9. Soil-Vegetation-Atmosphere Flux Studies

Aim and Scope

To determine the source/sink strengths of different vegetation biomes with respect to the net carbon budget for India, 'soil-vegetation-atmosphere flux' studies were initiated under the National Carbon Project (NCP) in the 11th FYP. The main aim of the study is to carry out cutting-edge research toward quantitative assessment of mass (CO_2, H_2O) and energy (sensible, latent, and soil heat) fluxes through the establishment of a network of state-of-the-art eddy covariance flux towers across representative vegetation types (forests, agriculture, plantations, grasslands, etc.). The project also aims to up-scale ecosystem-specific net carbon fluxes to regional/national scale through satellite remote sensing proxies and modeling. The scope of the study includes (a) the establishment of an eddy covariance tower network, (b) long-term measurements of mass and energy fluxes along with micro-meteorology at the flux tower sites, (3) analysis of intra- and inter-annual fluxes and variability with respect to environmental drivers, (4) ground data collection of ancillary and relevant vegetation biophysical parameters and (5) integrated modeling approach towards assessment of net carbon budget.

Current status

So far, 7 dy flux towers have been established and operational in representative forest and agriculture ecosystems as follows;

a. Forest Ecosystem
    i. Teak mixed forests of Betul, Madhya Pradesh.
    ii. Mangrove forests of Sundarbans, West Bengal.
    iii. Sal forests of Kanha Tiger Reserve, Madhya Pradesh.
b. Agriculture Ecosystem
    i. Tropical flooded rice agroecosystem: Regional Agricultural Research Station, Maruteru, West Godavari, Andhra Pradesh
    ii. Rainfed Bajra agroecosystem: Research farm of ICAR-CAZRI, Jodhpur, Rajasthan
    iii. Rainfed cotton agroecosystem: Research farm of ICAR-CICR, Nagpur
    iv. Jute-based agroecosystem: Research farm of ICAR-CRIJAF, Barrackpore, West Bengal.

Methodology

The towers are equipped to measure fast response measurements of CO_2, H_2O, and orthogonal wind components (u, v, w) at a frequency of 10Hz (averaged to half hourly fluxes) or higher, along with meteorological and soil parameters at a frequency of 10 sec (averaged to 10 min). Continuous mass and energy exchange measurements are carried out using open-path IRGAs and three-dimensional sonic anemometers. Primary and secondary flux data processing, removal of erroneous data, correction of nighttime fluxes, gap filling, and flux partitioning is carried out for all the study sites to create a seamless database of processed flux data. The CO_2 flux data is subsequently partitioned into Gross primary productivity (GPP), ecosystem respiration (Reco), and net ecosystem productivity (NEP). Flux data is analyzed for diurnal, seasonal, intra, and inter-annual variability of mass and energy fluxes with relevance to climate controls.
Further, remote sensing proxies are used to upscale the ecosystem-specific tower-derived productivity parameters to a regional scale. Light use efficiency (LUE), data-driven, and data assimilation models are currently envisaged in the study.

Constraints / Challenges

1. The current tower network represents only a portion (3 forest types and 4 crop types) of different vegetation biomes available in India. Data representation from more vegetation ecosystems is required to quantify the net carbon fluxes. This can be achieved by establishing more towers as part of the current program or collaborating with potential research partners from other government institutions /academia within India.
2. Sustained project funding support for long-term measurements (contemporary towers across the globe have an operational status of > 20 years).
3. Maintenance of towers and sensors and periodic repair/augmentation/replacement of sensors creates considerable data gaps that appropriate data-filling techniques need to fill.
4. The eddy covariance science is constantly evolving with more insights and instrumentation additions. Upkeep of the instrumentation and adaptation to the current methodologies and protocols is challenging.
5. Establishing India-flux (regional network of towers) is the need of the hour. The regional network connecting all flux towers within India for integrated analysis is currently insufficient and thus needs to be improved.

Salient Results

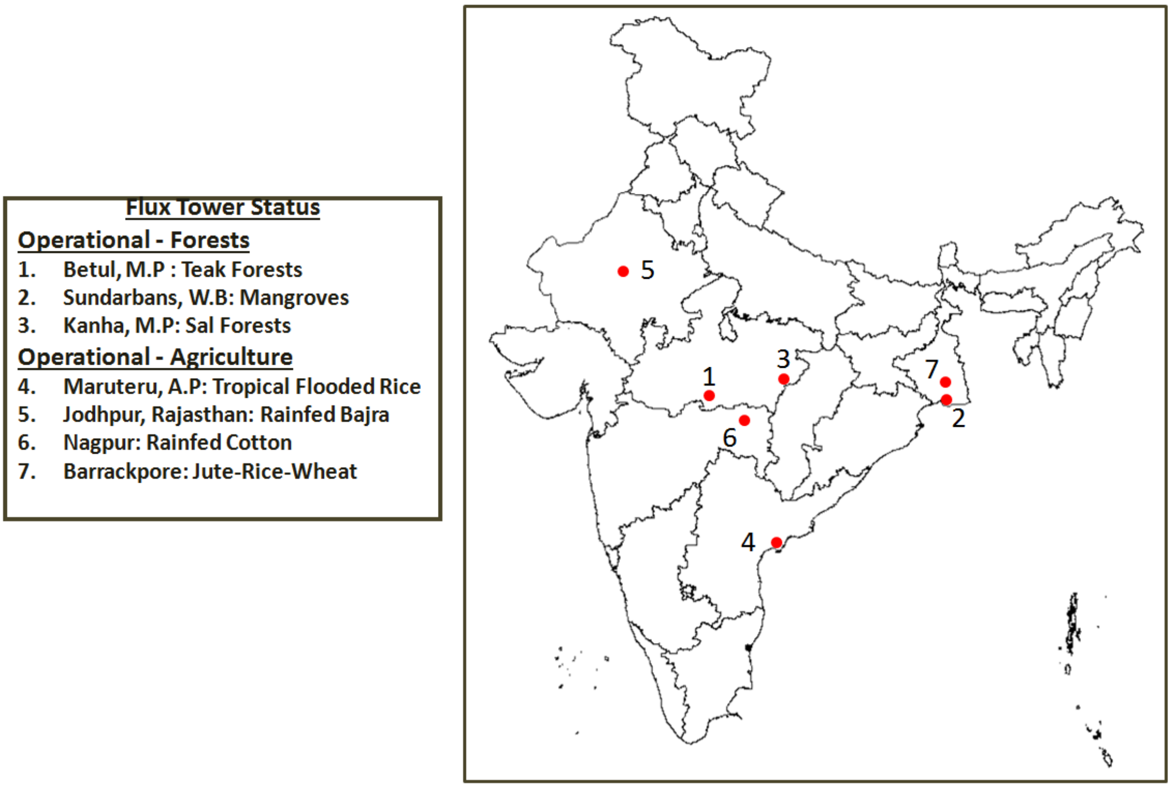
Forest ecosystems:

1. The teak forests of Betul are a net sink of atmospheric CO_2 (figure-2) with NEP of 524 ± 40 gC m^{-2} yr^{-1} with a 233 (± 15) growing season. The NEE was further partitioned into gross primary productivity (GPP) of 3358 gC m^{-2} yr^{-1} and annual carbon loss due to respiration and decomposition (Reco) of 2834 gC m-2 yr-1 (Suraj Reddy et al., 2021). Being a deciduous system, a strong seasonality is observed in Betul in terms of leaf-off (summer) and leaf-on (monsoon and winter).

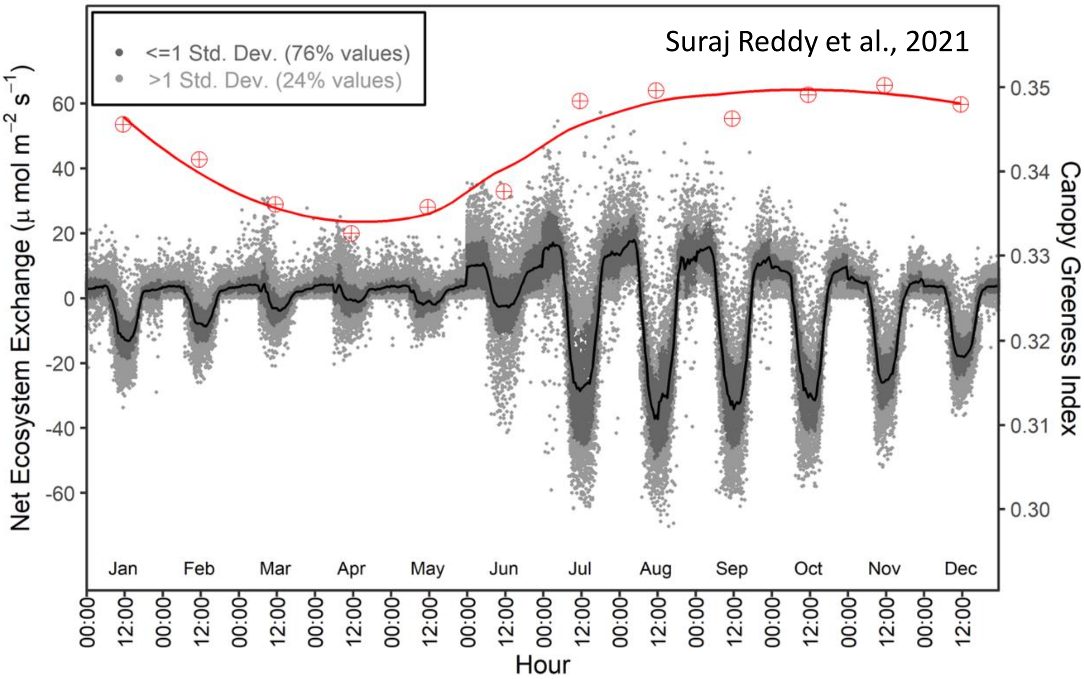
2. Sundarban mangroves are net carbon sinks (figure-3) with NEP of 276 ± 35g. C m-2 yr-1. The NEP was further partitioned to 1581g. C m-2 yr-1of GPP and 1305g. C m-2 yr-1of Reco. Being an evergreen system, not many phonological changes were observed.

3. Sal forests of Kanha are carbon sinks (unpublished) with NEP (-NEE) of 303 gC m-2 yr-1.

Study Area - Flux Towers Status



Current Operational Towers



(Suraj Reddy et al., 2021): All half-hourly net ecosystem exchange of CO_2 (NEE) measurements from Nov 2011 to May 2019. The solid black line represents the Mean Diurnal average (month-wise). The NEE measurements within 1 standard deviation from the mean are colored in dark gray and the rest in light gray. The red line indicates the canopy greenness index (green chromatic coordinate) averaged per month.

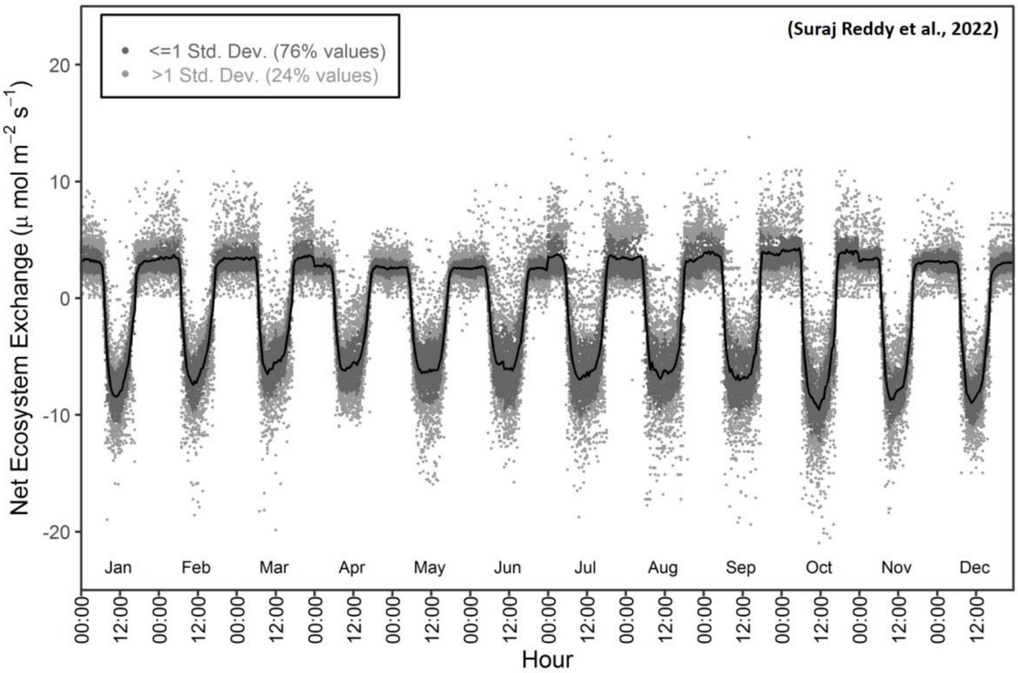


Figure 3 (Suraj Reddy et al., 2022): All half-hourly net ecosystem exchange (NEE) measurements at the study site from April 2012 to March 2016. The solid black line indicates the mean diurnal average (month-wise). The NEE measurements within ±1 standard deviation of the solid black line are shown in dark gray, and the rest are in light gray.

Agro ecosystems:

1. The rainfed cotton crop was found to be a strong net CO_2 sink, with seasonal NEE, GPP, R_{eco}, and evapotranspiration (ET) of -333 gC m^{-2}, 990 m^{-2}, 656 gC m^{-2}, and 468 mm respectively. The seasonal Ecosystem Water Use Efficiency (EWUE) was estimated to be 1.9 - 2.1 gC kg^{-1} H_2O. Maximum values of crop coefficient (K_c) were observed to be 1–1.2 during 30–75 DAS, signifying favorable conditions for crop growth (Chakraborty et al., 2022; doi.org/10.1016/j.fcr.2022.108595).

2. The rainfed chickpea was found to be a weak carbon sink with cumulative NEE of -32 gC m^{-2}; GPP of 163 gC m^{-2}; Ecosystem Respiration (R_{eco}) of 127 gC m^{-2}; ET of 177 mm. The maximum ecosystem water use efficiency (GPP/ET) and crop coefficient were found to be 1.7 gC m^{-2} mm^{-1} and 0.6 respectively, at peak vegetative stage, which are sub-optimal compared to well-managed chickpea crop (Chakraborty et al., 2021; doi.org/10.1016/j.fcr.2021.108307).

3. Jute ecosystem was found to be a net CO_2 sink daily except for the initial 9 days from the date of sowing. The total seasonal NEE over the jute season was found to be −268.5 gC m^{-2} (i.e.10.3, t CO_2 ha^{-1}). Ecosystem-level photosynthetic efficiency parameters were estimated at each growth stage of the jute crop. The maximum photosynthetic capacity (P_{max}, 63.3 ± 1.15 μmol CO_2 m^{-2} s^{-1}) and apparent quantum yield (α, 0.072 ± 0.0045 μmol CO_2 μmol $photon^{-1}$) were observed during the active vegetative stage, and the fiber development stage, respectively (Barman et al., 2022; doi.org/10.1007/s10661-022-09872-2).

4. Tropical flooded rice is a very strong net ecosystem CO_2 sink, with rabi season NEE, GPP, and R_{eco} of - 418 gC m^{-2}, 994 gC m^{-2}, and 556 gC m^{-2}, respectively. Whereas Kharif season NEE, GPP, and R_{eco} were found to be -349 gC m^{-2}, 878 gC m^{-2}, and 531 gC m^{-2}, respectively. The net ecosystem CH_4 exchanges during rabi season were found to be 27.5 gC m^{-2}. Considering the global warming potential, the ecosystem acts as a net contributor.

Table 1: The Ecosystem Carbon exchanges from different agroecosystems.

Season/Crop	Duration (days)	GPP (gCm^{-2})	NEE (gCm^{-2})	R_{eco} (gCm^{-2})	CH_4 (gCm^{-2})
Rabi rice (Andhra Pradesh)	95	994	-418	576	27.5
Kharif rice (Andhra Pradesh)	110	878	-349	531	--
Wheat (West Bengal)	115	497	-292	205	NA
Jute (West Bengal)	111	949	-268	680	NA
Cotton (Maharashtra)	200	990	-333	656	NA
Chickpea (Karnataka)	106	163	-32	127	NA

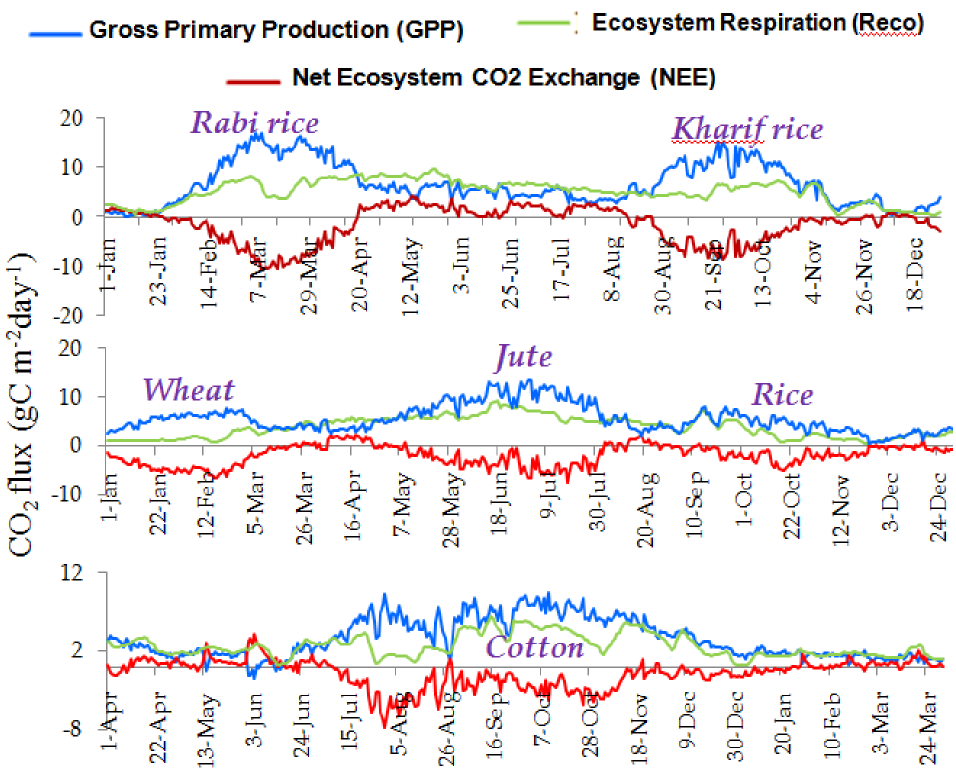


Figure 4: Temporal variations of daily ecosystem exchanges (NEE, Net Ecosystem CO_2 Exchange; GPP, Gross Primary Production; R_{eco}, Ecosystem Respiration during the crop growing season.

Expected Outcome

- Eddy flux towers are a reliable means of quantifying ecosystem-specific mass and energy fluxes. The data is expected to give the most reliable estimates of carbon sequestration potential and net carbon balance.

- Eddy flux tower sites can be used as validation sites for satellite-derived biophysical variables such as GPP and for energy balance studies (evapotranspiration)
- Continuous long-term measurements of the tower are required, along with meteorological and environmental drivers, to understand the impact of changing climate on the carbon sequestration potential of different Indian vegetation types. (most of the contemporary global towers have been operational for > 2 decades)