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CO_2 EFFLUX MEASUREMENTS ON AQUATIC AND TERRESTRIAL ECOSYSTEMS IN THE CONTEXT OF CLIMATE CHANGE

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Abstract

Ecosystem-based approaches to climate change mitigation involves the use of ecosystems carbon storage and sequestration services. For this purpose, comprehensive CO_2 efflux (R_{eco}) measurements of the wetland and terrestrial ecosystems were performed in the adjacent area of Bucharest, by applying two complementary methods using close chambers: dynamic by respiration chamber and static by injection kit. For the evaluation and comparison in time, the measurements were performed simultaneously with the two methods at relevant time intervals. The results of both practices have been inter–compared in the established plots. The aim of this paper is to highlight the values of R_{eco} measured on days when extreme temperatures and precipitations were recorded. The data set from the selected days was statistically analyzed in comparison with the recorded measurements during the corresponding season. The results highlight the response of CO_2 efflux in relation with daily meteorological parameters, for analyzing the ecosystems storage and carbon sequestration in the context of climate change. In addition, the analysis performed contributes to the uncertainty reduction for the independent use of the two methods as a monitoring tool for greenhouse gases exchanges between ecosystems and atmosphere.

***Keywords**: Ecosystem respiration; Chamber method; Injection kit; Wetland; Forest*

Introduction

With rising temperatures and CO_2 concentrations in the atmosphere, the worldwide environment is changing. Extreme temperatures have a negative impact on society and environment. Severe weather events have been occurring more frequently and with increased intensity in recent years, based on climate reports. CO_2 and temperature are two important factors that influence plant growth, development and function, and both have changed recently and are expected to change in the future [1]. Because these two factors are intertwined and the

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global CO_2 rise will have an impact on all ecosystems across the entire global temperature range, it's critical to revisit the theory and observations between the effects of temperature and CO_2 efflux, also the interactions on plant carbon balance, growth, development, and biomass accumulation.

Concern about global climate change and its implications for our future environment needs a deeper knowledge of the global carbon cycle on a global scale. Soils are particularly important in the global carbon cycle [2, 3], because they contain more carbon than living biomass [4], and CO_2 emission from the soil is a substantial flux of C into the atmosphere [5]. Soil CO_2 efflux accounts for 40–80 percent of forest ecosystem respiration [6, 7], making it one of the most important processes to include when calculating a forest's carbon balance. Wetlands represent transitional zones between aquatic and terrestrial environments. Global climate change is expected to have an impact on their hydrology, with significant spatial variation [8].

In recent decades net CO_2 emissions from agriculture, forestry and other land uses (AFOLU) activities have resulted in CO_2 emissions. The total net flux of CO_2 between land and atmosphere is estimated to have averaged 6.0 ± 2.0 Gt CO_2 yr^{-1} (likely range) from 2007–2016 [9, 10]. Direct anthropogenic activities, especially tropical deforestation, but also afforestation/reforestation, forest management and other types of land management, as well as peatland drainage and burning, contributed to this net flux [11, 12]. By reducing the uncertainties in carbon fluxes knowledge, the impact of mitigation actions based on ecosystem's management can be better estimated.

Land-atmosphere interactions, particularly the interplay of soil moisture, play a key role in the regulation of temperature extremes at the regional level, changing the distribution of maximum temperatures compared to the mean. During a major heat wave, a lack of precipitation as well as soil moisture deficit limits the latent cooling of the surface, leading to an increase in the duration and intensity of daily maximum CO_2 efflux. Additionally, organic matter decomposition controls the rate of carbon loss (CO_2 and CH_4) in wetlands, which has consequences for carbon sequestration in the face of rising global temperatures. Over the last decade, research has focused on the measurement of fluxes of greenhouse gases at the soil surface using a variety of methods. Chamber method can be used also on water surface. Monitoring the fluxes of greenhouse gases between ecosystems and atmosphere, coupled with other dependent parameters as temperature and precipitation, is important to better understand the uncertain exchanges in carbon cycle.

The first objective of this paper is to describe and compare the two methods applied in case studies for estimating CO_2 efflux from aquatic and terrestrial ecosystems: the respiration chamber technique and the injection kit method, as well as the results obtained. The second objective is to highlight the values of R_{eco} measured on days when extreme temperatures and precipitations were recorded. The data set from the selected days was statistically analysed in comparison with the recorded measurements during the corresponding season.

Experimental

Materials

The research area, located in the south-eastern Romania, Bucharest outer districts, is represented by two types of ecosystems: wetland and forest with a climate specific to the country, respectively temperate continental. A wetland along the Dambovita River represents the aquatic case study, with three locations of measurement: upstream, center, and downstream, near the river's discharge on an accumulation lake (Fig.1). The terrestrial ecosystems case study is represented by a forested area covered with black locust (*Robinia pseudoacacia* L.). The linear distance between the two ecosystems is 17.8km (Fig. 2).

Fig. 1. Spatial representation of the measurement plots in the wetland case study

Fig. 2. Spatial representation of the forest ecosystem study area

Methods

The standard equipment for the direct flux measurements (CO_2 EGM-5 analyzer with SRC respiration chamber) as well as the injection kit method were used to perform measurements and analyses for the implementation of the two approaches at the experimental locations to determine soil and water column respiration.

EGM-5

The dynamic respiration chamber measuring system (Fig. 3) consists of two main components, a portable CO2 gas analyzer (EGM-5) on which the operating system is installed and that contains an infrared gas analyzer for CO_2 determination, a pump that allows continuous sampling of the air flow, and a monitor on which the results are represented. The system's second component is a closed chamber with a surface area of 78cm^2 and a volume of 1171mL [13], as well as an optional in-situ sensor that may simultaneously measure the soil's temperature and humidity. A Stevens HydraProbe sensor was also used to measure soil moisture and temperature in the first 5cm of soil. This sensor on the EGM-5 delivers data every second on soil moisture between 0 and 100 percent and soil temperature between -10 and 55°C. As a result, data on these two parameters can be obtained concurrently with CO_2 efflux data.

In order to measure CO_2 efflux on at the water-air interface, the chamber system was closely connected to a floating device. The measurement duration was raised to 300 seconds, the utmost allowed by the device capacity, to adapt the methodology for monitoring CO_2 efflux in wetlands with a dynamic closed chamber.

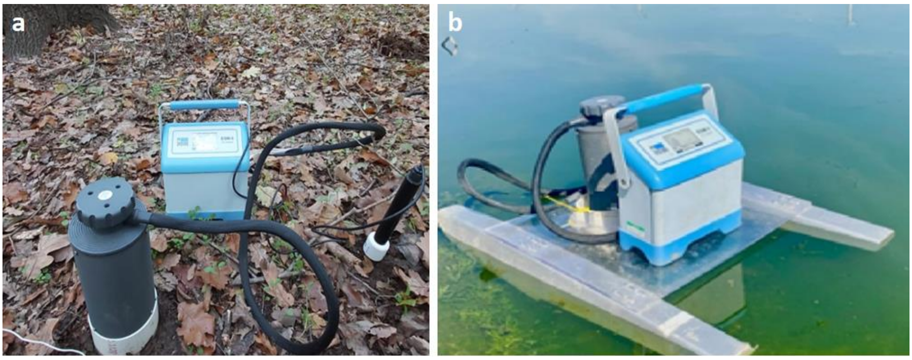

Fig. 3. CO_2 flux analyser EGM-5 with respiration chamber on soil (a) and adapted for water surfaces (b)

Injection Kit

The injection kit (Fig. 4) has two basic components: a network of tubing that links to the sampling vessel, the CO_2 accumulation chamber, and a series of injections with a volume of 10mL for the collected samples that allow monitoring the CO_2 content inside the chamber [14]. The source gas was swapped manually every 1 minute, and the Injection Kit sensor and the EGM-5 were both zero-calibrated at the beginning of the series. The injection system can be utilized as a replacement for portable in-situ greenhouse gas analysis equipment as well as for laboratory sample analysis.

To date, measurements have been conducted using both the portable device and injection system devices to test greenhouse gas exchanges in forest ecosystems and wetlands.

Fig. 4. Injection kit for carbon dioxide collecting and the analysis process

To compare the results of the two methods, preliminary measurements were taken simultaneously, and the values of the outcomes were compared. In addition, the variation of

CO_2 efflux was evaluated in relation to the main weather parameters (e.g. air temperature, precipitation). The temperature values were obtained from Baneasa station, which is the nearest meteorological station to the study areas and precipitation was obtained from satellite data.

Results and discussion

Forested area

In the following figure is represented the evolution of R_{eco} from forested area, measured with the two methods (EGM and Injection Kit) during the selected days. Also, in the same graphic can be observed the evolution of temperature and precipitations in the analyzed period.

From the graphic above (Fig. 5) it can be observed on the left axis the evolution of the CO_2 fluxes during the monitoring campaign with two distinct periods: before 1 July with recorded fluxes above the average and after 1 July with fluxes below the average. The precipitations and temperatures recorded in the analyzed period are represented on the right axis. The value of the precipitations represented on 23 June corresponds to the accumulated values from the beginning of the month.

It can be observed the increasing of the precipitation after the 1 July which corresponds also to the inflection point from the evolution of CO_2 fluxes. In the analyzed period the temperatures presented fluctuations of +/-4.5°C around the average value of 25.8°C. Statistical analysis is presented in the next section.

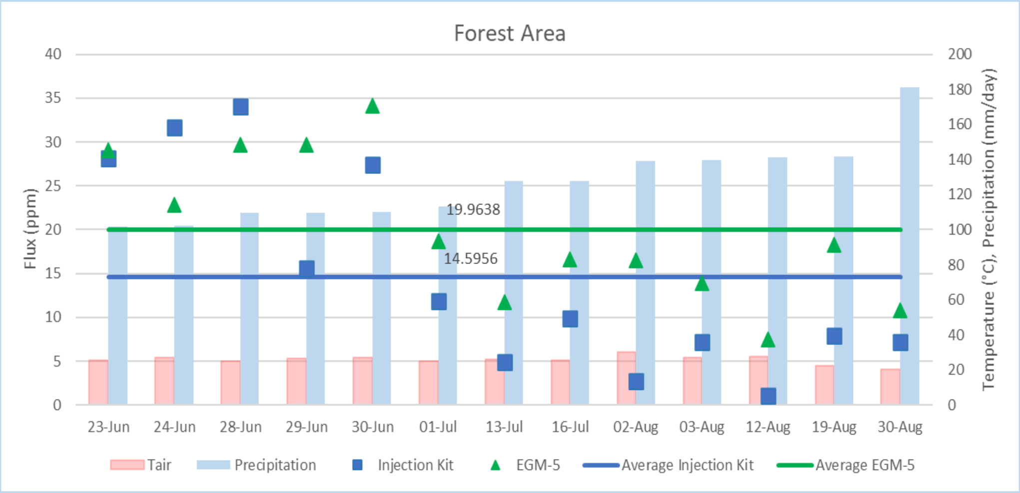

Fig. 5. Correlation of CO_2 flux values obtained by the injection kit method and the EGM-5 close chamber method in relation with weather parameters in the forest ecosystem

Pearson correlation of EGM-5 and KIT efflux was found to be strongly positive and statistically significant ($r = 0.837$, $p < 0.01$). Hence, the hypothesis that the relationship is significant was supported (Table 1). There were also significant, positive correlations between precipitations cumulated for 10 and 23 days and efflux calculated based on the two methods. A negative significant correlation was obtained between fluxes and cumulative precipitations.

It was also performed a bivariate regression to see how well KIT could predict level of EGM-5. The regression equation for predicting EGM-5 is $y = 0.607x + 11.107$. The r^2 for this equation was 0.701; it means that 70.1% of the variance in EGM-5 was predictable from the recorded values of KIT, resulting a strong correlation. The bootstrapped 95% confidence level for the slope to predict KIT from EGM-5 range from 0.344 to 0.870.

Wetland

The tables and figures below contain the results of the R_{eco} values measured with the dynamic closed chamber adapted to the wetland ecosystem and the injection kit and also the recorded precipitations and temperatures in the case studies area.

The CO_2 efflux was analyzed in this study area from November until February, the months from the cold season of the year, with the day of 06-Jan being identified as the day with the highest temperature, a value that exceeds the periods normal.

Table 1. Correlation matrix showing Pearson's r for efflux and meteorologic parameters for forest area

	KIT efflux	EGM-5 efflux	Tair	Daily PP	10 day PP	23 days PP	Cumulative PP
KIT efflux	1						
EGM-5 efflux	.837**	1					
Tair	-.019	.110	1				
Daily PP	.142	.034	-.473	1			
10 day PP	.691**	.403	-.292	.476	1		
23 days PP	.829**	.798**	-.041	.469	.717**	1	
Cumulative PP	-.719**	-.745**	-.437	.024	-.293	-.718**	1

**. Correlation is significant at the 0.01 level (2-tailed).
PP – precipitations
Tair – air temperature

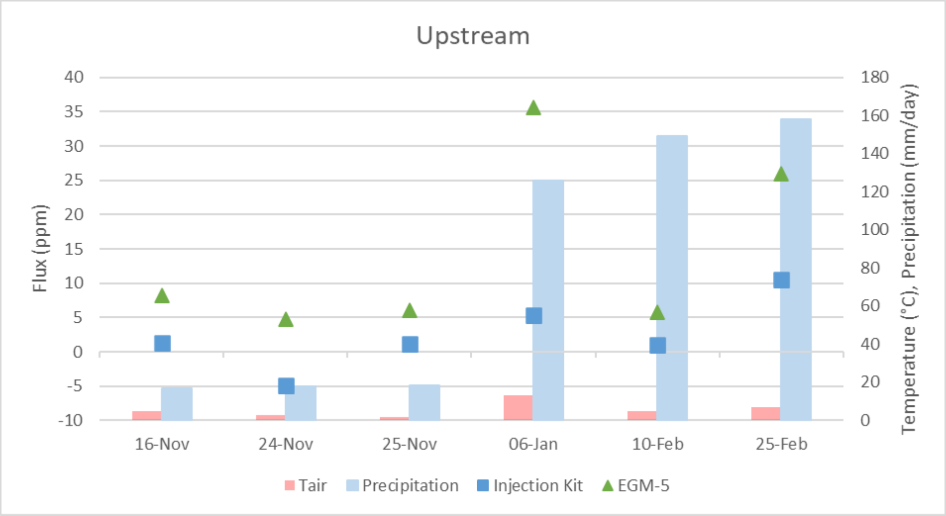

Fig. 6. Graphical representation of CO_2 flux values measured in the upstream area and its dependence on weather parameters

In the case of measurements in the wetland study area, the values obtained with EGM-5 closed chamber were predominantly higher than the values obtained by the injection kit method. In addition, as shown in figure 6, the highest temperature of 17°C recorded locally in the upstream area had a significant impact on the CO_2 efflux monitored by EGM-5. The precipitation value for the 16th of November corresponds to the accumulated values since the beginning of the month. After January 6, precipitation increases, which coincides with the peak point in the evolution of CO_2 efflux (Fig. 7).

R_{eco} values were obtained above the average of the series of measurements on January 6 in the central area of the river using both methods, as shown in figure 7. Also, the 15°C local temperature, along with the cumulative precipitation, resulted in a significant increase in CO_2 efflux values for the same day. The rest of the data set shows that the two methods are highly correlated, but with the EGM-5 measured efflux maintaining a higher trend than the injection kit method.

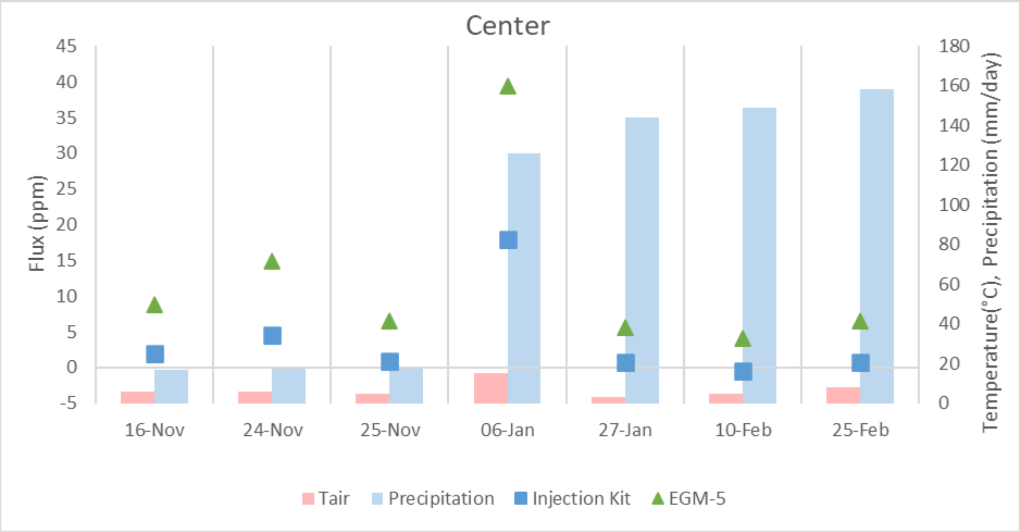

Fig. 7. Graphical representation of CO_2 flux values measured in the center area and its dependence on weather parameters

The CO_2 efflux values recorded in the downstream area are relatively noisy throughout the series of measurements, as can be seen in figure 8.

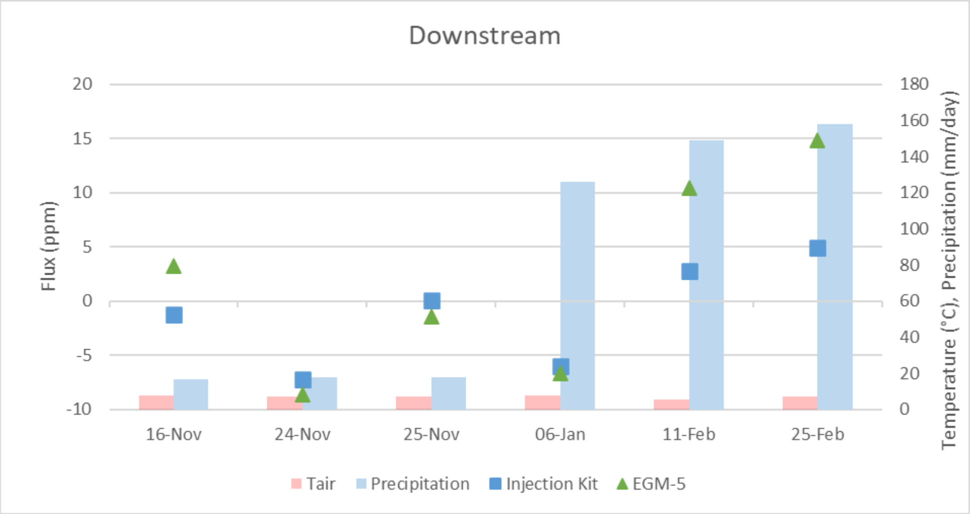

Fig. 8. Graphical representation of CO_2 flux values measured in the downstream area and its dependence on weather parameters

The values measured in this plots area by the two methods responded similarly to changes in CO_2 concentration. The plot's proximity to an accumulation lake along the river, as well as the complete lack of vegetation in this area, could be a determining factor that impacts respiration rate and, implicitly, CO_2 flux.

For the three locations within the wetland ecosystem, namely upstream, center and downstream statistical analyses were done between the efflux obtained using the two approaches and meteorological indicators of temperature and precipitation (Table 2 for upstream, Table 3 for center and Table 4 for downstream).

Table 2. Correlation matrix showing Pearson's r for efflux and meteorologic parameters for Upstream

	KIT efflux	EGM-5 efflux	Tair	Precipitations
KIT efflux	1			
EGM-5 efflux	.488	1		
Tair	.585	.921**	1	
Precipitations	.252	.894*	.874*	1

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

Table 3. Correlation matrix showing Pearson's r for efflux and meteorologic parameters for Center

	KIT efflux	EGM-5 efflux	Tair	Precipitations
KIT efflux	1			
EGM-5 efflux	.996**	1		
Tair	.917**	.915**	1	
Precipitations	.971**	.950**	.918**	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4. Correlation matrix showing Pearson's r for efflux and meteorologic parameters for Downstream

	KIT efflux	EGM-5 efflux	Tair	Precipitations
KIT efflux	1			
EGM-5 efflux	.830*	1		
Tair	-.372	-.167	1	
Precipitations	-.534	-.370	.976**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

For the upstream area, only statistically significant correlations between the EGM-5 efflux and air temperature and precipitation were observed based on the values gathered and assessed from a statistical standpoint. Thus, a bivariate regression was conducted to examine how well temperature and precipitations could predict the level of EGM-5 efflux in the upstream point.

The correlation between EGM-5 and air temperature was $r = 0.921$, $p < 0.01$. The regression equation for predicting EGM-5 efflux is: $y = 2.224x – 0.735$. The r^2 for this equation was 0.848 and depicts that the model explains 84.8% of the variance in EGM-5, which is a very strong correlation [15]. The bootstrapped 95% confidence level for the slope to predict efflux from temperature range from 0.916 to 3.533.

The correlation between EGM-5 and daily precipitations was $r = 0.894$, $p < 0.05$, with regression equation for predicting EGM-5 efflux of: $y = 10.211x + 7.609$. The r^2 for this equation was 0.799 and depicts that the model explains 79.9% of the variance in EGM-5, resulting a very strong correlation [15]. The bootstrapped 95% confidence level for the slope to predict efflux from temperature range from 3.101 to 17.321.

Pearson product correlation of center's EGM-5 and KIT efflux was found to be strongly positive and statistically significant ($r = 0.996$, $p<0.01$). Hence, the hypothesis that the correlation is significant was supported. This shows that an increase in EGM-5 values would lead to a higher KIT value.

There were also significant, positive correlations between air temperature and efflux calculated based on the two methods approached. Thus, a correlation of temperature with KIT of $r = 0.917$, $p < 0.01$ and with EGM-5 of $r = 0.915$, $p < 0.01$ was registered. The same was observed in the case of daily precipitation, with $r = 0.971$, $p < 0.01$ for KIT and $r = 0.950$, $p < 0.01$ for EGM-5.

A bivariate regression was conducted to examine how well KIT could predict the level of EGM-5 in the center point. The correlation between them was statistically significant, $r = 0.996$, $p < 0.01$. The regression equation for predicting KIT from EGM-5 is $y = 1.06x – 5.17$. The r^2 for this equation was 0.991; that is 99.1% of the variance in KIT was predictable from the level of EGM-5, representing a strong correlation [15]. The bootstrapped 95% confidence level for the slope to predict KIT from EGM-5 range from 0.943 to 1.173.

A regression was also performed to observe how well the air temperature could predict the level of KIT and EGM-5. Thus, the correlation between air temperature and KIT was statistically significant, and the regression equation was $y = 1.51x – 6.51$. The r^2 for this equation is 0.841, which represents 84.1% of the variance in KIT was predictable from air temperature. This is a strong correlation [15]. The bootstrapped 95% confidence level for the slope to predict KIT from air temperature range from 0.756 to 2.266; thus, for each one unit of increase of temperature, KIT increases by about 0.76 to 2.27 points. For EGM-5, the equation was $y = 1.417x – 1.201$, the r^2 was 0.836, that is 83.6% of the variance was predictable from air temperature. This is a very strong correlation [15]. The bootstrapped 95% confidence level for the slope to predict EGM-5 from air temperature range from 0.697 to 2.138.

Regarding the relation with the daily precipitations, the following could be observed: both correlations were statistically significant. With an equation of $y = 7.846x + 0.870$ and r2 of 0.943, which represents 94.3% of the variance in KIT was predictable from precipitation. The bootstrapped 95% confidence level for the slope to predict EGM-5 from air temperature range from 5.632 to 10.061. And with an equation of $y = 7.221x + 5.776$ and r^2 of .903 which represents 90.3% of the variance in EGM-5 was predictable from precipitation. The bootstrapped 95% confidence level for the slope to predict EGM-5 from air temperature range from 4.498 to 9.945.

Pearson product correlation of down stream's EGM-5 and KIT efflux was found to be strongly positive and statistically significant ($r = 0.830$, $p<0.05$). Hence, the hypothesis that the relationship is significant was supported. This shows that an increase in EGM-5 values would lead to a higher KIT value.

Also, it was conducted a regression to examine how well KIT could predict EGM-5 values in downstream point. The correlation between EGM-5 and KIT was statistically significant, $r = 0.830$, $p < 0.05$. The regression equation for predicting KIT from EGM-5 is $y = 0.862x + 4.050$. The r^2 for this equation was 0.688 and depicts that the model explains 68.8% of the variance in EGM-5, being a moderately strong correlation [15]. The bootstrapped 95% confidence level for the slope to predict EGM-5 range from 0.057 to 1.668.

The correlation matrix containing Person's r for efflux from all monitored points from wetland and precipitations is presented in the next table.

Table 5. Correlation matrix showing Pearson's r for efflux and precipitations for wetland area

	KIT UP	EGM UP	KIT DOWN	EGM DOWN	KIT CENTER	EGM CENTER	Precipitations
KIT UP	1						
EGM UP	.488	1					
KIT DOWN	.586	-.391	1				
EGM DOWN	.585	-.170	.830*	1			
KIT CENTER	.132	.909*	-.681	-.494	1		
EGM CENTER	.082	.899*	-.724	-.514	.997**	1	
Precipitations	.252	.894*	-.538	-.375	.970**	.950**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

From the table above it can be observed the significant correlation between flux values measured with KIT and EGM-5 in downstream point, EGM-5 in upstream with KIT and EGM-5 in center point and the correlation of KIT and EGM-5 in center point. The lack of correlation between fluxes measured in upstream or center with the downstream values indicate that downstream fluxes can be affected by particular elements as the proximity of the reservoir. Regarding the correlation of recorded fluxes with the precipitations it also can be observed the lack of correlation with the values in downstream.

Conclusions

Large differences in the magnitude of CO_2 efflux were observed between the average of reference period and the selected days when compared. In both ecosystems, CO_2 efflux obtained by the two methods was statistically analyzed with temperatures and precipitation, as indicated by the slopes of the linear regression. R_{eco} was correlated positively with cumulated precipitations in forest ecosystem in case of 10th and 23nd days. In the wasteland ecosystem significant correlation was obtained for upstream and center plots between fluxes and both weather parameters analyzed (precipitations and temperature). Also, the efflux was linearly correlated with both applied methods, the closed dynamic chamber EGM-5 method and the Injection Kit method in all measurement plots, excepting the upstream plot in wetland area.

This methodology can be used to support circumstances involving forest management efficiency and, on the other side, capitalizing on the efficiency of wetlands as eco-services, indicating their value in CO_2 storage. The purpose of this applied methodologies is to reduce the uncertainties regarding the dependence between the R_{eco} and weather parameters. By comparing different plots in the same conditions, the estimation of the dynamics of carbon fluxes can be improved. Thus, the application of management practices for carbon capture can be properly evaluated in terms of ecosystem storage and sequestration of carbon in the context of climate change.

In this study, air temperature and precipitation were important factors influencing efflux. In order to correlate the measurements made by the EGM-5 and injection kit procedures, pedoclimatic parameters were also determined using a humidity and temperature sensor, with the aim to better explain the variation in R_{eco}. This points out the need to comprehensively measure both the physical and chemical parameters that can affect CO_2 efflux.

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