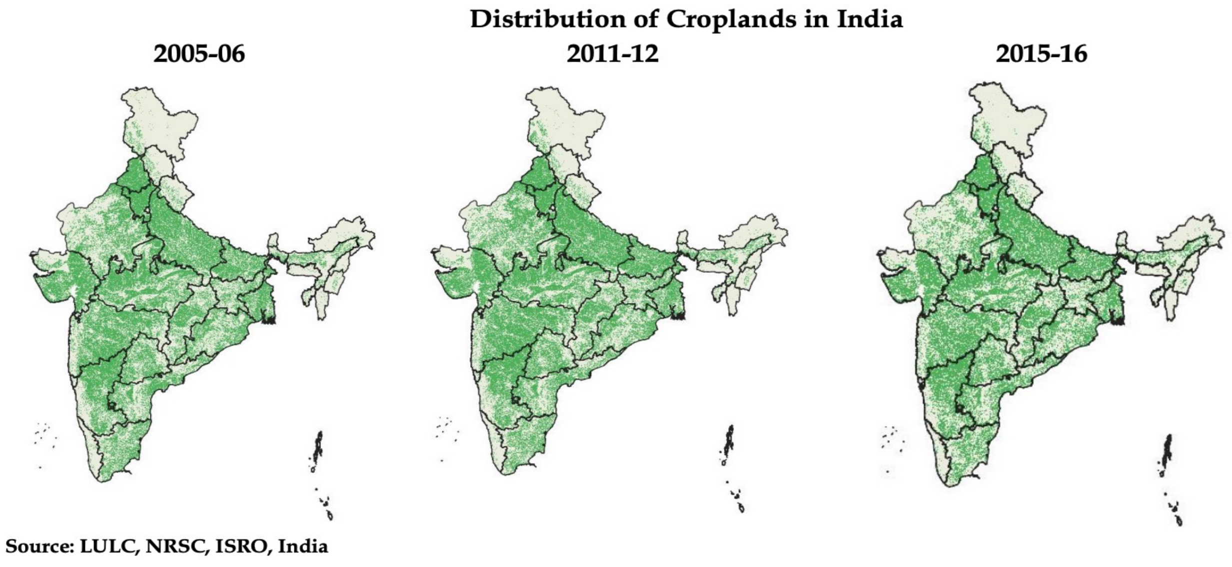
*Correspondence email: knreddy@cas.iitd.ac.in

Supplementary Material

This study is funded by the ISRO Geosphere Biosphere Program (IGBP)

S1: Importance of accurate representation of croplands

vBG.7
EGU23-6395



- Through both biogeochemical and biogeophysical routes, crops can affect local and global climate.
- Recent research has proved croplands as a factor in the increased seasonal amplitude of atmospheric CO_2 concentrations.
- Agricultural management practises, such as tillage harvest and fertilisation, can significantly increase net greenhouse gas emissions from agricultural areas even if crops absorb CO_2 more quickly during the growth season.

Crop management can also alter land surface biogeophysical characteristics, which affect climate.

- Irrigation and crop intensification increase latent heat, which cools the region and changes precipitation.
- Recent research suggests that managing crop albedo, which is higher than forest ecosystems but lower than perennial grasses, could reduce crop climate impacts by modifying land surface energy.
- Tillage, crop residue management, and cover cropping can also modify biogeophysical characteristics of croplands by changing soil moisture retention, albedo, and regional temperatures.

Although crops are an important part of the land surface, the representation of Indian crops has major issues in CLM5.

- Even though crop phenology can differ significantly from that of natural grasslands, many land models often depict crops as grasses or, if expressly included, are depicted simplistically (e.g., without management like irrigation or fertiliser application; McPherson et al., 2004).
- Numerous land components of ESMs have recently obtained the ability to represent crops due to the significance of agricultural practises on carbon, water, and energy fluxes (McDermid et al., 2017). These studies have found that crops enhance simulated carbon and water fluxes.

S2: Gaps in the literature

vBG.7
EGU23-6395

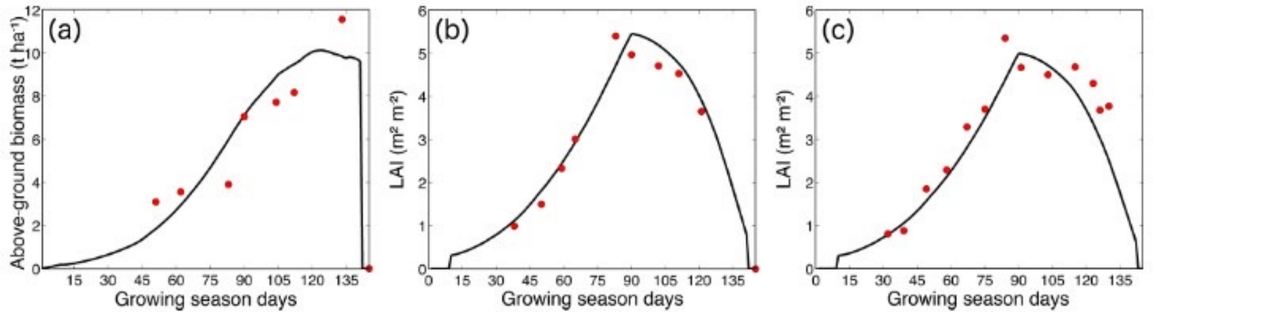


Figure : Model calibration and validation plots for the experimental wheat site at IARI, New Delhi. **(a)** Model calibration for above-ground biomass for the 2015–2016 growing season. **(b)** Model calibration for LAI for the 2015–2016 growing season. **(c)** The model-estimated LAI validated with site-measured data for the 2014–2015 growing season. The red dots are site-measured values and the black lines are ISAM-simulated values.

- To calibrate, and validate a spring wheat model field data on spring wheat growth is required. Such information is not frequently accessible in the public domain for Indian crops.
- Better data will also increase the simulations' fidelity. The absence of facts on irrigation water consumption is a major obstacle to simulating crop development at regional to global scales. **[Gahlot et al., 2020]**
- Due to the data limitation, ISAM land surface model calibration and validation was carried out at just one agricultural location.
- The current aims to bridge this gap by developing a dataset from various source which are not conventional and ready to use for model calibration.

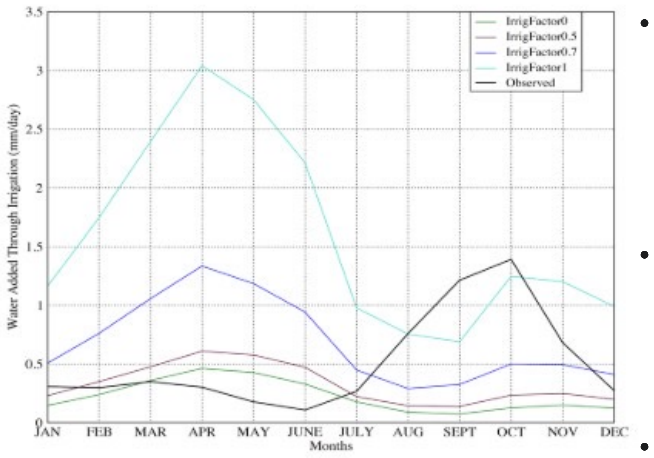
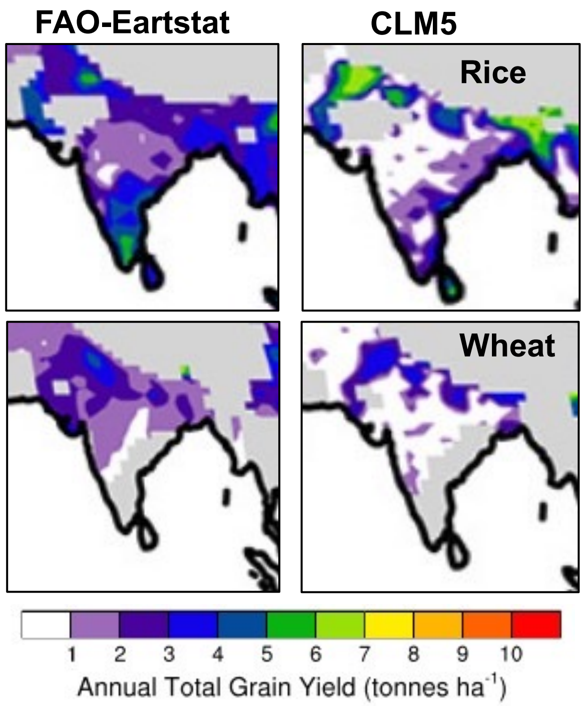


Fig: Annual cycle climatology of irrigation water added (mm/day) in the different irrigation factor experiments shown along with observed estimates used in Cook et al. (2015) based on the work of Wisser et al. (2010). The data is shown only for grid cells where greater than 20% PFTs (Supplementary Figure S13) are irrigated crop types predominantly in the Indo-Gangetic plain

[Mathur et al., 2020]

- The growing season of the major Indian crops, rice and wheat, is far from observations. E.g., spring wheat in India is grown between November and April but in CLM5 its grown between April to September.
- Due to this difference in growing season, irrigation pattern observed in CLM5 differs from observations and modelling studies like Biemans et al. (2016).
- The study by Mathur et al., (2020) simulates the irrigation in the Indian region during the monsoon period.



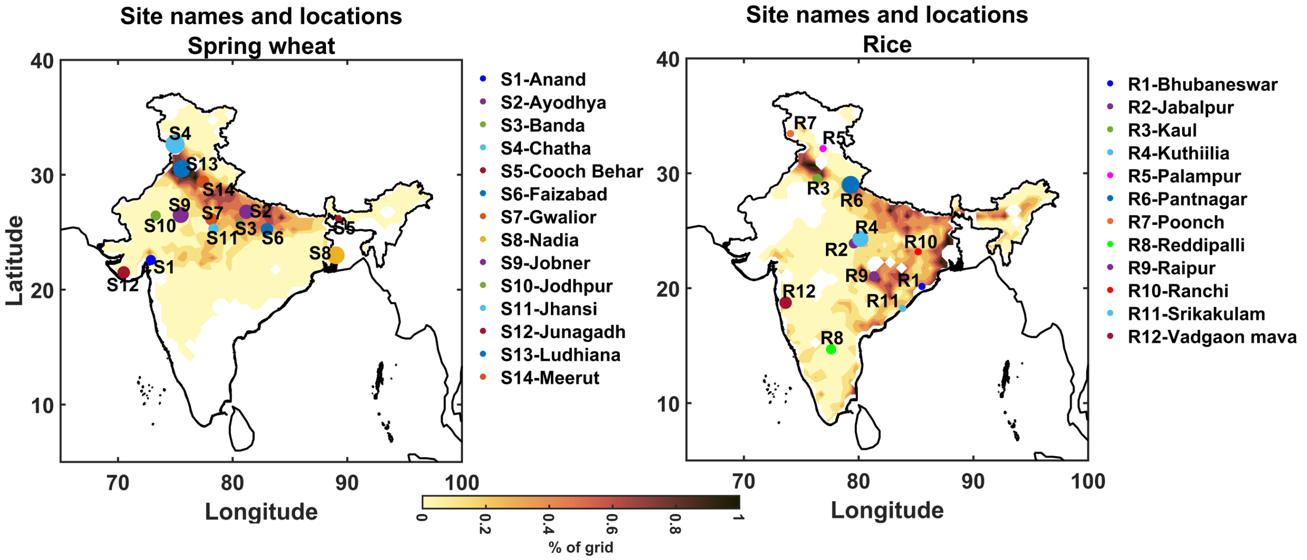
[Lombardozzi et al., 2020]

- CLM5 model simulations looking at yields from major crops found less yield values in case of rice and wheat for the Indian region.
- Crop yield inaccuracies can be caused by several factors, each of which will probably vary depending on the region and type of crop. One possible source of mistake is phenology, which is dependent on cumulative temperatures.

S3: Crop dataset from experimental agricultural site

vBG.7
EGU23-6395

- Site-scale observations of Indian crops are very rarely available for public access.
- As part of their curriculum, students at all of India's agricultural institutes conduct experiments on Indian crops and write theses reporting the results. The thesis from such institutes is uploaded to the Krishikosh repository (https://www.krishikosh.egranth.ac.in).
- To fill the gap of the absence of crop data on Indian crops, we started to look at this repository and collect data. The thesis provided us with crop phenology and agricultural management data for major Indian crops such as spring wheat and rice.
- In the current study, we have extracted the site scale experiment and results of rice and wheat crop. We have extracted rice crop from 12 sites. With some of the the sites containing data for more than one growing season, in total we have 26 growing seasons data. Similarly for wheat crop we have 14 sites and in total 38 growing seasons.
- The past modelling studies had one or two growing seasons of crop data from one experimental site. Through our efforts we have bridged the gap in creating the dataset required for modelers to calibrate and validate their models.



* Rice and Spring wheat crop harvested maps from FAO-EartStat

Crop Parameters extracted

Leaf Properties
- Leaf Area Index
- Leaves/hill
- Mean leaf area

Above ground biomass
- Total Dry Matter
- Shoot Dry Matter
- Stem dry matter
- Crop growth rate (g/m2/day)

Irrigation
- Irrigation requirement (mm)
- Crop water use efficiency (kg ha mm-1)
- water use efficiency (kg ha-1mm-1)
- Total evapotranspiration (mm)

Yield
- Grain Yield (q/ha)
- Harvest Index (%)
- 1000-Test Weight (g)
- 1000 Grain Weight (g)

Root parameters
- Total Root Length (cm)
- Root volume (cm3)

S4: Modifications made in the CLM5 model

vBG.7
EGU23-6395

1. Modifications made in CLM5 crop parameters

S. No	Parameter	Spring wheat		Rice	
		Default	Modified	Default	Modified
1	Min Planting Date (MMDD)	401	1115	101	601
2	Max Planting Date (MMDD)	615	1231	228	815
3	Tp (planting temp) K	280.15	290.15 (Asseng et al., 2016; Mukherjee et al., 2019)	294.15	300.15 (Jat et al., 2019)
4	Tp_{min} (min coldest planting temp)	272.15	283.15	283.15	294.15
5	GDD_{min} (°days)	50		50	
6	T_{base} base temperature for GDD (°C)	0	5 (Mukherjee et al., 2019;Mehta and Dhaliwal, 2023)	10	10
7	GDD_{mat} (°days)	<= 1700	<=1900	<= 2100	<=2200

Model simulations codes:-

- CLM5_D -> Default settings
- CLM5_M -> Min. and Max. Planting date changed, Tp, Tp_{min}
- CLM5_M2 -> CLM5_M + T_{base}, GDDmat

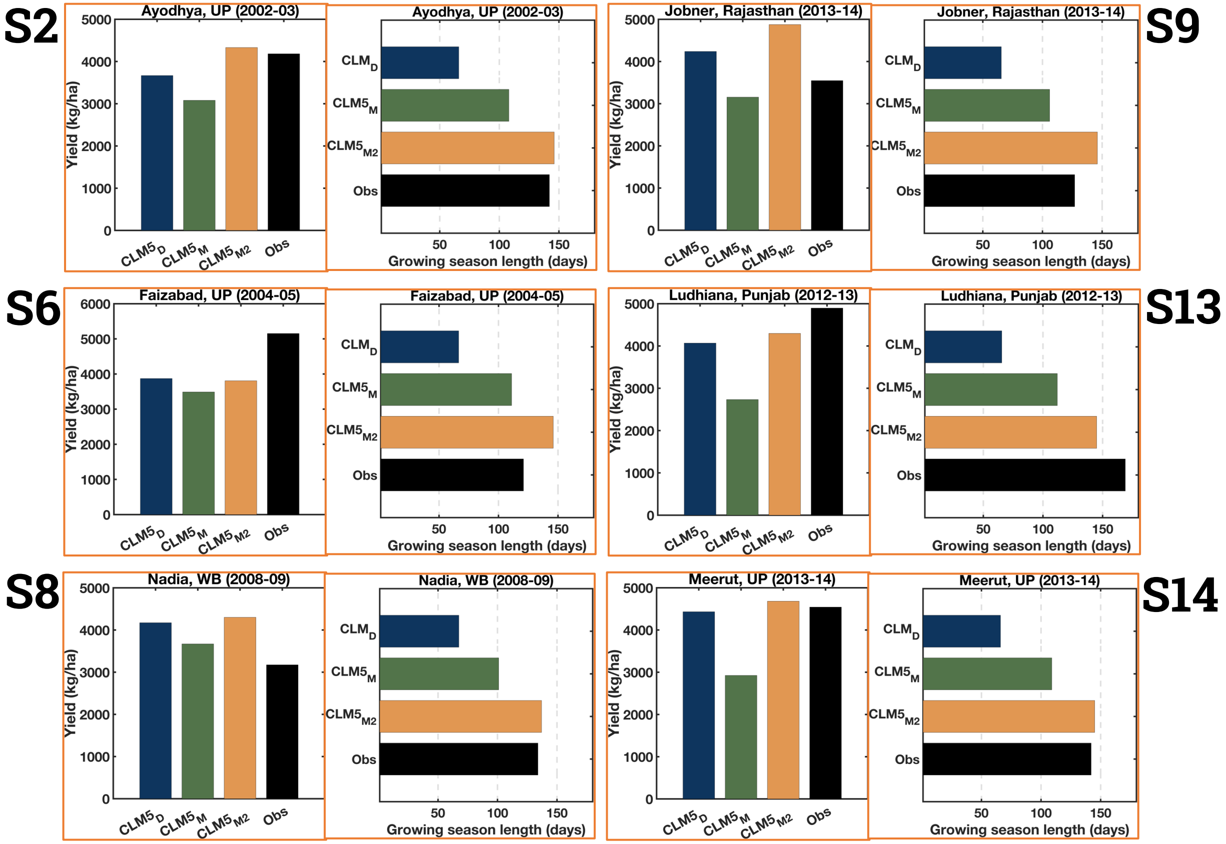
2. Modifications made in CLM5 code

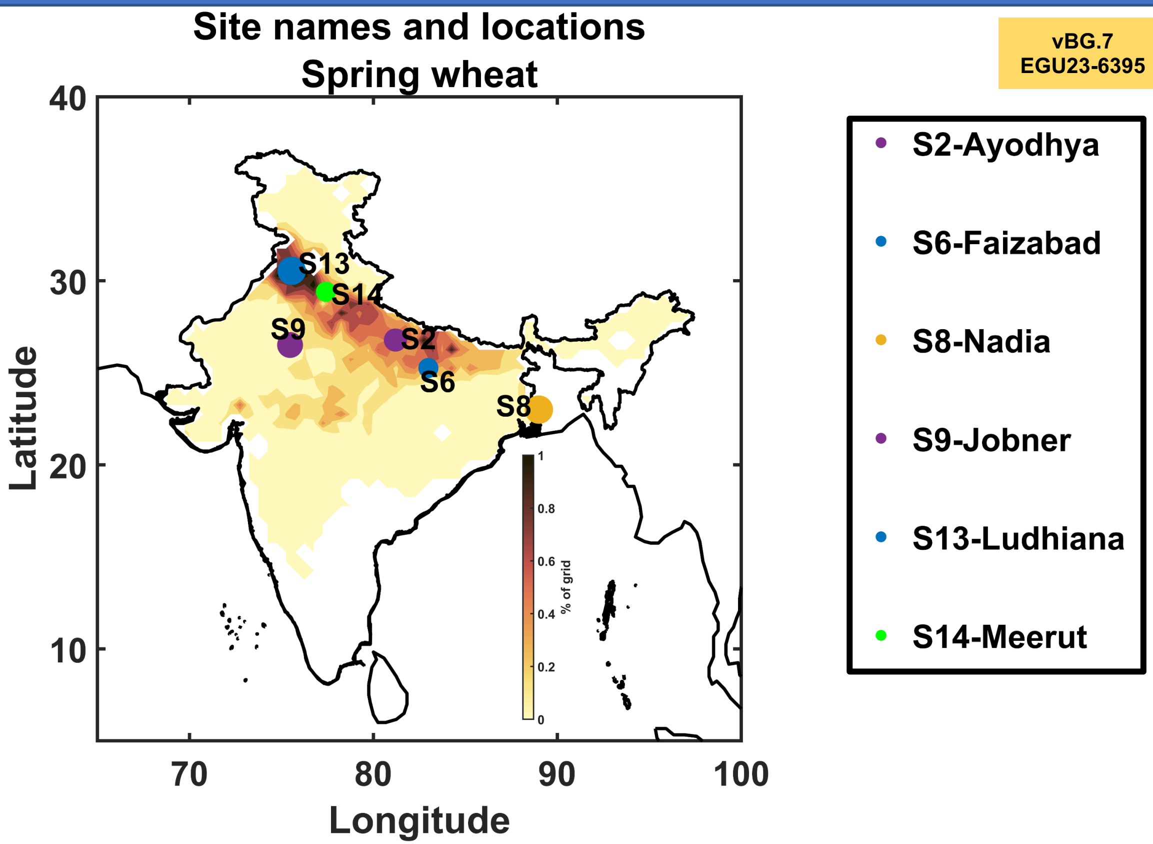
- In the default version of the CLM5, a crop is not allowed to be sow in a year once it is harvested. But when the wheat planting window was changed, wheat was harvested in April and had to be sown in November the same year.
- To facilitate the sowing of the crop in a year it was harvested we added the following changes to the code (changes suggested and supervised by Dr. Sam Rabin):

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!! Add_KNR !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!! If crop is growing in 2 calendar years, reset crop plant to sow again in the second calendar year
    if (cphase(p) == 4._r8) then                !!!! Enter the loop if crop phase is harvested
      if (idop(p) > jday) then                  !!!! Enters if crop is planted in the last calendar year
        cropplant(p) = .false.                  !!!! Sets crop to not planted in this calendar year
        idop(p) = NOT_PLANTED
      else
        cropplant(p) = .true.
      end if
    else
    end if
!!!!!!!!!!!!!!!!!!!!!!!!!!!!! END !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

S5(a): CLM5 yield and growing season length against observations – Spring Wheat

vBG.7
EGU23-6395

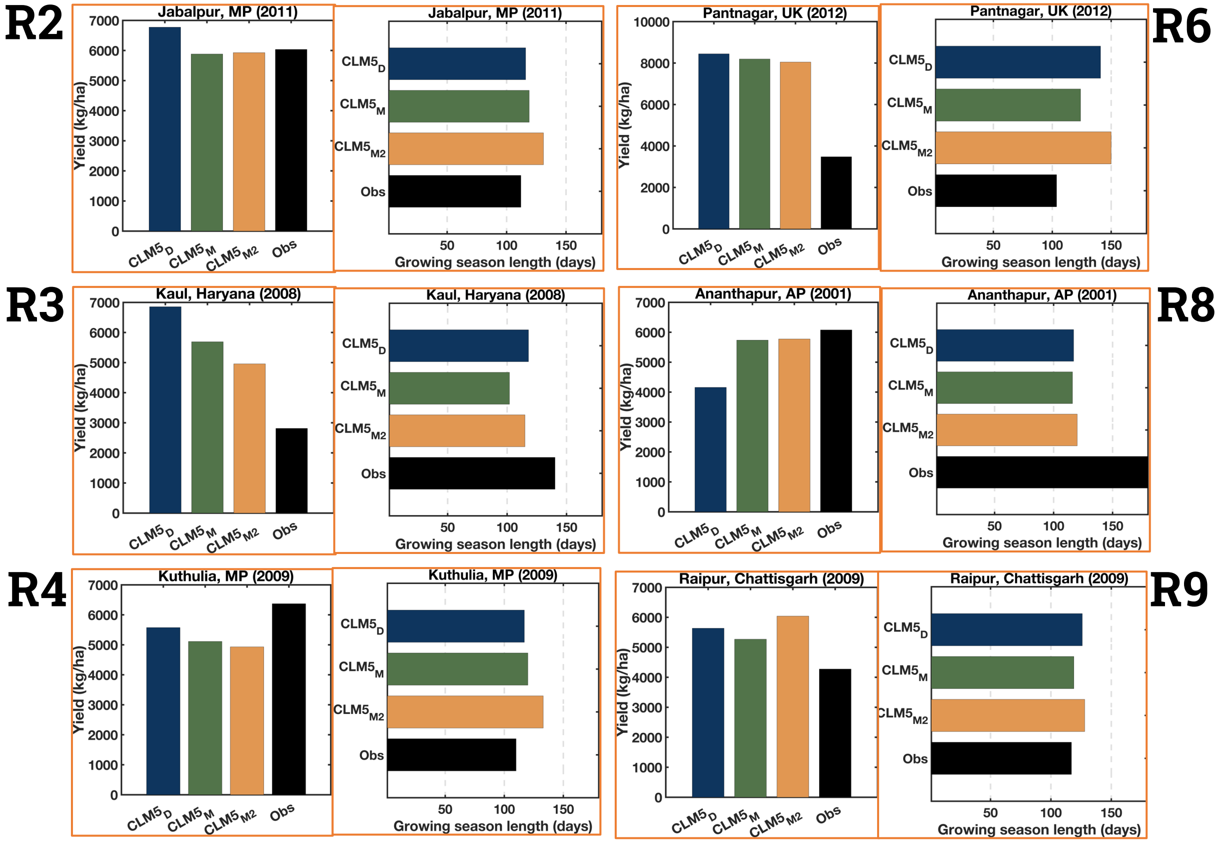


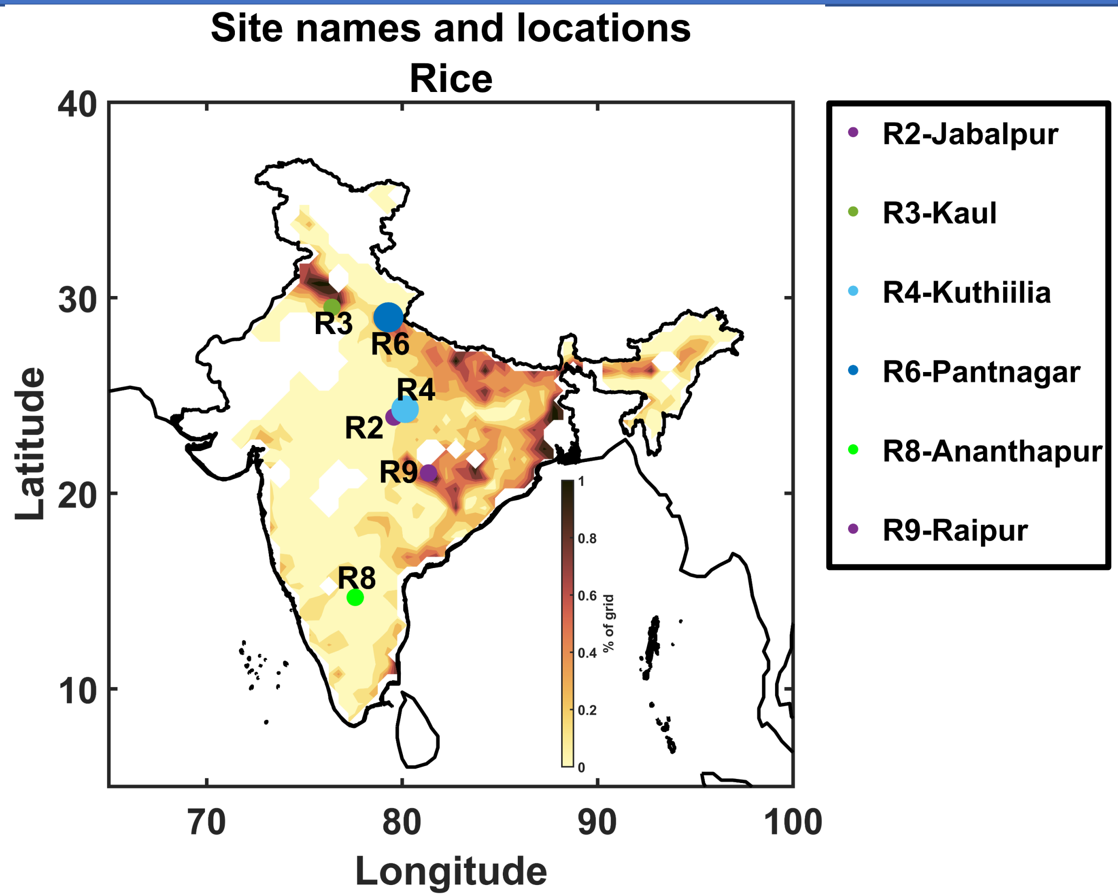


- In CLM5 harvest is assumed to occur as soon as the crop reaches maturity. When GDD_{T2m} reaches 100% of GDD_{mat} or the number of days past planting reaches a crop-specific maximum, then the crop is harvested.
- Base temperature is used to calculate GDD_{T2m}. In CLM5 spring wheat has the latitudinal variation of base temperature, which allows the spring wheat to grow reasonably good in all conditions, evident from the above figures. Growing season in warm environments like S8, or comparatively colder conditions S14 is well captured by CLM5.
- However, in S9 which is in similar latitude as S2, both growing season and yield are overestimated due to to the warmer and humid conditions in Rajasthan.

S5(b): CLM5 yield and growing season length against observations – Rice

vBG.7
EGU23-6395

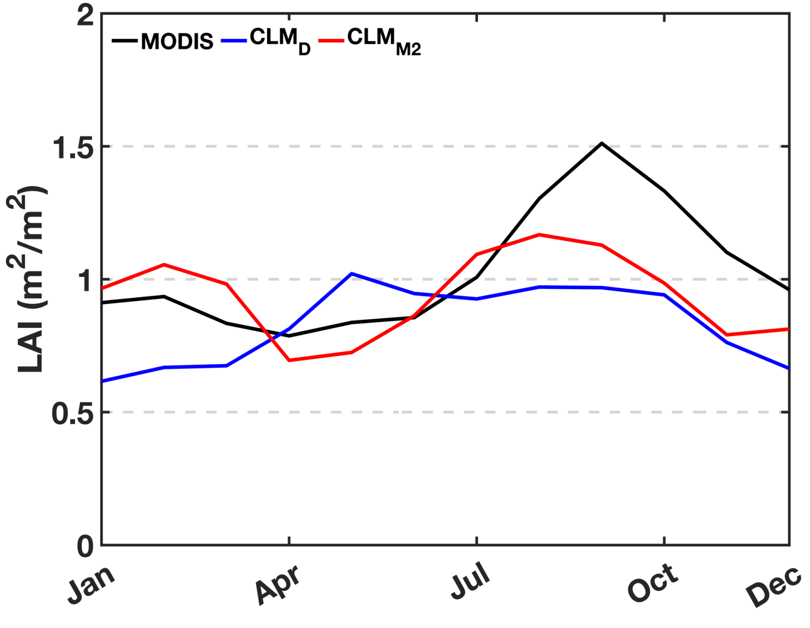


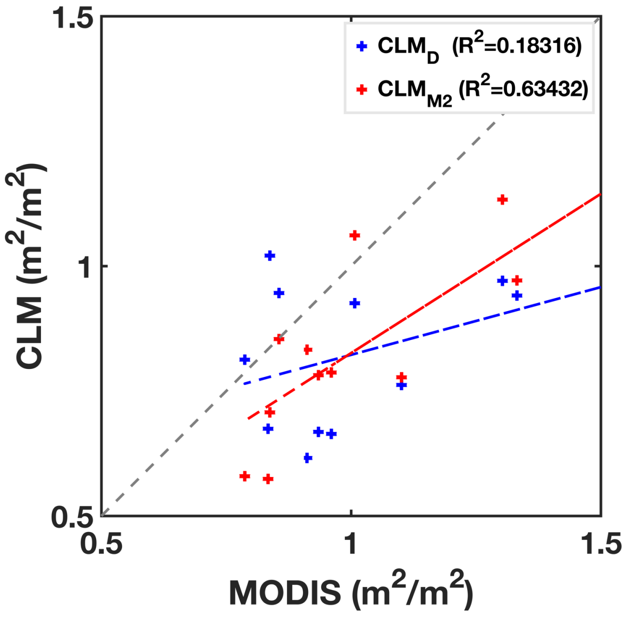


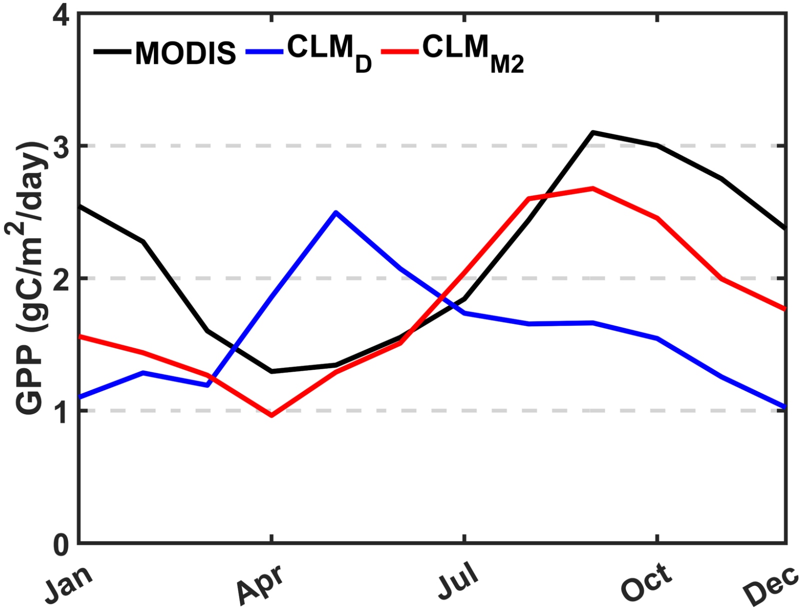
- Heat units accumulated by the crop is calculated using the base temperature. Rice crop does not have a latitudinal varying base temperature. Due to this the southern rice growing regions (warmer) and northern rice growing regions (colder) accumulate heat units above a constant base temperature. Therefore, causing longer growing season and higher yields in colder northern rice growing regions.
- One way to resolve this issue is to implement a latitudinal variation in base temperature like spring wheat.

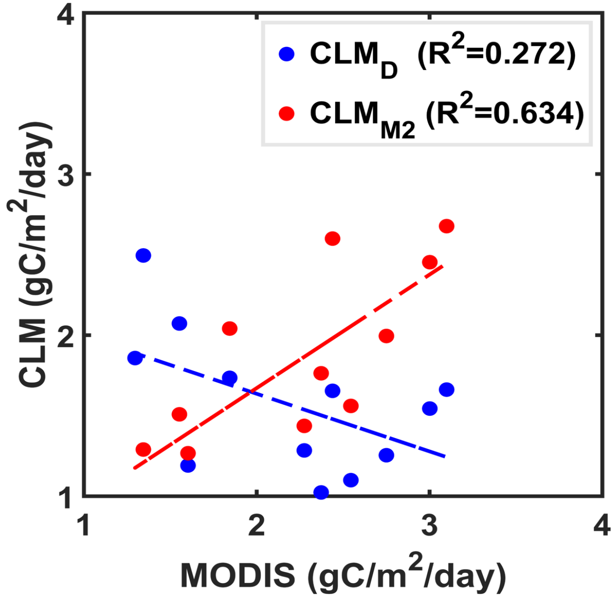
S5(c): CLM5 comparison with MODIS (LAI and GPP)

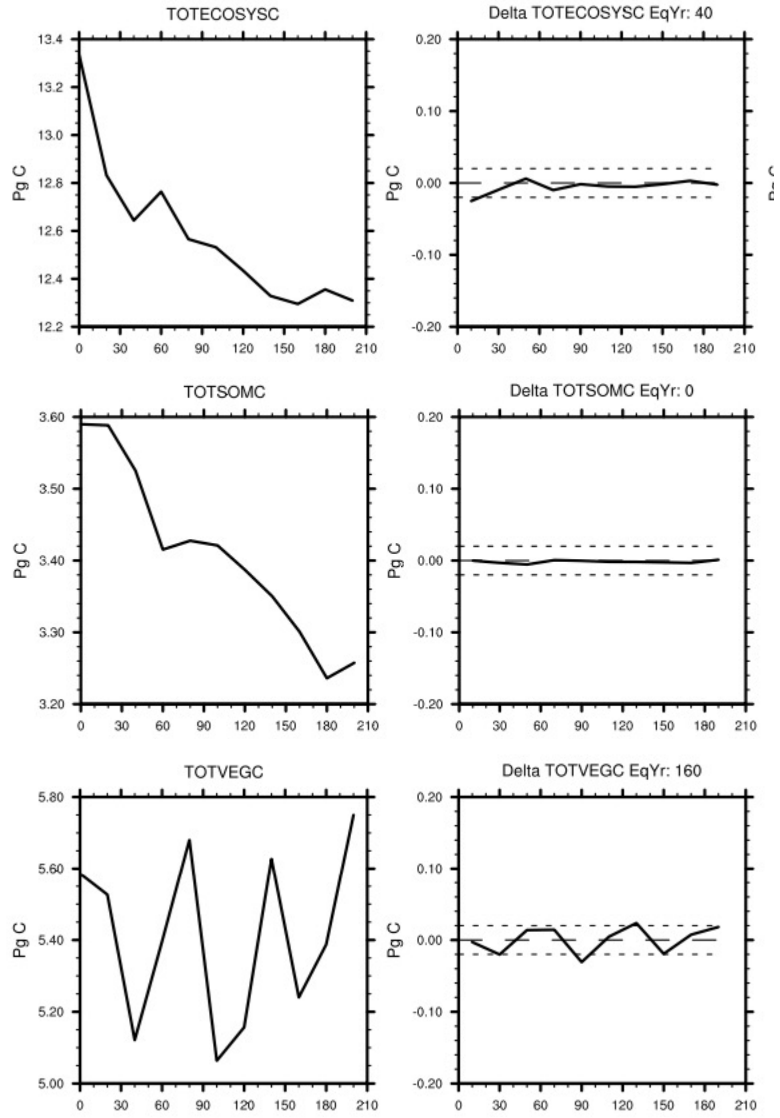
vBG.7
EGU23-6395







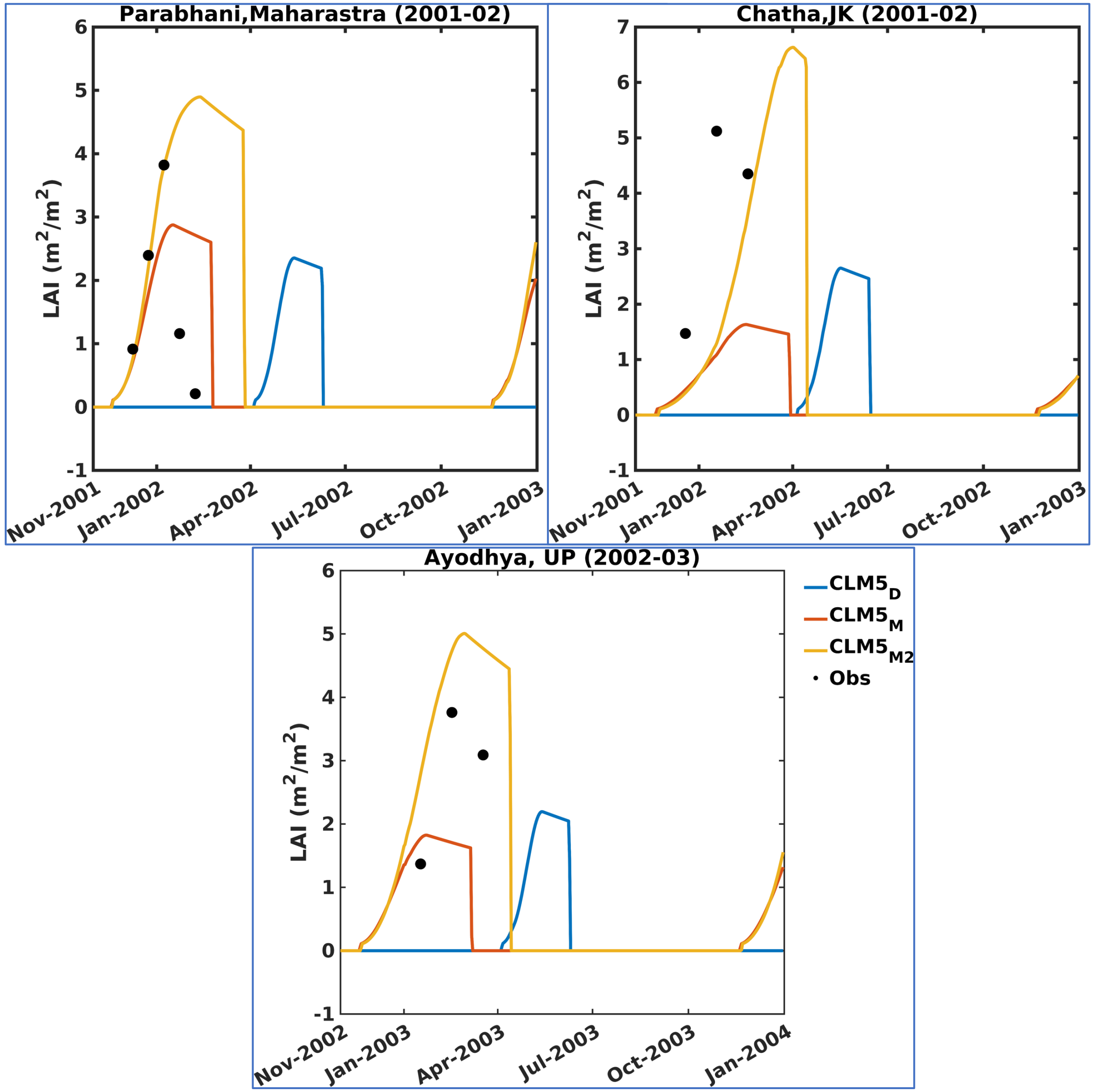




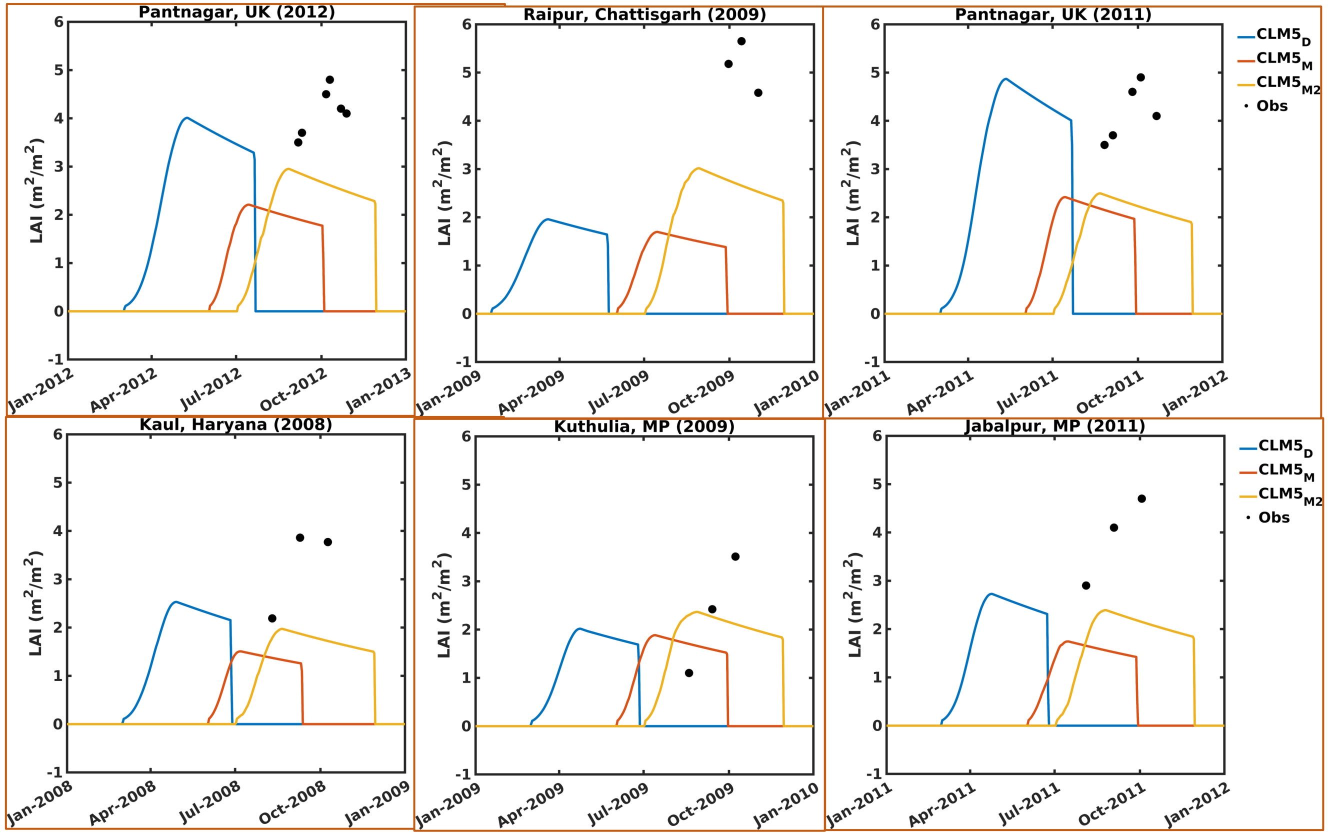
CLM5 AD-spinup results

S5(c): CLM5 LAI against observations – spring wheat and rice

vBG.7
EGU23-6395



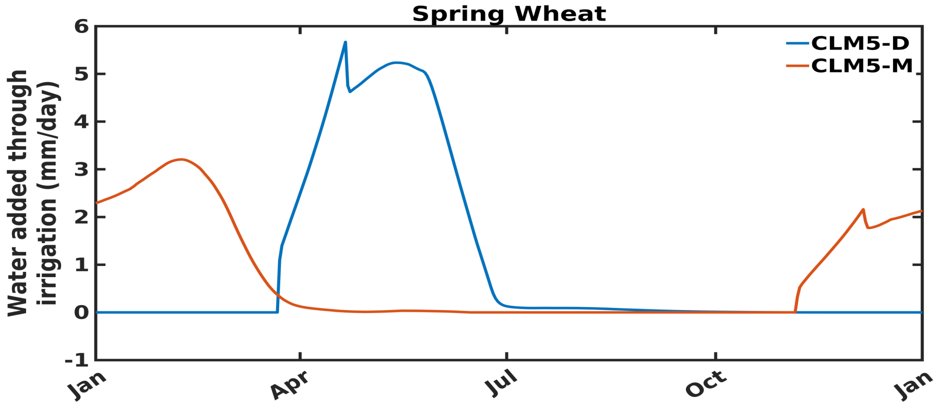
spring wheat

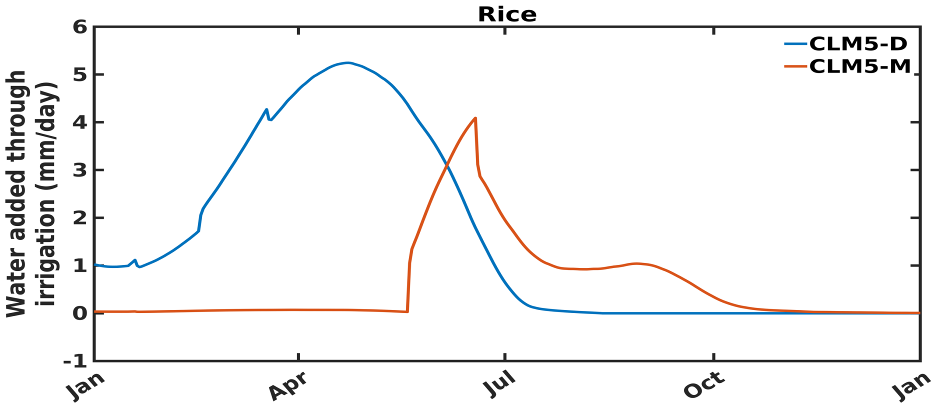


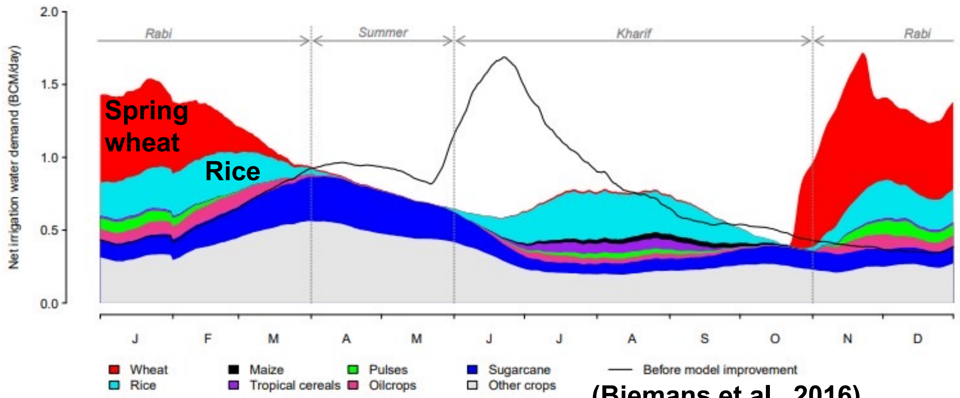
rice

S5(d): CLM5 irrigation

vBG.7
EGU23-6395

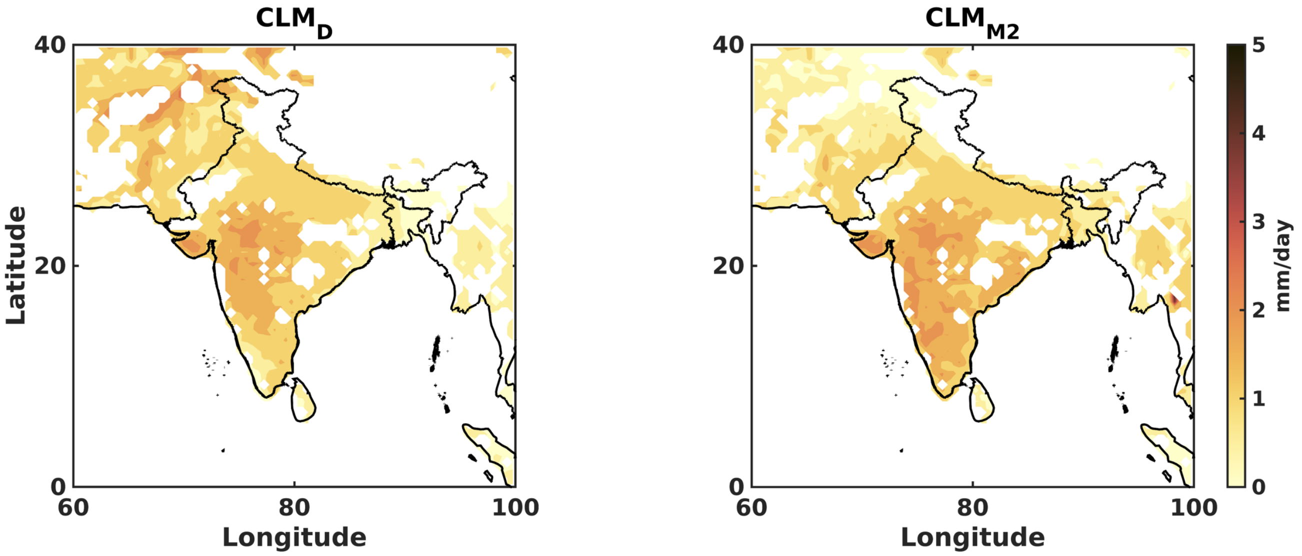




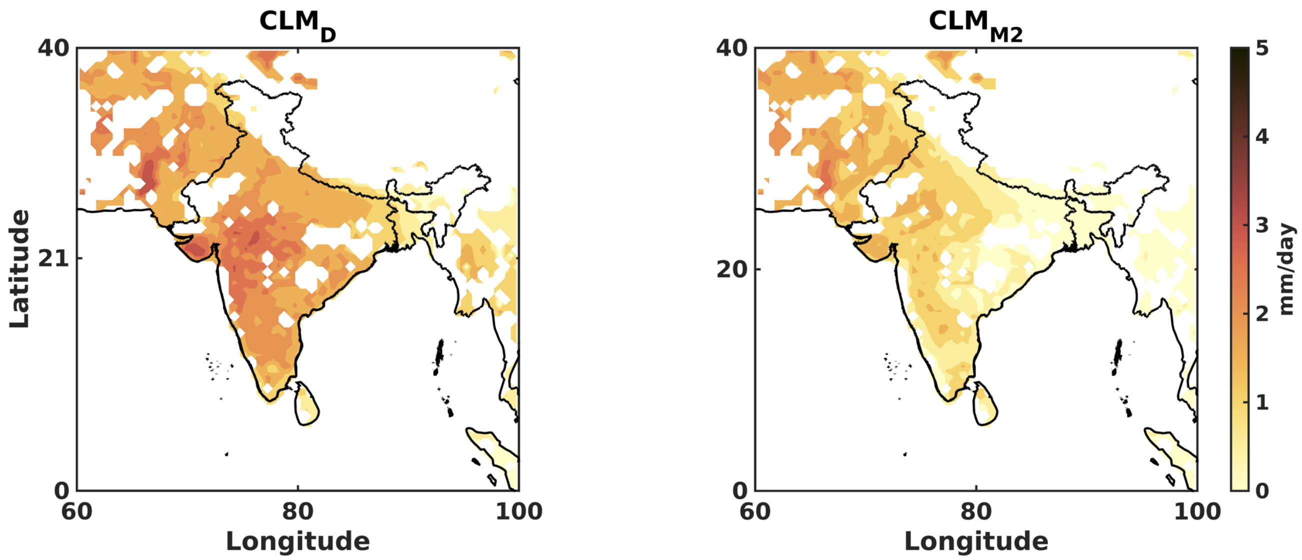


(Biemans et al., 2016)

Annual mean of water added through irrigation in Spring wheat



Annual mean of water added through irrigation in Rice



Acknowledgement and References

vBG.7
EGU23-6395

Acknowledgement:

- The funding for this work comes from SAC, ISRO through the ISRO-Geosphere-Biosphere Programme. All the model simulation work was carried out on the HPC resources at IIT Delhi.
- The development of the CLM5 crop model is an ambitious endeavor, and without the assistance of the land model working group on the cesm forum, we would not have made it to this point. Thank you very much to Sam Rabin, Peter Lawrence, and Danica Lombardozzi for taking the time to assess our work and offer some incredibly insightful suggestions.

References:

- Mathur, R., & AchutaRao, K. (2020). A modelling exploration of the sensitivity of the India's climate to irrigation. Climate Dynamics, 54(3–4), 1851–1872. https://doi.org/10.1007/S00382-019-05090-8
- Lombardozzi, D. L., Lu, Y., Lawrence, P. J., Lawrence, D. M., Swenson, S., Oleson, K. W., … Ainsworth, E. A. (2020). Simulating Agriculture in the Community Land Model Version 5. Journal of Geophysical Research: Biogeosciences, 125(8), e2019JG005529. https://doi.org/10.1029/2019JG005529
- Gahlot, S., Lin, T. S., Jain, A. K., Baidya Roy, S., Sehgal, V. K., & Dhakar, R. (2020). Impact of environmental changes and land management practices on wheat production in India. Earth System Dynamics, 11(3), 641–652. https://doi.org/10.5194/esd-11-641-2020
- Matthews R.B., Kropff M.J., Bachelet D., Horie T., Lee M.H., Centeno H.G.S., Shin J.C., Mohandass S., Singh S. & Defeng Z. (1995) Modeling the impact of climate change on rice production in Asia. In Climate Change and Rice (eds R.B. Matthew,M.J. Kropff,D. Bachelet & H.H. van Laar), pp. 314–325.CAB International, Wallingford, UK.
- Veeranjaneyulu, K. (2014), "KrishiKosh: an institutional repository of national agricultural research system in India", Library Management, Vol. 35 Nos 4/5, pp. 345-354, https://doi.org/10.1108/LM-08-2013-0083
- Asseng, S., Ewert, F., Martre, P., Rötter, R. P., Lobell, D. B., Cammarano, D., Kimball, B. A., Ottman, M., Wall, G., White, J., Reynolds, M., Alderman, P., Prasad, P., Aggarwal, P., An- othai, J., Basso, B., Biernath, C., Challinor, A., De Sanctis, G., Doltra, J., Fereres, E., Garcia-Vila, M., Gayler, S., Hoogen- boom, G., Hunt, L., Izaurralde, R., Jabloun, M., Jones, C., Kerse- baum, K., Koehler, A.-K., Müller, C., Naresh Kumar, S., Nen- del, C., O'Leary, G., Olesen, J., Palosuo, T., Priesack, E., Eyshi Rezaei, E., Ruane, A., Semenov, M., Shcherbak, I., Stöckle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Thorburn, P., Waha, K., Wang, E., Wallach, D., Wolf, J., Zhao, Z., and Zhu, Y.: Ris- ing temperatures reduce global wheat production, Nat. Clim. Change, 5, 143–147, 143, https://doi.org/10.1038/nclimate2470 , 2015
- Jat, R. K., Singh, R. G., Kumar, M., Jat, M. L., Parihar, C. M., Bijarniya, D., … Gupta, R. K. (2019). Ten years of conservation agriculture in a rice–maize rotation of Eastern Gangetic Plains of India: Yield trends, water productivity and economic profitability. Field Crops Research, 232, 1–10. https://doi.org/10.1016/J.FCR.2018.12.004
- Mehta, P., & Dhaliwal, L. K. (2023). Agromet wheat app for estimation of phenology and yield of wheat under Punjab conditions. International Journal of Biometeorology, 1, 1–7. https://doi.org/10.1007/S00484-022-02423-X/FIGURES/4
- Biemans, H., Siderius, C., Mishra, A., & Ahmad, B. (2016). Crop-specific seasonal estimates of irrigation-water demand in South Asia. Hydrology and Earth System Sciences, 20(5), 1971–1982. https://doi.org/10.5194/HESS-20-1971-2016
- Jones, J. W., Antle, J. M., Basso, B., Boote, K. J., Conant, R. T., Foster, I., … Wheeler, T. R. (2017). Brief history of agricultural systems modeling. Agricultural Systems, 155, 240–254. https://doi.org/10.1016/j.agsy.2016.05.014
- Long, S.P., Ainsworth, E.A., Leakey, A.D.B., Nösberger, J., Ort, D.R., 2006. Food for thought: lower-than-expected crop yield stimulation with rising CO2 concentrations. Science 312, 1918–1921.