India is drying out its terrestrial carbon: An inference by multi-model estimation of primary productivities

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November 30, 2022

Abstract

Terrestrial primary productivity plays a pivotal role as a forcing factor of atmospheric CO2 and drives biospheric carbon dynamics. India is one of the largest GHGs emitters, yet less is understood in carbon cycling in terrestrial ecosystems. Here we explored the trend and magnitude of gross and net productivities of India for the last two decades (2000 – 2019) by integrating satellite observation from MODIS, remote sensing-based CASA model and twenty DGVMs from the TRENDY ensemble. Preliminary results exhibited a unimodal response across the data products with an overall positive trend and a declining decadal trend for 2010 – 2019. Alongside, the SPEI drought severity index across various ecological zones indicated India was more positively sensitive to wet span than the dry. We found that the ecosystems were drastically shifting their nature to C source with a positive trend in the productivities and were mediated by the changing climate. The analysis also revealed the increasing decadal amplitude of GPP by 0.0884 ± 0.013 Pg C Year–1, NBP by 0.0096 ± 0.001 Pg C Year–1, NEP by 0.0195 ± 0.004 Pg C Year–1, NPP by 0.0448 ± 0.009 Pg C Year–1 and NEE by 0.0161 ± 0.004 Pg C Year–1. CASA underestimated the magnitudes but with the temporal synchronisation of the ensemble. Seasonal variability across the agro-ecological zones was more sensitive and was an offset for the declining productivities in the primaeval forests of India. The monsoon season contributed to the interannual variability of India. Higher uncertainty in productivities was observed in the high greening areas, whereas it contradicted for NBP by reflecting a stable trend. Our results underscore the nature of C variability in the terrestrial ecosystems of India; and, they indicate that C release has reacted stronger than the C uptake, which was substantially inferred from NEE across the ecological zones.

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"INDIA IS DRYING OUT ITS TERRESTRIAL CARBON"

AN INFERENCE BY MULTI-MODEL ESTIMATION OF PRIMARY PRODUCTIVITIES

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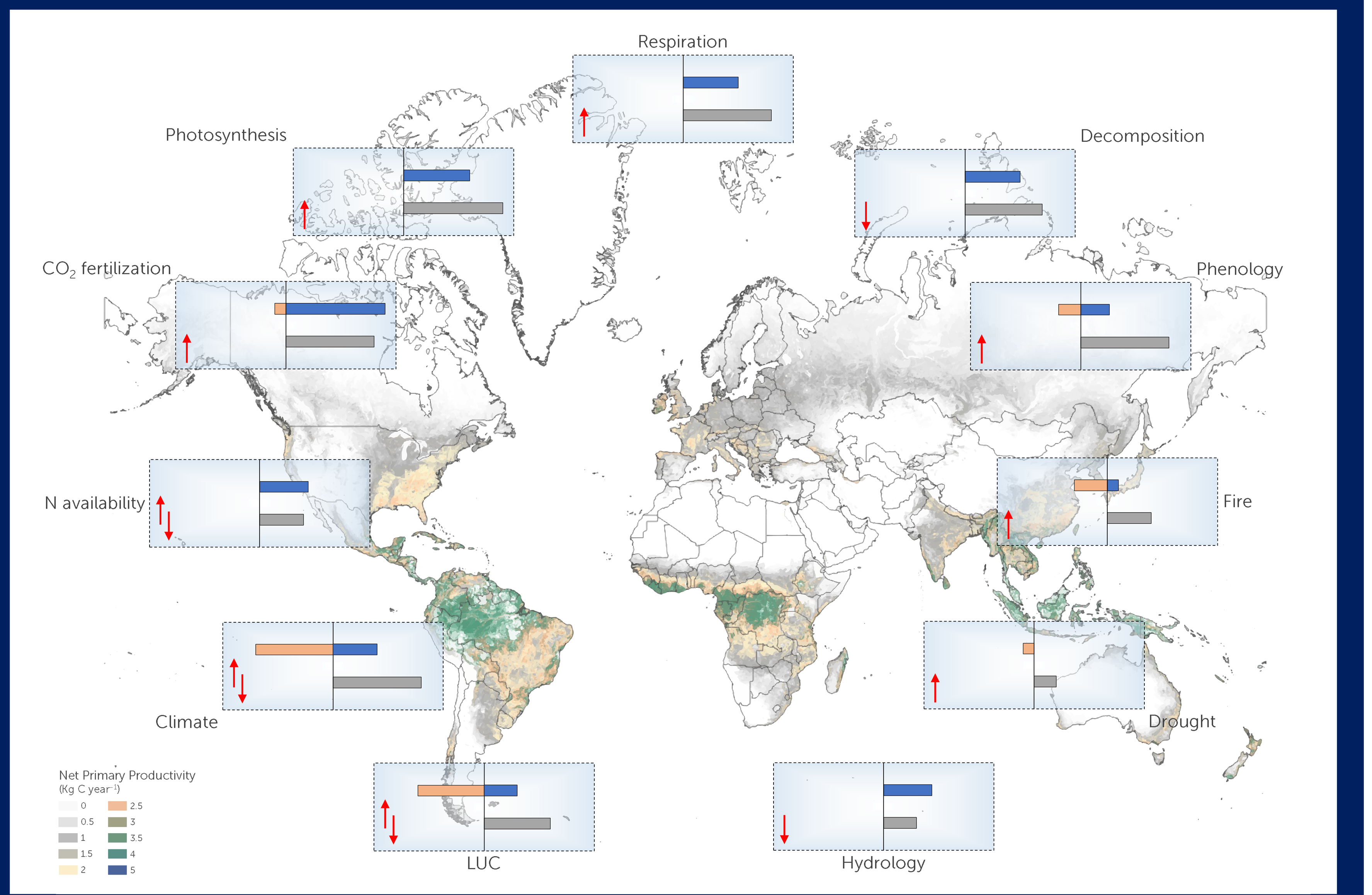

HIGHLIGHTS

Understanding India's multi-ecosystem variability of C sink and source by quantifying the ecosystem productivities using CASA, MODIS and TRENDY

Agroecological zones were seasonal sensitive and offset the reducing productivities in the tropical forest zones, with monsoon and pre-monsoon being the significant seasonal turners

NEE trend reveals that India is recasting as C source with a decadal magnitude of 0.0161 Pg C year^{-1}, with most of the ecosystems are reshaping their potential in C uptake

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BACKGROUND | METHODS

TRENDYv9 DVGMs were used to understand the dynamics of the primary productivities and the base C fluxes of **India**

*S3 with dynamic CO_2, Climate and LUC from **2000 – 2019** was resample to 0.5° and used, for spatial and temporal consistency with other data products*

Carnegie Ames Stanford Approach **(CASA)** model sub-structured by **APAR** and **LUE** was used to model **NPP**, **GPP** and **NEP**

$$NPP\ (x,t) = APAR\ (x,t) \times \varepsilon\ (x,t)$$

$$GPP\ (x,t) = NPP\ (x,t) \div 0.58$$

$$NEP\ (x,t) = NPP\ (x,t) \div R_S\ (x,t)$$

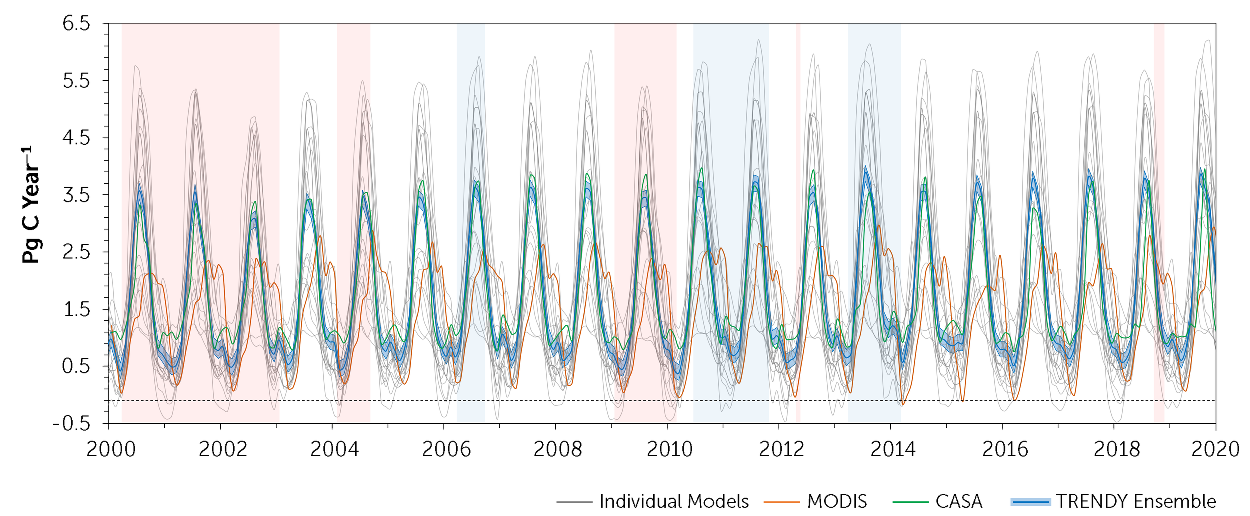
MODIS primary productivity products was synthesised from 2000 – 2009

*Various MODIS **VIs** were used for the development of **CASA**, where the results were examined with the **TRENDY** ensemble as a **proxy***

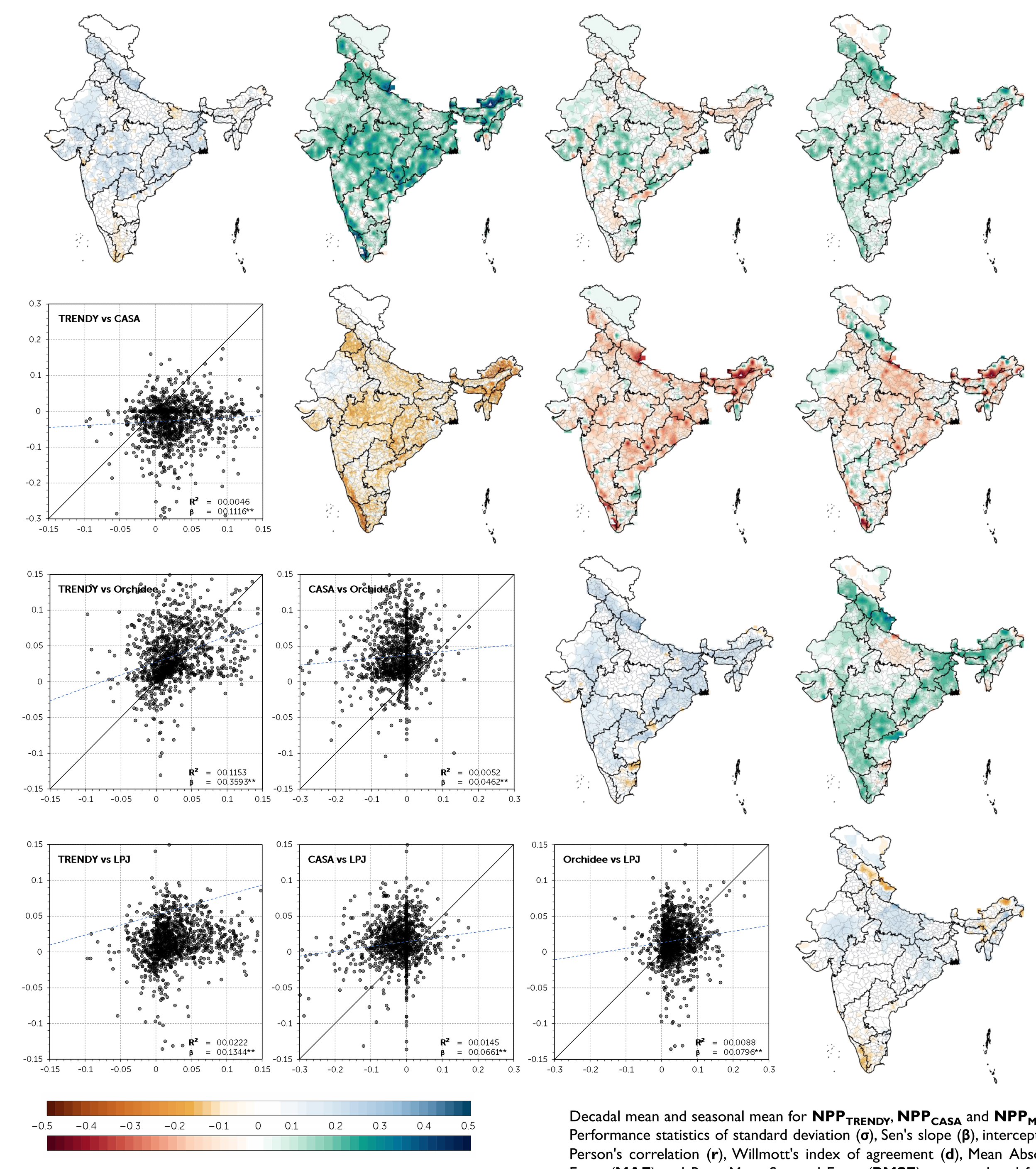
Standardised Precipitation Evapotranspiration Index **($SPEI_{12}$)** with twelve months timescale was incorporated to analyze the **annual drought stress**

*Threshold for **drier** (< **–0.42**) and **wetter** (> **0.39**) conditions from $SPEI_{12}$ were analyzed*

Timeseries for spatially aggregated **NPP** estimations over the study period. The shaded region represents the confidence interval of the **TRENDY ensemble** over the aggregated pixels. The vertical shaded period represents the level of dryness condition for the regional aggregated $SPEI_{12}$ with the threshold: **blue > 0.39** and **red < –0.42**



Comparison of NPP_{TRENDY} with NPP_{CASA} and other highly correlated models. The median diagonal grid plot signifies the **decadal amplitude** (scale: blue to red); relatively, the adjacent grids represent the **difference between the models** (scale: green to red) and the correlation between the models. β** and β* exhibit magnitude with statistical significance at 5% and 10%



RESULTS | DETERMINISTIC

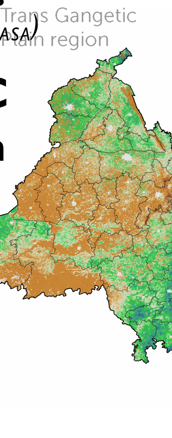
Higher **GPP_{TRENDY}** and **NPP_{TRENDY}** were observed over the highlands of India with maximum amplitude during **post-monsoon** and minimum during the **pre-monsoon**

*CASA **agrees** with the ensemble overall, but contradicts it with **higher** magnitude for the **winter** (DJF) span and **lower** for the **monsoon** (JJA) season*

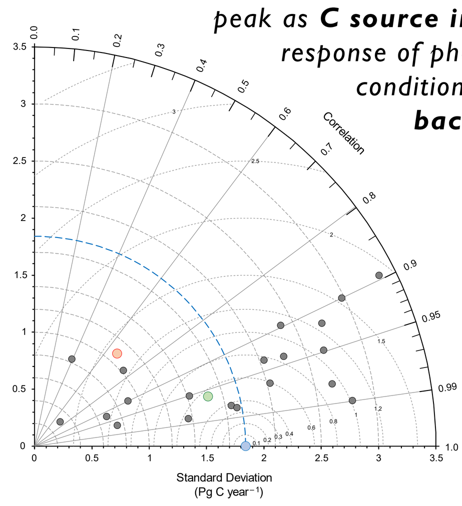
Decadal trend by the models for the ecosystem productivities exhibits a **negative** trend but balanced by the **overall positive trend**

*Out of 15, **eight ecological zones** exhibited a **negative trend** with the decadal loss of **0.39** (GPP_{CASA}) and **0.21** (NPP_{CASA}) Pg C year^{-1}. **Seven ecological zones** were being a counterpart, **accounting positive trend** with an increase of **0.38** (GPP_{CASA}) and **0.19** (NPP_{CASA})*

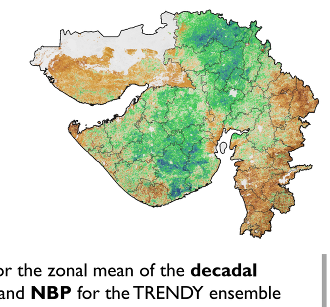
NEE trend transformed from **–0.17 Pg C year^{-1}** to **–0.01 Pg C year^{-1}** resulting in **decline** in the **net C uptake**



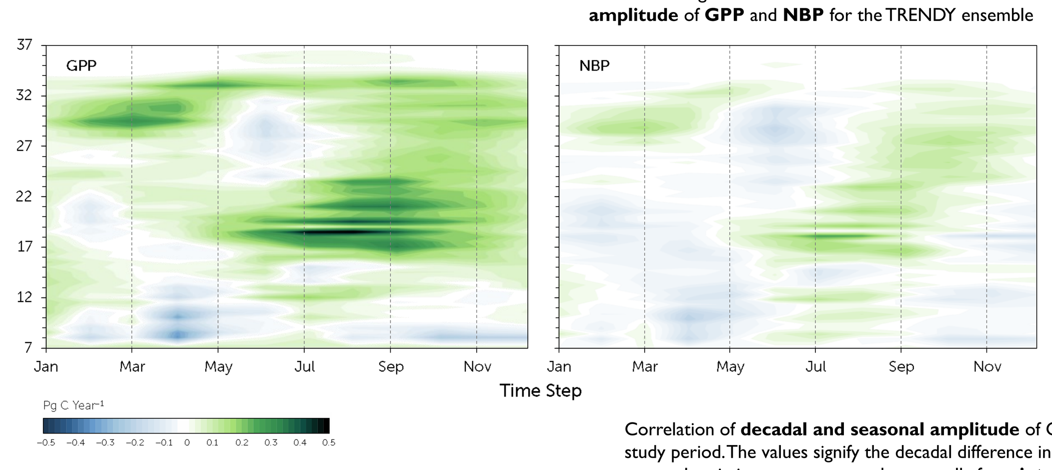
***NEE** continues to lose its potential of being a **C sink,** at a peak as **C source in post-monsoon** owing to the response of phenology to ideal environmental conditions. Zones of the with an **active background of seasonal cropping**, always acts as a C source*



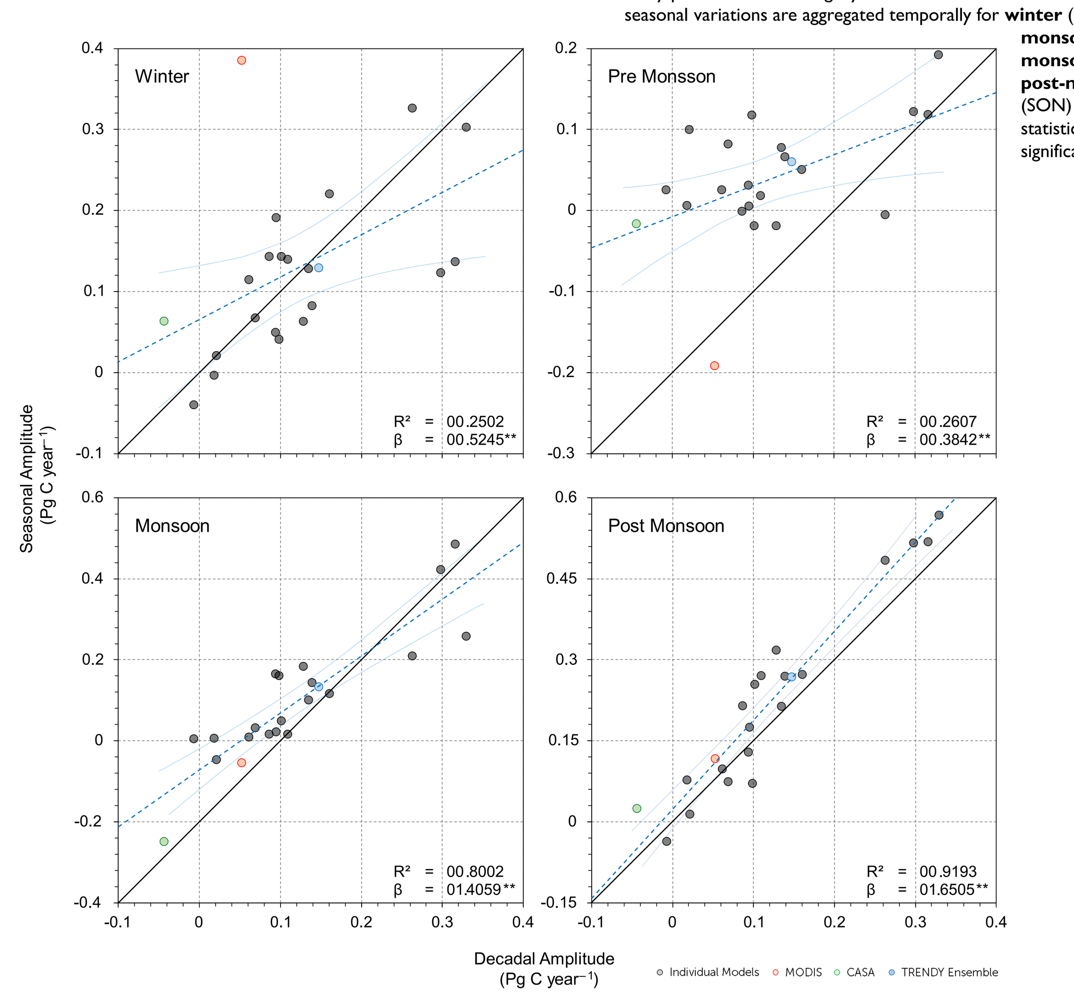
Taylor diagram representing the correlation of **GPP** for **TRENDY ensemble**, **CASA**, **MODIS** and individual models from TRENDY



Hovmöller diagram for the zonal mean of the **decadal amplitude** of **GPP** and **NBP** for the TRENDY ensemble



Correlation of **decadal and seasonal amplitude** of GPP for the study period. The values signify the decadal difference in amplitude. The seasonal variations are aggregated temporally for **winter** (DJF), **pre-monsoon** (MAM), **monsoon** (JJA) and **post-monsoon** (SON) with (β**) statistical significance at 5%



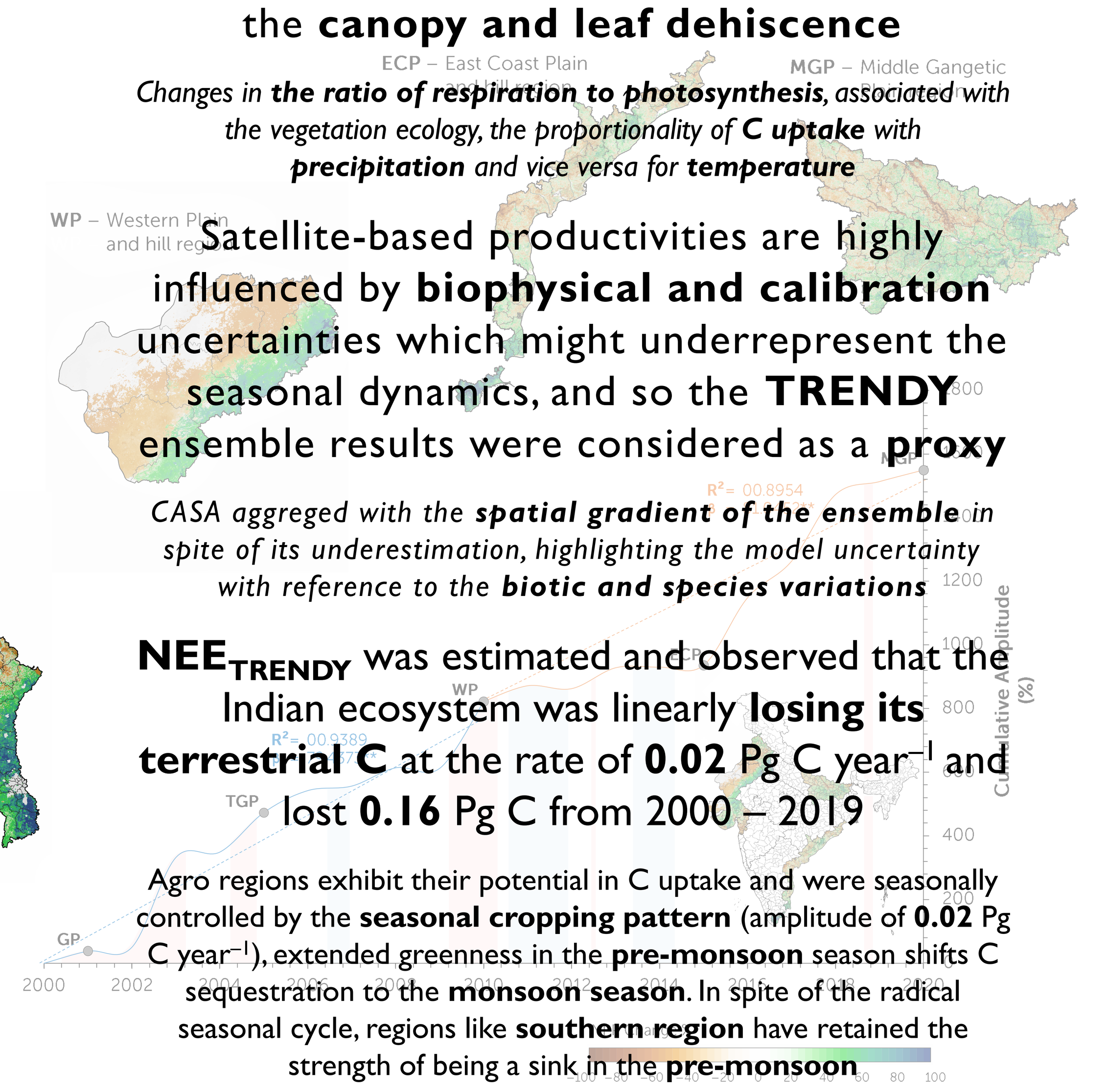
	Analysis	NPP_{TRENDY}		NPP_{CASA}		NPP_{MODIS}	
		D_1	D_2	D_1	D_2	D_1	D_2
Mean	**Overall**	1.6725	**1.8199**	**1.7474**	1.7916	1.4387	1.4626
	Winter	0.8701	0.9993	0.9960	1.0612	**1.9072**	**2.0831**
	Pre-monsoon	0.6606	0.7205	**1.0536**	**1.0331**	0.3784	0.2911
	Monsoon	**2.5913**	**2.7243**	2.4197	2.1334	1.1307	1.1062
	Post-monsoon	**2.5570**	**2.8250**	2.4963	2.5460	2.3042	2.3574
Statistics	**σ**	1.0521	1.1220	0.9508	0.9317	0.8124	0.8994
	β			0.8653	0.7478	0.3219	0.3447
	α			0.2958	0.3308	0.8987	0.8353
	r			0.9575	0.9004	0.4168	0.4300
	d			0.9740	0.9350	0.5670	0.5670
	MAE			0.2670	0.3761	0.9023	0.9987
	RMSE			0.3238	0.5107	1.0538	1.1522

Decadal mean and seasonal mean for **NPP_{TRENDY}**, **NPP_{CASA}** and **NPP_{MODIS}**. Performance statistics of standard deviation (**σ**), Sen's slope (**β**), intercept (**α**), Person's correlation (**r**), Willmott's index of agreement (**d**), Mean Absolute Error (**MAE**) and Root Mean Squared Error (**RMSE**) were analyzed for D_1 (2000 – 2009) and D_2 (2010 – 2019)

INFERENCE | PPROBABILISTIC

Ecosystem productivities were highly controlled by **precipitation** whereas temperature **negatively influence** the productivity mostly in the dry season due to the **canopy and leaf dehiscence**

*Changes in **the ratio of respiration to photosynthesis**, associated with the vegetation ecology, the proportionality of **C uptake** with **precipitation** and vice versa for **temperature***



Satellite-based productivities are highly influenced by **biophysical and calibration** uncertainties which might underrepresent the seasonal dynamics, and so the **TRENDY** ensemble results were considered as a **proxy**

*CASA aggreged with the **spatial gradient of the ensemble** in spite of its underestimation, highlighting the model uncertainty with reference to the **biotic and species variations***

NEE_{TRENDY} was estimated and observed that the Indian ecosystem was linearly **losing its terrestrial C** at the rate of **0.02** Pg C year^{-1} and lost **0.16** Pg C from 2000 – 2019

Agro regions exhibit their potential in C uptake and were seasonally controlled by the **seasonal cropping pattern** (amplitude of **0.02** Pg C year^{-1}), extended greenness in the **pre-monsoon** season shifts C sequestration to the **monsoon season**. In spite of the radical seasonal cycle, regions like **southern region** have retained the strength of being a sink in the **pre-monsoon**

SUMMARY

Agroecological areas played a dominant role in the **seasonal trend**, and the tropical forests poise the **overall trend**

Anthropogenic and climate change offset the **increasing overall trend** in the ecosystem productivity by CO_2 fertilization

On the seasonal scale, the whole country acts as **C sink in pre-monsoon** except few agro-regions (seasonal cropping) but overall, ecosystems in India are reshaping their potential from **C uptake**

KEY POINTS

Increasing temperature and **declining** precipitation are considered to the major dominant drivers in the **declining decadal trend** of the ecosystem productivities

Positive productivity extremes were observed on **the wet span** which was highlighted by the **agro-regions**, whereas **the dry spans** were highlighted with negative extremes by the **tropical forest**

TAKE HOME MESSAGE

Use public transportation/zero-emission vehicle; and if you can, Plant a TREE

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Acknowledgement

The authors would like to thank the NASA's MODIS program for making the data available and TRENDY project team/modelers for contributing to the model outputs. MH extends his special thanks to Dr. Guillermo N. Murray-Tortarolo for his guidance in TRENDY ensemble acquisition