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Carbon and Water Dynamics in the Sandhills of South Carolina

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I. Abstract

An investigation was conducted to better understand the relationship between the carbon and precipitation cycles in the atmosphere. The carbon cycle is an important biogeochemical process in which a plant takes in carbon during photosynthesis and releases it during respiration. Why plants take or release carbon can be explained by various environmental conditions throughout the year. By using eddy-covariance measurements of rainfall and evaporation, we can describe the carbon cycle in the sandhills of South Carolina.

We examine those measurements in comparison to soil water over the course of five years at an eddy covariance tower, located in a long leaf pine forest at the Savannah River Site in Aiken, South Carolina. The study illustrates how ecosystem fluxes respond to rainfall events and drought periods on site, specifically the lowest and highest moisture periods through the year. Additionally, this study also explores how resistant the store of carbon is during a drought and its resilience when rains return.

II. Introduction

The soft wood forest of South Carolina can potentially sequester 47.7 million tons of carbon[1]. Generally, forests help to sequester atmospheric carbon by fixing it through photosynthetic processes as part of the constant release and absorption of CO_2 from the atmosphere that makes up the carbon cycle. To further explain, Plants take in carbon through photosynthesizing and release some CO_2 through autotrophic respiration. As plants grow and develop, the amount of carbon they take in grows while only a small fraction of the carbon uptake is released through respiration. These processes are greatly dependent on the conditions of the atmosphere and the soil environment. Sudden changes in the environment like drying soil moisture can help explain changes in carbon fluxes and help us further understand the stress impact to vegetation in certain conditions.

'Pulses' of rain in an area will stimulate environmental dynamics such as decomposition, germination, and growth. The productivity of these process relies on the attainability of water. The correlation between productivity, rainfall and evaporation has been studied in predominately dry or abundantly hydric environments[2]. The current study has been implemented in a xeric clay environment to study carbon fluxes annually over a period of five years (2017-2021). In addition, this study also characterizes resilience and resistance in the forest through a drought and the period following one.

By calculating the average precipitation levels and analyzing seasonal periods, we can better understand how precipitation varies during the year and identify the periods of productivity. We can also determine how much incoming net energy is converted to evaporation and how it changes with soil moisture. We then assumed that the pulse periods of soil moisture regulate evaporation and CO_2 fluxes because the amount of energy used to evaporate water typically decreases as the environment is becomes arid. This project will result in a better understanding of how soil water content can regulate plant respiration responses in dry periods.[3]

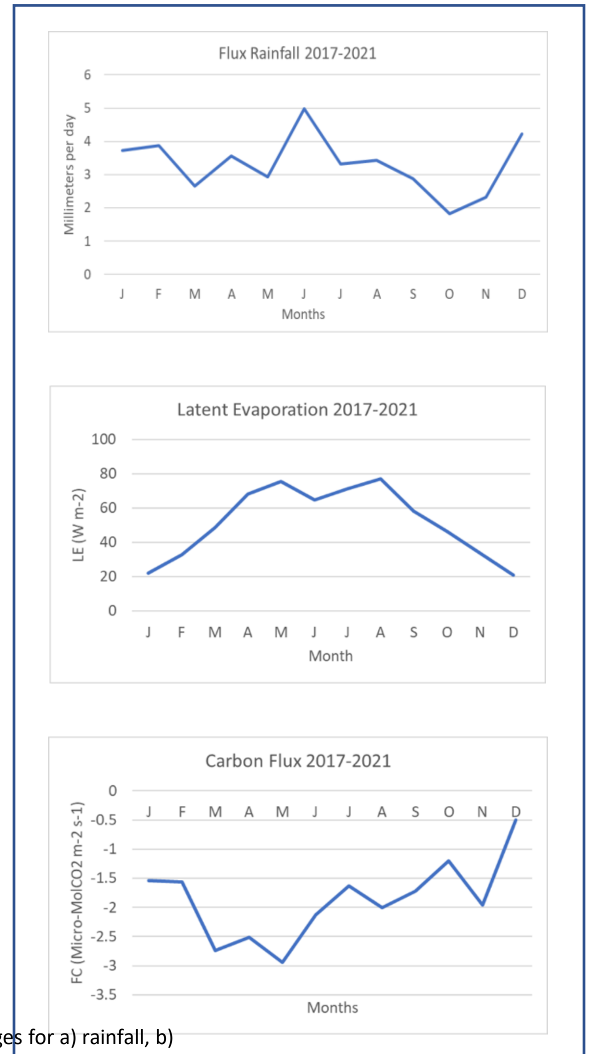
III. Methods

The US-Akn AmeriFlux tower is located at the Savanna River Site in the sandhills of South Carolina. The tower lies in a forest of loblolly pines (*P. taeda*) that have an average height of 24 meters with the tower extending to 30 meters. A Campbell Scientific CSAT-3A sonic anemometer and Li-COR 7500 open-path gas analyzer are affixed to the tower and sit at the highest elevation of 28 meters. These sensors provide measurements of atmospheric winds, carbon, moisture, and temperature which can be used to calculate the fluxes of these variables and are averaged every 30 minutes. The Eddy-Pro software distributed by Li-Cor is used to analyze those measurements of precipitation, soil water, LE (Latent heat flux, an indicator of evaporation), and net ecosystem CO_2 (carbon flux).

Identification of the wettest and driest periods were measured by averaging the 30-minute intervals taken from the Eddy-Pro, with averages per day and per month. In the years of 2017-2021 the wettest periods were in summer months (May- July) and the driest in winter months (December- February). Five drought periods were identified between 2017 and 2021 in primarily wetter months. The droughts where further analyzed and the resilience following each drought.

IV. Results

The precipitation levels at the Savannah River Site had a tendency to spike in May through July (Fig. 1a). As a result, it can be inferred that the soil is wettest in those months. Because of the moisture content and net radiation, the most evaporative months are roughly the summer months (Fig. 1b). Vegetation absorbed the most carbon (greatest negative flux) in the spring months and trends upwards (that is, towards weaker intake) in late summer (Fig. 1c) possibly due to the spring being the most productive for vegetation.



When the soil surrounding plants is dry it constricts the stomata from exchanging water vapor and CO_2 with the atmosphere in order to conserve moisture[4]. Following a dry period, the stomata of plants show a pattern of opening and begin to transpire again, slowly becoming less stressed. The soil dries through evaporation and absorption (but will never be completely dry).

Figure 1: Annual averages for a) rainfall, b) latent heat flux (LE) c) carbon flux. Note that a negative carbon flux indicates carbon dioxide intake by the plants. (LE)

A pulse model analysis was applied to soil moisture and precipitation levels (Fig. 2) to illustrate how much water was in the soil in the days following a rain event. In Figure 2, the soil moisture is represented as a percentage, and we see soil moisture rarely falls beneath 5% even several days after a rain event. We also see that 14% seems to be a maximum, with soil moisture failing to increase beyond that value despite high rainfall amounts. As the days without rain increase, the soil water levels decrease.

Incoming energy is partitioned to heating the soil and evaporating soil water. If more water is added to a moisture rich area, it will not result in further opening of the stomata and thus transpiration is unaffected by soil water at higher wetness levels, while under drier conditions evaporation is limited by (and therefore strongly related to) soil water. In Fig. 3, the evaporation fraction is at its highest and is decoupled from soil water beyond about 8% soil moisture. Below the 8% threshold soil moisture and the evaporation fractions have a strong correlation.

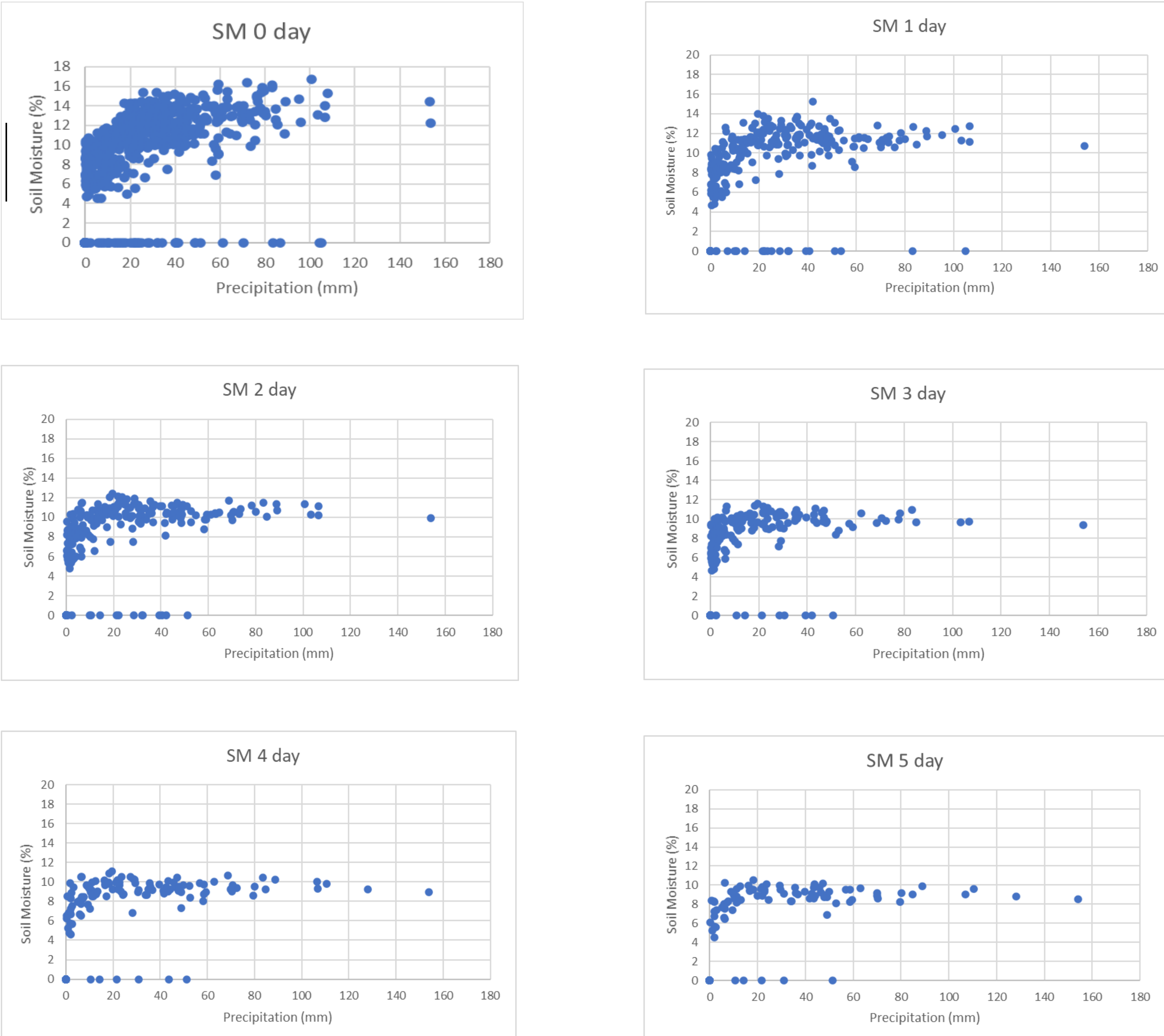


Figure 2: The gradual decrease of soil moisture days after rain event

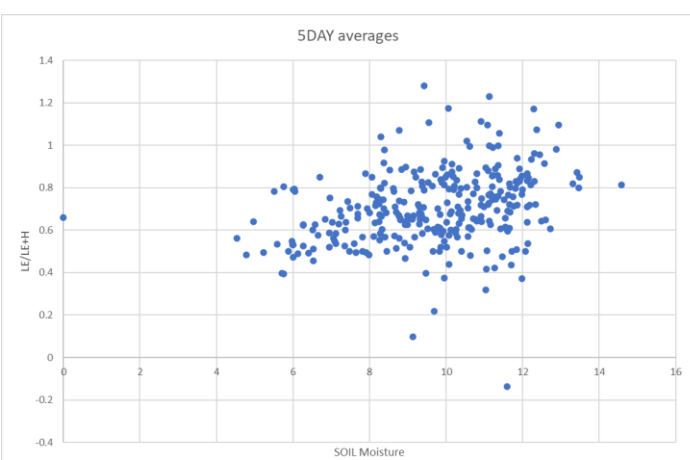


Figure 3: Evaporation fraction to soil water of 5-day average representing each point

Over the five-year period we were able to detect five major ‘drought’ events (sequences of rain-free days) varying in length during or around the peak rainfall:

TABLE 1: Drought periods

Apr-2018	Aug-2018	May-2019	Mar-2020	May-2021
17 days	20 days	23 days	15 days	21 days

These droughts showcase the resilience of a softwood forest in a stressed environment (Figure 4). As expected, soil moisture levels decrease as the soil dries following a rain event. However, the soil will never reach zero percent moisture, and towards the end of a drought levels are roughly constant as the moisture content of the soil reaches its permanent wilting point, or the level when no additional moisture is available to the plant. Similarly, evaporation measurements decrease, as the amount of water content decreases. The flux of CO_2 into the vegetation decreases as the length of the drought extends; the droughts in the ecosystem cause osmotic stress causing reduction in photosynthesis rates [5].

The days that follow the end of a drought allow the environment to recover- the trees open their stomates fully and increase photosynthesis. As show in Figure 5 the increase of carbon caused by the drought takes time to balance after a rain event. Then around the fifth day the carbon returns to the normal absorption rate in the environment. The data collected post-drought enforces the idea that the forest exhibits roughly high resilience after a drought [6]. So, even after a long duration of no precipitation the data illustrate that the forest begins sequestering more carbon again relatively soon.

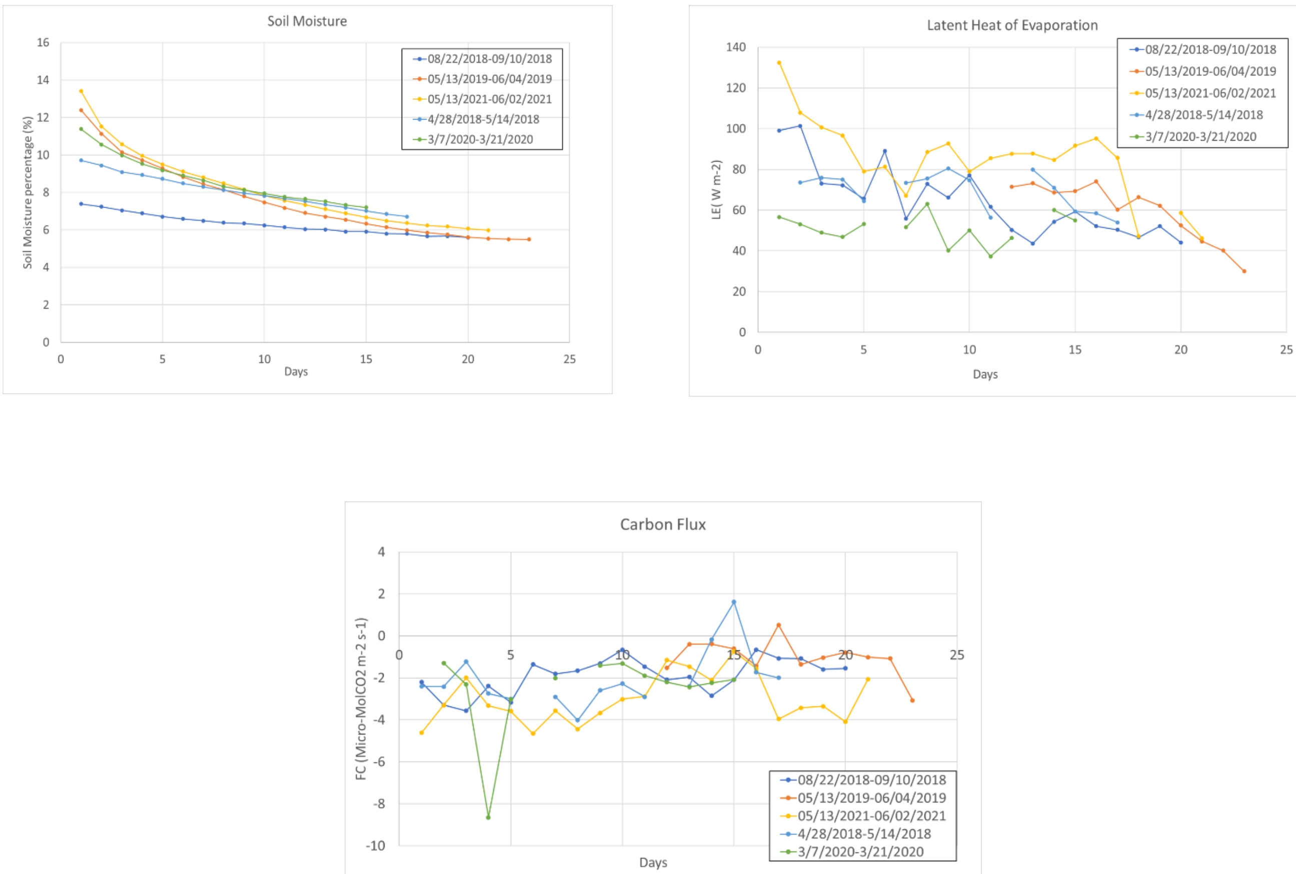


Figure 4: soil moisture, LE, and CO2 fluxes during a drought period

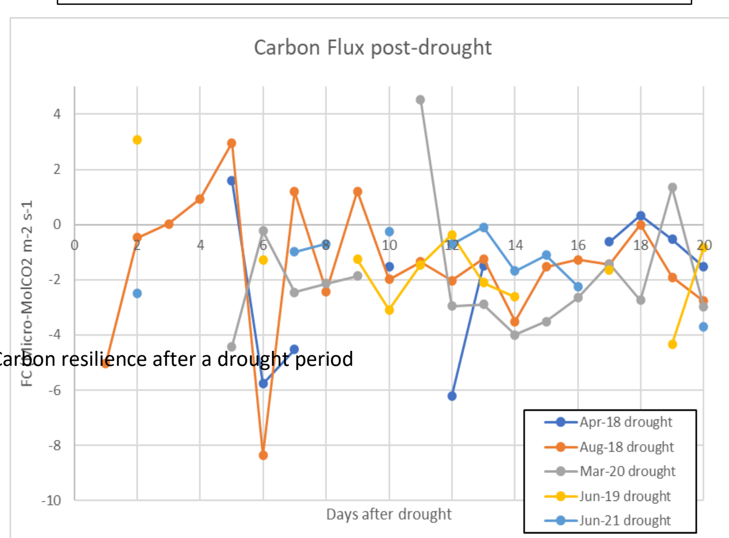


Figure 5: Carbon resilience after a drought period

V. Discussion/ Conclusion:

Throughout the five drought periods from 2017 to 2021, it can be concluded that the amount of carbon the loblolly pine and other vegetation can absorb after a rainfall event decreases during the subsequent dry period. Also, as the moisture in the soil dries, it causes the forest to respire less water over time. This information is useful for further investigations into forests of South Carolina and the relationship to the environment. While the data over five years is an accurate depiction of carbon sequestration in the environment, having data for a longer duration of time would be more beneficial.

The xeric and soft wood forests of the sandhills of South Carolina provide the main source of carbon sequestration by storing the carbon in their trunks. The data exhibited in this investigation shows the effects dry weather can have on sequestration, and that the vegetation is both relatively resistant and resilient. Overall, it provided a unique study into the relationship of the atmosphere and vegetation and the result it can have in our ecosystem.

Because of the location of the Savannah River Site, this study can be implemented again at other flux towers in different locations with different soil compositions. Weather events or U.S forestry thinning can also be studied in hopes to broaden the understanding of the carbon cycle and how this affects vegetation. This research is an important part of understanding the result of climate fluctuations in an ever-evolving ecosystem.

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