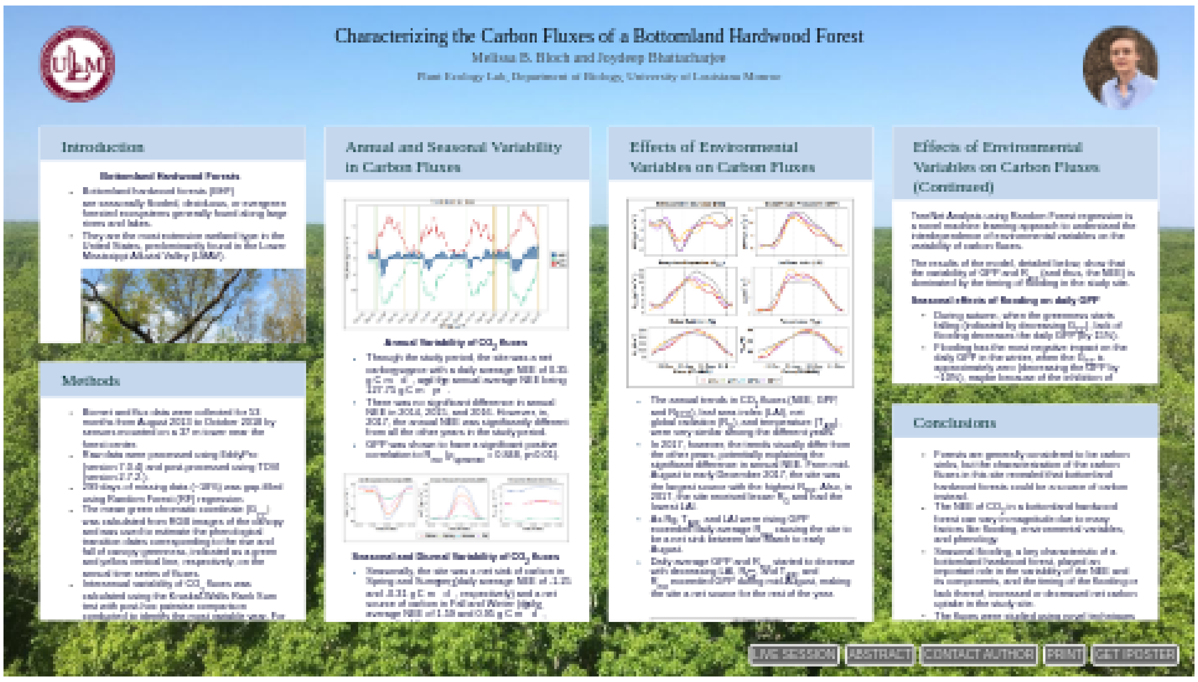
# Characterizing the Carbon Fluxes of a Bottomland Hardwood Forest





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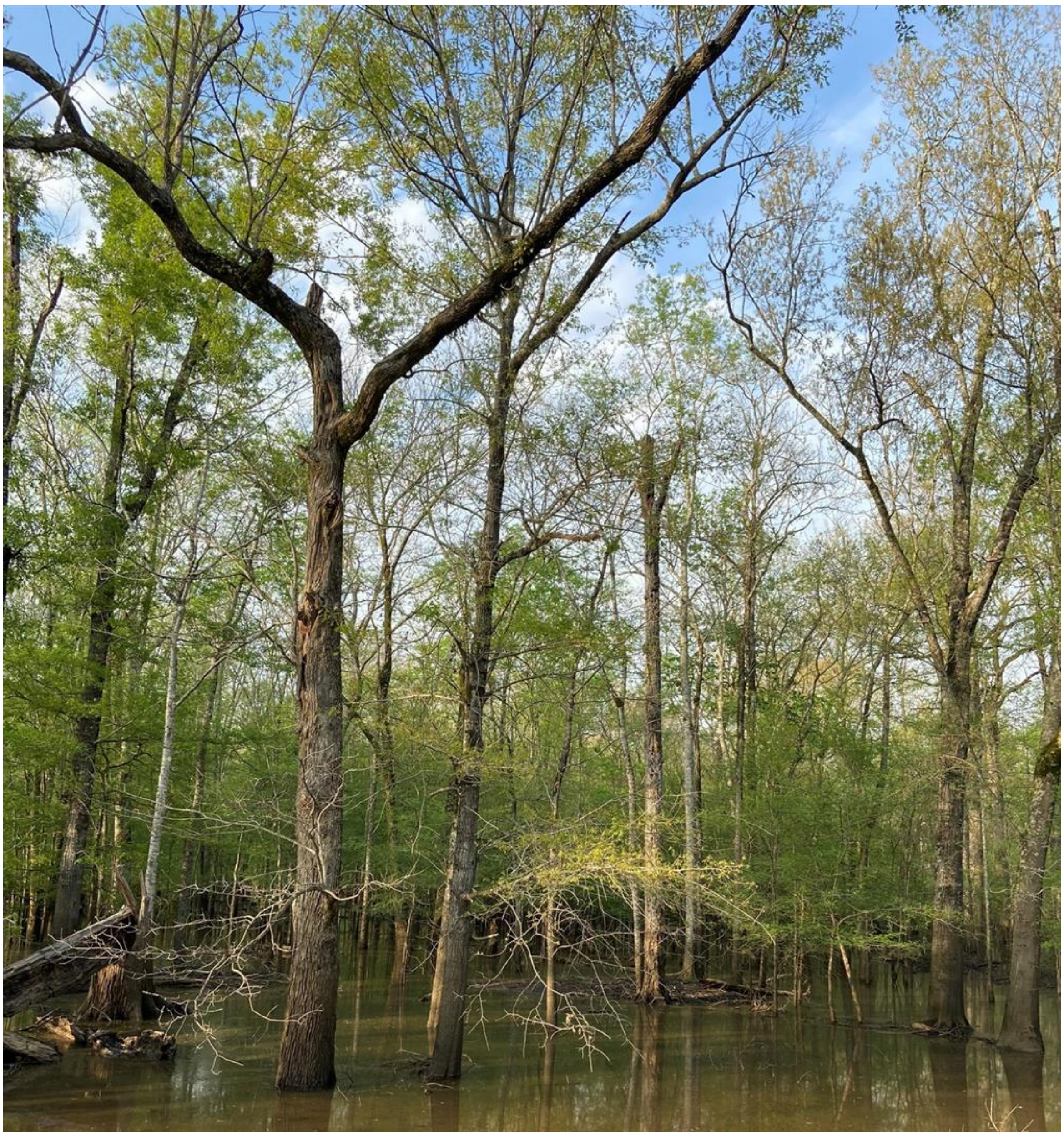
# INTRODUCTION

### Bottomland Hardwood Forests

- Bottomland hardwood forests (BHF) are seasonally flooded, predominantly deciduous, forested ecosystems generally found along rivers and streams.



- This study was conducted at the US-ULM tower, located in a broadleaf deciduous (Oak-Elm-Ash) BHF at the Russell Sage Wildlife Management area (32.456961 °N, -91.974322 °E; elevation 18 m).
- The study site is located within the Bayou Lafourche floodplain and is subject to annual, late winter-early spring flooding.

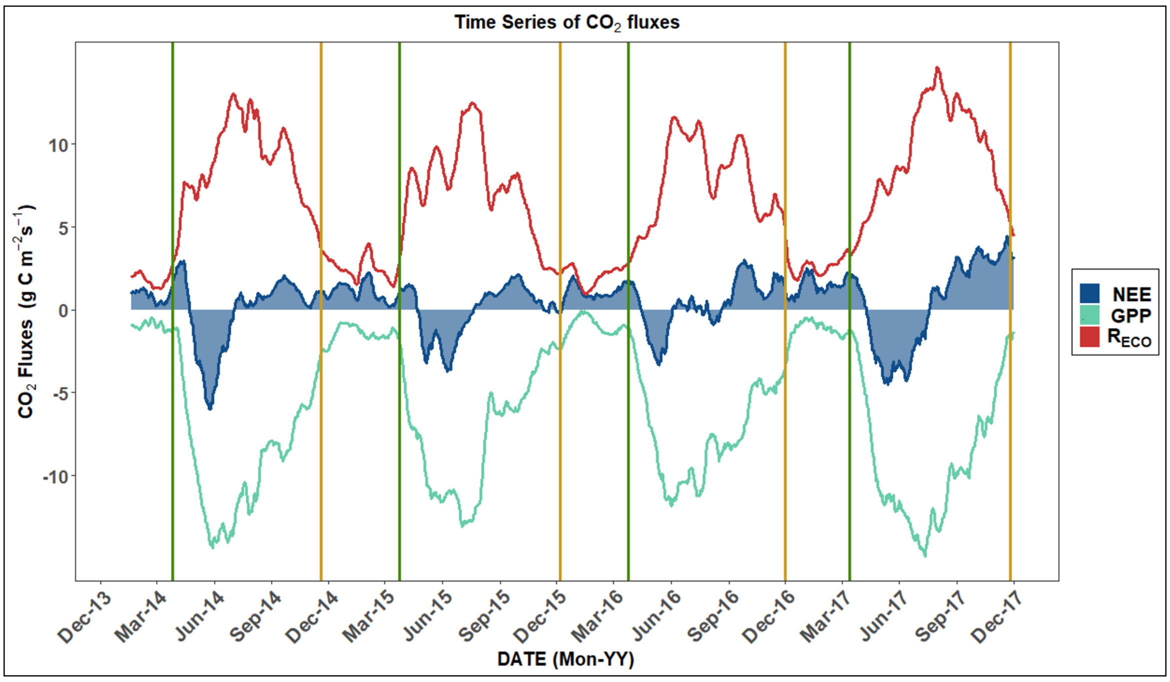
### $CO_2$ Fluxes

- The forest-atmosphere carbon dioxide ($CO_2$) exchange of BHFs is yet to be studied in detail and therefore their role in the global carbon cycle is not yet definitively known.
- The purpose of this study was to characterize the forest-atmosphere $CO_2$ exchange of this system by:
  - Estimating the $CO_2$ fluxes over a BHF for over 5 years, using the eddy covariance method;
  - Identifying if the site was a net carbon sink or a source;
  - Measuring the annual, seasonal, and diurnal variability of the $CO_2$ fluxes;
  - Evaluating the effects of environmental variables on the variability of the fluxes

# METHODS

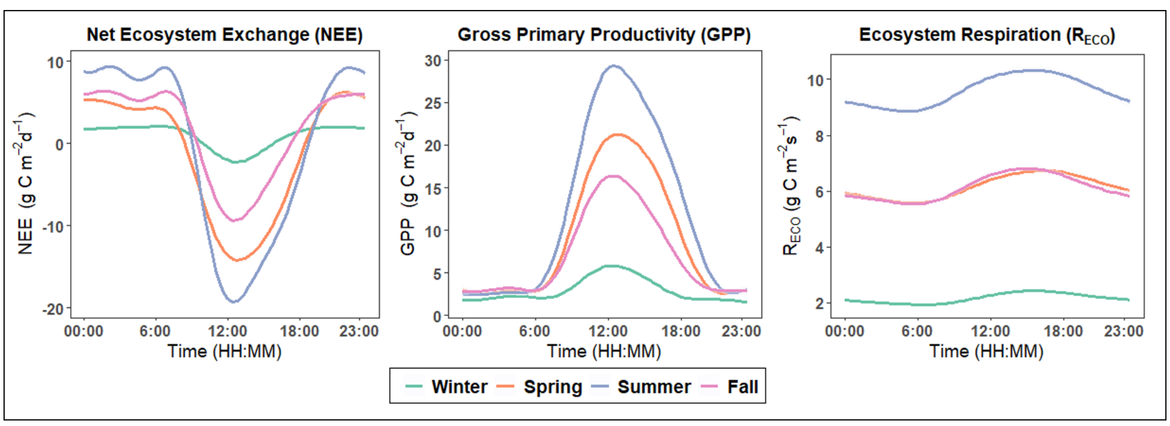
- Biomet and flux data were collected for 53 months from August 2013 to October 2018 by sensors mounted on a 37 m tower near the forest center.
- Raw data were processed using EddyPro (version 7.0.4) and post-processed using TOVI (version 2.7.2.).
- 299 days of missing data (~18%) was gap-filled using Random Forest (RF) regression.
- The mean green chromatic coordinate ($G_{CC}$) was calculated from RGB images of the canopy and was used to estimate the phenological transition dates corresponding to the rise and fall of canopy greenness, indicated as a green and yellow vertical line, respectively, on the annual time series of fluxes.
- Interannual variability of $CO_2$ fluxes was calculated using the Kruskal-Wallis Rank Sum test with post-hoc pairwise comparison conducted to identify the most variable year. For annual comparisons, 2013 and 2018 were not used.
- Seasonal and diurnal variability of $CO_2$ fluxes were studied through a 24-hour time-scale plot using seasons as categories.
- The relationship of NEE, daytime GPP, and nighttime $R_{eco}$ was calculated using Spearman's correlation.
- The effect of environmental variables on the diurnal and seasonal variability of NEE and its components (GPP and $R_{eco}$) were visualized using general additive models (GAMs) with seasons and years as categorical variables.
- To determine periods when the carbon fluxes were affected by extended flooding, the relationship of $R_{eco}$ and GPP with the gage height of Bayou Lafourche was evaluated, and the inflection point was identified. The inflection point was then added as an indicator of site-flooding to a time series of the 7-day moving average of the gage height.
- RF regression models for GPP and $R_{eco}$ were built and two-variable dependence plots were used to understand the effects of seasonal interdependence of phenology, flooding, and temperature, on the fluxes.
    - The variables were first converted into categorical values for this step. Seasons had 4 categories (Spring, Summer, Fall, Winter); temperature had 5 categories ("Cold" < 5 °C, "Cool" > 5°C and < 15°C, "Warm" >15°C and <25°C, "Hot" > 25°C and <30°C, and "Very Hot" > 30°C); $G_{CC}$ had 11 categories (0.32 = "1", and 0.41 = "11", with every 0.01 unit increase = "n+1", where n=previous category); and, flooding had 2 categories (7-day SMA gage height > 12 ft = "Flood" and < 12 ft = "No_Flood").

# ANNUAL AND SEASONAL VARIABILITY IN CARBON FLUXES




**Annual Variability of $CO_2$ fluxes**

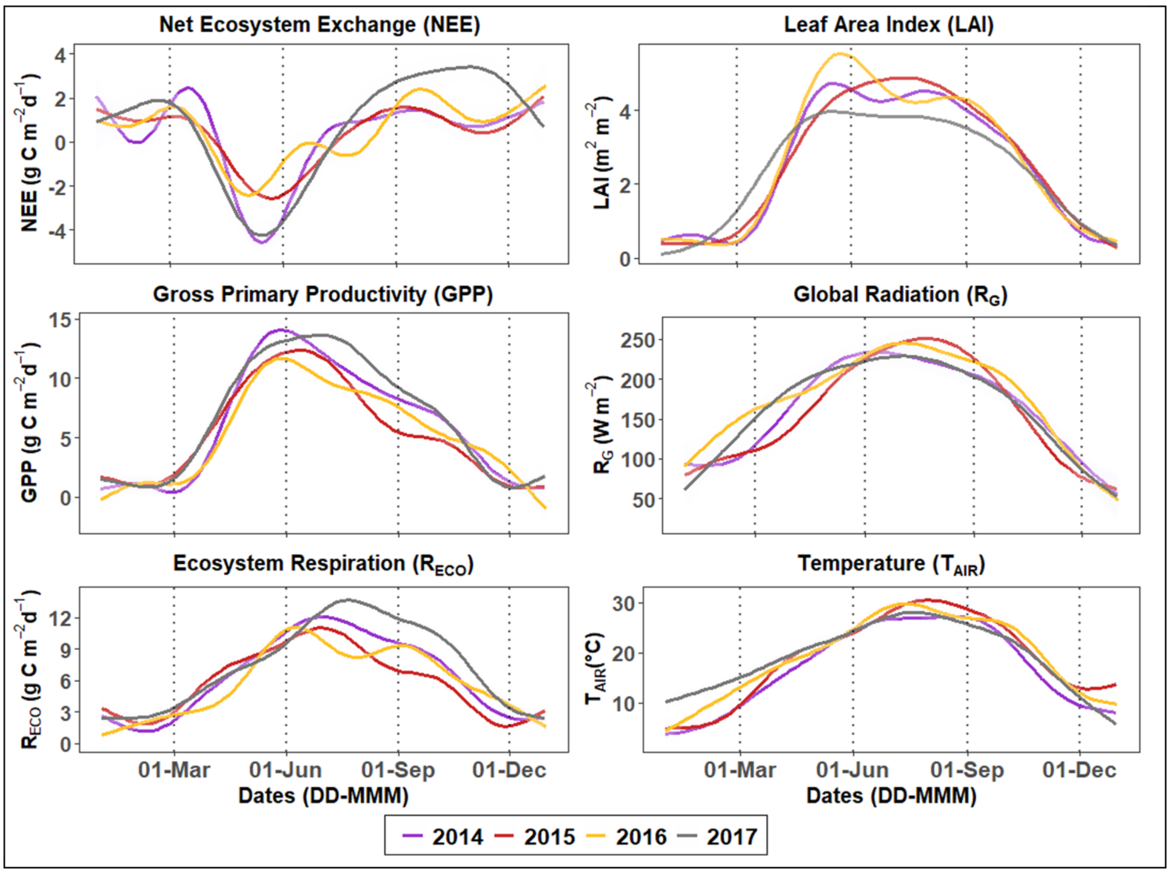
- Through the study period, the site was a net carbon source with a daily average NEE of 0.35 g C $m^{-2}$ $d^{-1}$, and the annual average NEE being 127.75 g C $m^{-2}$ $yr^{-1}$.
- There was no significant difference in annual NEE in 2014, 2015, and 2016. However, in, 2017, the annual NEE was significantly different from all the other years in the study period.
- GPP was shown to have a significant positive correlation to $R_{eco}$ ($\rho_{spearman}$ = 0.848, p<0.01).



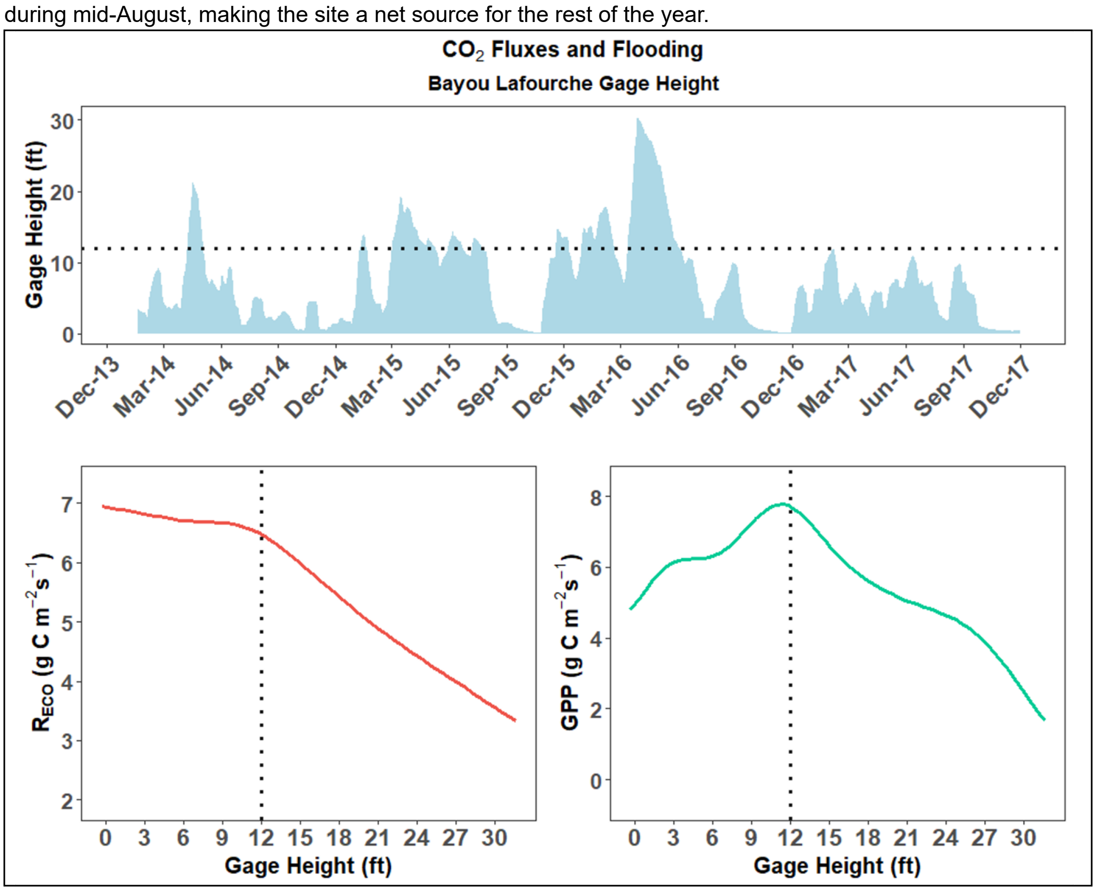

**Seasonal and Diurnal Variability of $CO_2$ fluxes**

- Seasonally, the site was a net sink of carbon in Spring and Summer (daily average NEE of -1.25 and -0.31 g C $m^{-2}$ $d^{-1}$, respectively) and a net source of carbon in Fall and Winter (daily average NEE of 1.59 and 0.95 g C $m^{-2}$ $d^{-1}$, respectively).
- Diurnally, the site was net sink between 800 to 1700 hrs. on average with peak carbon uptake around 1200 to 1400 hrs.
- The variability of NEE was more strongly affected by the variability in GPP than $R_{eco}$ on a diurnal scale.

# EFFECTS OF ENVIRONMENTAL VARIABLES ON CARBON FLUXES

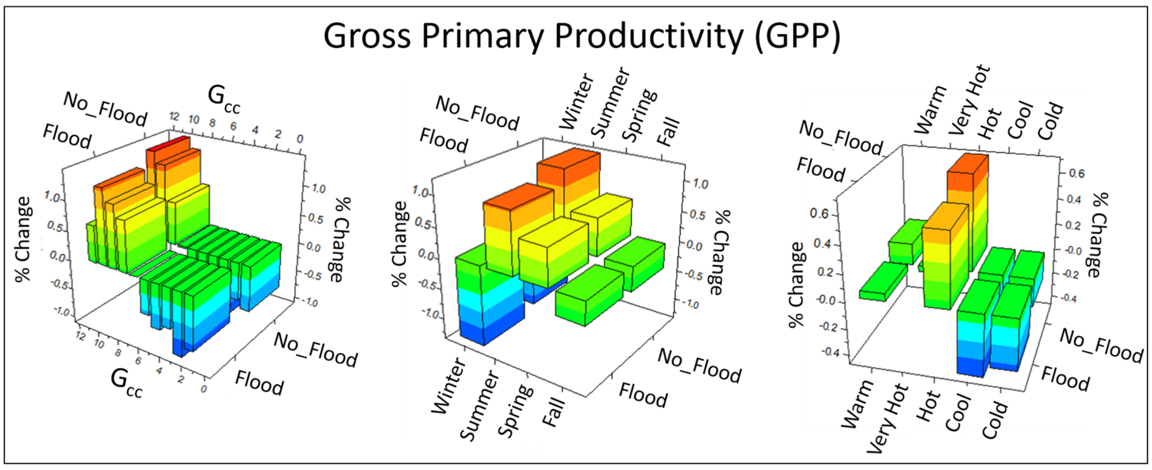



- The annual trends in $CO_2$ fluxes (NEE, GPP, and $R_{ECO}$), leaf area index (LAI), net global radiation ($R_G$), and temperature ($T_{AIR}$), were very similar among the different years.
- In 2017, however, the trends visually differ from the other years, potentially explaining the significant difference in annual NEE. From mid-August to early December 2017, the site was the largest source with the highest $R_{eco}$. Also, in 2017, the site received lesser $R_G$ and had the lowest LAI.
- As $R_G$, $T_{AIR}$, and LAI were rising GPP exceeded daily average $R_{eco}$ causing the site to be a net sink between late March to early August.
- Daily average GPP and $R_{eco}$ started to decrease with decreasing LAI, $R_G$, and $T_{AIR}$, and $R_{eco}$ exceeded GPP during mid-August, making the site a net source for the rest of the year.



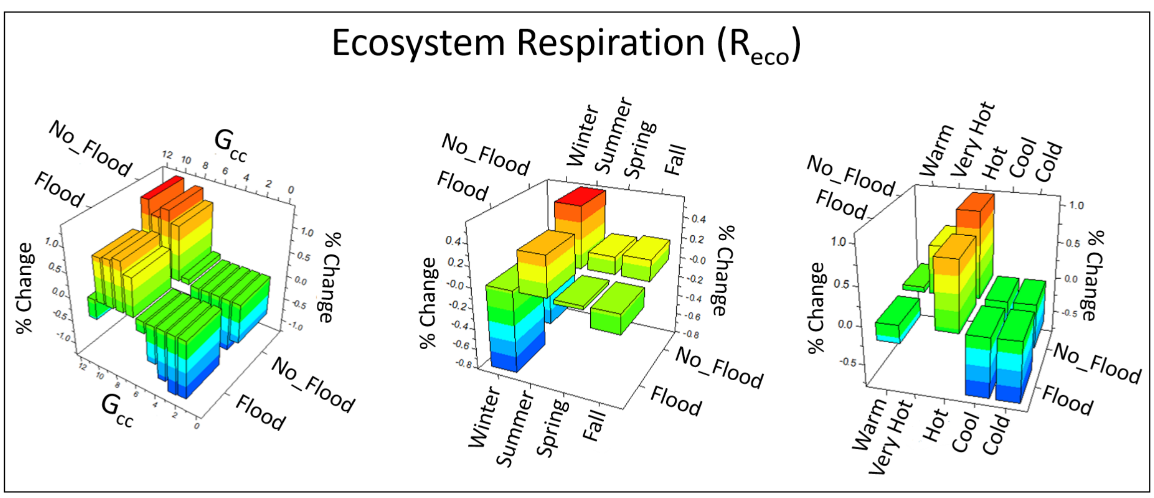

- Flooding (gage height >12 ft) had a key impact on the NEE. Extended flooding inhibited $R_{eco}$, making the site a smaller source when subjected to extended flooding. This can be noticed in 2017 when a lack of extended flooding during the dormant period resulted in a spike in $R_{eco}$ during late fall and early winter.

# EFFECTS OF ENVIRONMENTAL VARIABLES ON CARBON FLUXES (CONTINUED)




**Seasonal effects of flooding on daily GPP**

- The GPP was positively correlated to $G_{CC}$ when > “6”, and negatively correlated to $G_{CC}$ when < “6”.
- The GPP started increasing in the “Spring” and was the highest during “summer”. GPP increased when the temperature was “Warm”, “Hot” and “Very Hot”.
- If there was flooding, the GPP was ~ 20% lower when $G_{CC}$ was > “8”, and the season was “Summer”, compared to if there was no flooding.
- GPP was ~ 10% higher when $G_{CC}$ was “7” (usually in August), if there was flooding, compared to if there was no flooding.
- GPP was considerably higher if there was no flooding when the temperature was “Very Hot” compared to if there was flooding.
- When $G_{CC}$ was at the lowest (usually in winter), lack of flooding, compared to flooding, decreased the GPP by as much as 50%.




**Seasonal effects of flooding on $R_{eco}$**

- $R_{eco}$ also increases when $G_{CC}$ > "8"; in the “Summer” season, and when the temperature was “Warm” or higher.
- In the above scenarios, $R_{eco}$ was higher, if there was no flooding compared to if there was flooding.
- $R_{eco}$ was considerably lower when the temperature was “Hot” if there was flooding compared to if there was no flooding.
- The only period when flooding resulted in higher $R_{eco}$ compared to, if there was no flooding, was when the temperature was "Warm" and the $G_{CC}$ was ~ “6”, usually in early spring.
- Flooding during the winter and when the $G_{CC}$ was < “4” would also result in lower $R_{eco}$ compared to if there was no flooding.
- Inhibition of respiration due to flooding could be caused by many reasons including submerged roots and ground vegetation.

**Effects of seasonal flooding on net carbon uptake**

- Flooding in peak summer and winter can result in an increase in net carbon uptake because the reduced productivity is offset by an even larger inhibition of respiration, as noticed in 2017 when the lack of winter flooding contributed to the year being the largest annual source during the study period.
- Flooding, during the spring, on the other hand, can have a detrimental effect, since respiration increases and productivity is further decreased. In 2016, record-high precipitation during the spring resulted in extended flooding causing the site to be a source instead of a sink during that period.

# CONCLUSIONS

- Forests are generally considered to be carbon sinks, but the characterization of the carbon fluxes in this site revealed that bottomland hardwood forests could be a source of carbon instead.
- The NEE of $CO_2$ in a bottomland hardwood forest can vary in magnitude due to many factors like flooding, environmental variables, and phenology.
- Flooding reduces the productivity of the forest throughout the year except in August when it increases productivity
- Flooding inhibits respiration throughout the year except in early spring when it increases the respiration.
- The fluxes were studied using novel techniques like GAMs and RF regressions, and continued research could provide more insights on the usefulness of such techniques for in-depth understanding of the effects of the changing climate on carbon fluxes.

# ABSTRACT

Bottomland hardwood forests are a historically dominant ecosystem in the Southeastern United States, with 5.3 million-acres remaining in the Lower Mississippi Alluvial Valley. Despite the importance of forested wetlands in the global carbon cycle, not much is known about $CO_2$ exchanges in such periodically flooded ecosystems. To address this, $CO_2$ fluxes were measured over a mature, predominantly oak bottomland hardwood forest canopy in Northeast Louisiana. Measurements were carried out from a 37m tower, between August 2013 to October 2018, using the eddy covariance technique. Like other deciduous broadleaf forests, the site exhibited distinct diurnal and seasonal variability and was a net carbon sink during the spring and summer months, but unlike the majority of such forests and inland wetlands, the site was a net source of carbon annually. The cumulative annual net ecosystem exchange (NEE) ranged from 95.99 g C $m^{-2}$ in 2014, to 267.91 g C $m^{-2}$ in 2017, with an average annual NEE of 127.75 g C $m^{-2}$. To better understand the variability, the relationship between the environmental factors and the components of NEE were observed. Diurnally, GPP increased with increasing global radiation and exceeded $R_{eco}$ from around 830 till around 1800 hrs. Seasonally, nighttime $R_{eco}$ increased with temperature. GPP increased and exceeded $R_{eco}$ from late March to early August, with a corresponding increase in the length of daylight, temperature, and leaf area index. GPP values showed more variability than $R_{eco}$ on a daily scale, thereby having a more distinct effect on the NEE. Research is on-going to better understand the effects of the characteristic flooding on carbon fluxes in this unique ecosystem.