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Reconciling Carbon Flux Discrepancies In A Desert Environment: Characterizing Influences Of Soil Processes Using Automated Co2 Flux Chambers

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RECONCILING CARBON FLUX DISCREPANCIES IN A DESERT ENVIRONMENT: CHARACTERIZING INFLUENCES OF SOIL PROCESSES USING AUTOMATED CO_2 FLUX CHAMBERS

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DEDICATION

I would like to dedicate this thesis to all the people that supported me throughout my master's degree. Thank you to all my professors and my advisor for all this support and help. I would like to dedicate this especially to my dad, sister and my mother who passed away three years ago. As I promised you, this is for you mom!

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by

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THESIS

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ABSTRACT

Dryland ecosystems play a fundamental role in controlling the balance of carbon on a global scale. These ecosystems dominate the inter-annual variability of carbon uptake by terrestrial ecosystems, and this is driven by temperature and precipitation patterns. Despite this global importance, there are some important discrepancies that have been reported between CO_2 fluxes measured with differing techniques, particularly between eddy covariance tower measurements of net ecosystem exchange (NEE) of carbon (C) versus on-the-ground methods such as chambers and biomass surveys. The discrepancy is a consequence of instrumentation and measurement technique differences; yet, its biological origins remain unknown. The goal of this thesis is to investigate some of these differences, particularly with respect to the CO_2 fluxes coming from soils. The first objective of this thesis was to design and build a set of CO_2 automated flux chambers. Using these automated flux chambers, I then investigated (1) the magnitude of soil CO_2 fluxes (R_S) over time and in comparison to environmental variables such as temperature and moisture; (2) comparisons of R_S with estimates of ecosystem respiration (ER) from a co-located eddy covariance tower; and (3) the influence of belowground autotrophic respiration (R_A) via a shrub removal experiment. The main findings include: (1) When temperature increases, CO_2 flux also increases over the course of spring and responds to rainfall. (2) The magnitude of CO_2 efflux from the soil to the atmosphere was similar between the eddy covariance tower and the automated flux chamber measurements. At midnight, a time when photosynthesis does not contribute to NEE measurements, the trends from both measurements matched closely, including a peak in CO_2 flux in the middle of March caused by a rain event in both measurements. This result suggests that both types of measurements can be accurately compared to each other. (3) In the shrub removal experiment, soil CO_2 efflux did not change as expected; instead it remained similar. Therefore, plants and especially roots did

not appear to contribute as much to soil respiration as expected. I believe environmental factors such as temperature, humidity, and pedogenic carbonates may contribute to this result, given the low amount of rainfall during this period. Overall, my results indicate that the discrepancies between tower and ground measurements are less likely to arise from the eddy covariance tower, since they matched the automated flux chamber values relatively well. Instead, the differences are more likely to originate from difficulties in measuring biomass-related fluxes such as belowground production.

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INTRODUCTION

1.1 Carbon flux in desert environments

Dryland ecosystems play a fundamental role in understanding the balance of carbon on a global scale. They constitute approximately 45% of the world's land area (67 mil km^2) and are predicted to expand because of climate change and desertification; as such, they warrant detailed study (Prăvălie, 2016; Feng & Fu 2013). Recent studies have shown that dryland ecosystems dominate the inter-annual variability of carbon uptake by terrestrial ecosystems worldwide, and this is driven by temperature and precipitation patterns (Poulter et al., 2014; Wang et al., 2014; Ahlstrom et al., 2015).

In building toward these global-scale analyses, one of the most important techniques is tower-based eddy covariance measurement of Net Ecosystem Exchange (NEE), which measures carbon fluxes at the landscape scale. The towers compute the exchange rate of carbon across the atmosphere, via measuring the covariance between carbon mixing ratio and vertical wind velocity (Baldocchi, 2003). Eddy covariance tower measurements suggest that deserts pivot between being a carbon source or sink depending on water availability (Biederman et al., 2017). Despite the importance of the data from eddy covariance towers, controversy has arisen about the magnitude of the carbon fluxes that have been measured. For example, net uptake of carbon from dryland ecosystems have been reported as being in the range of -102 to 127 g m^{-2} yr^{-1}, which is vastly more than aboveground Net Primary Production (ANPP) values recorded at similar desert sites obtained from biomass experiments using quadrants (10-30 g m^{-2} yr^{-1}; Schlesinger et al., 2009).

A study performed in the Chihuahuan Desert used biomass quadrants to measure plant cover, height, and species composition, and found shrublands ANPP to be 59.2 g m^{-2} yr^{-1}, which was positively correlated with precipitation (Muldavin et al, 2008). There are several possible reasons for the discrepancy between these different measurement techniques. First, it is difficult to individually record the amount of CO_2 produced by plants on a seasonal timescale. Second, heterotrophic respiration from microbes cannot be a value of less than or equal to zero, since they must be a source of CO_2; thus, NPP should be greater than NEE, the difference being heterotrophic respiration. Consequently, the values recorded by eddy covariance towers may be high when compared to NPP values, generating a mismatch between the values recorded by eddy covariance towers and the different NPP values recorded from different studies.

1.2 Quantifying carbon flux measurements

A combination of biotic and abiotic processes determines the flux of carbon from the soil to the atmosphere and vice versa. Partitioning these components will be beneficial for identifying the origin of the apparent mismatch between eddy flux towers and ground-based measurements. Net Ecosystem Production (NEE) is partitioned into biotic and abiotic components. The NEE of a desert ecosystem is calculated as follows:

R_s (automated CO_2 flux chamber)

NPP = ANPP + BNPP (biomass)

$$\mathrm{NEE} = \mathrm{GPP} - R_{\mathrm{stem/leaf}} - R_{\mathrm{root}} - R_{\mathrm{H}} - R_{\mathrm{abiotic}}$$

(EC tower) R_{eco} (modelled from EC tower)

(Equation 1)

where GPP is the Gross Primary Production, corresponding to the gross uptake of carbon used for photosynthesis, $R_{\mathrm{stem/leaf}}$ is autotrophic respiration from the stem and leaves of plants, R_{root} is autotrophic respiration from roots and shoots, R_{H} is heterotrophic respiration from all non-plants, and R_{abiotic} includes processes such as carbon loss from pedogenic carbonates (Serna-Pérez et al., 2006) and photodegradation (Austin & Vivanco, 2006). NEE is positive if there is a loss of carbon from the ecosystem to the atmosphere, and negative if there is an uptake of carbon by the ecosystem.

Autotrophic respiration (R_A) is associated with the growth and maintenance of roots, while heterotrophic respiration (R_H) is the decomposition of carbon pools in the soil by microbes. Soil respiration (R_S) describes the sum of belowground and aboveground R_A and R_H including decomposition of organic matter at the soil surface. The amount of photosynthesis that is not used for respiration and is available for other processes is defined as Net Primary Production (NPP) and relates to Gross Primary Production (GPP) as GPP = NPP + R_A (Luyssaert et al., 2007).

Aerobic respiration in plants is influenced by abiotic factors such as environmental temperature and relative humidity. Abiotic factors also play an important role in the carbon flux from the soil to the atmosphere. A significant factor is pedogenic carbonates, which are formed by dissolved CO_2 originated from biological sources and precipitation of Ca^{2+} from the soil parent material and reprecipitating as calcium carbonate in the soil (Gocke, 2011). Arid ecosystem soils mainly develop on non-calcareous parent materials and the rate of carbonate accumulation is presumed to depend upon rates of Ca^{2+} influx (Gocke et al., 2012). Figure 1.1 illustrates the different biotic and abiotic factors which contribute to NEE on a landscape level in the Chihuahuan desert.

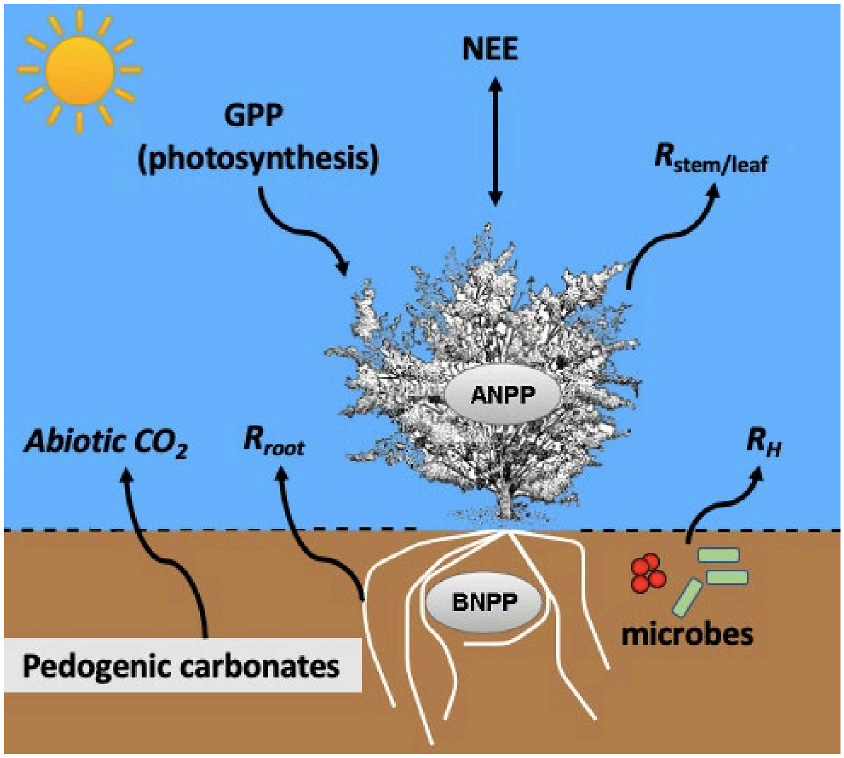


Figure 1.1 CO_2 diagram with biotic and abiotic factors which contribute to soil respiration

My aim was to design and build an automated flux chamber system for deployment at The Jornada Long Term Experimental Range (LTER) site to measure soil respiration (R_S) fluxes, with the goal of comparing time series of these fluxes to those from the nearby eddy flux tower (Hernandez 2014). Subsequently, I assessed and quantified the effectiveness of scaling patterns and controls of land-atmosphere carbon, water, and energy exchange in Chihuahuan desert shrubland with novel cyberinfrastructure from The University of Texas at El Paso.

1.3 Shrub removal study

In this study, I investigated belowground autotrophic respiration (R_A), by the complete removal of creosote shrubs with its roots in proximity to the automated flux chambers. I compared the belowground autotrophic respiration to NEE obtained from the Eddy Covariance Tower on a landscape level. The goals of this work were to investigate the influence creosote shrubs and their roots have on belowground NPP, and furthermore, to reconcile the discrepancy in measurements from the Eddy Covariance Tower and the automated flux chambers. Thus, this experiment examined how carbon flux in the automated flux chambers is influenced by the removal of nearby creosote bushes. The eddy covariance tower measured carbon on a landscape level, while automated flux chambers measured carbon on a small scale. Therefore, with a greater number of automated flux chambers, both output values were similar. My research benefited from a well-constrained and understood environment, as well as the existing instrumentation at The Jornada LTER site. The outcome contributes to the effort to reconcile the discrepancies between the eddy covariance towers and other types of smaller-scale instrumentation.

1.4 Objectives and study questions

The first objective of this study was to build the automated flux chambers in an effective manner. There was a lot of troubleshooting and trial-and-error to develop the automated flux chambers to an operative point. One of the improvements was the mechanism of opening/closing of the lid. This gave stability and strength to the lid itself and the base of the automated flux chambers attached in a coherent way. The second objective was to test the functionality of the automated flux chambers via addressing questions concerning carbon exchange at our study site. I addressed the following questions: (1) What is the magnitude of soil CO_2 fluxes (R_S) over time, and their relationship with environmental variables such as temperature and moisture?; (2) How do measurements of R_S from the automated chambers compare with estimates of ecosystem respiration (R_{eco}) from a co-located eddy covariance tower?; and (3) What is the influence of belowground autotrophic respiration (R_A) on overall R_S, which I examined via shrub removal experiment.

MATERIALS AND METHODS

2.1 Construction of CO_2 automated flux chambers

This project required the construction of six new automated flux chambers. Several improvements were made from the original design from Alan C. Riggs (Riggs et al., 2009) and subsequently from Ed Grote (Darrouzet-Nardi et al., 2015). The automated flux chambers collect CO_2 land-atmosphere exchange data from the soil automatically and record the data every ten seconds for a duration of four minutes every hour. The lids were able to open/close pneumatically with the help of a Viair 150 PSI High-Flow Air Compressor.

The primary goal was to attain long-term unattended operation by using 12-volt batteries and 100-Watt solar panels. The structure of the automated flux chambers was built from aluminium T-Slots to give them a more rigid structure and to make them more resistant to the sun. The opening/closing mechanism was changed in the position of the piston from the original design of Ed Grote (Figure 2.1).

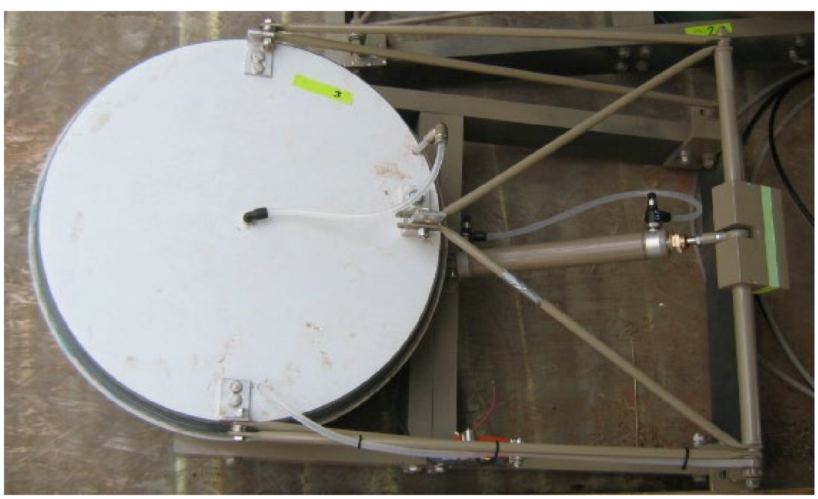


Figure 2.1 The original design of Ed Grote's automated flux chamber.

The piston was moved to the back of the automated flux chamber instead of the middle. In consequence this change affected how the automated flux chambers open/close by giving the collars and lids a stronger and better seal; allowing no CO_2 to escape and it puts more emphasis on having a sturdy and durable structural design with the use of T-Slots. It also allows for a quick and easy way to change the position of the different components such as the height/position of the lid, and the position of the piston in relevance to the base of the automated flux chamber.

This section includes a list of materials used, and brief outline of the process for constructing one automated flux chamber. The materials used for constructing a single automated flux chamber were:

- 15" diameter Irrigation PVC Pipe Length 6" (Quantity 1)
- 15" diameter Irrigation PVC Pipe Length 2" (Quantity 1)
- 1.5" x 3" T-Slotted Extrusion Length 30.75" (Quantity 2)
- 1.5" x 3" T-Slotted Extrusion Length 15.25" (Quantity 5)
- 1.5" x 1.5" T-Slotted Extrusion Length 20.15" (Quantity 3)
- T-Slots 15S 8 Hole Inside Corner Gusset (Quantity 8)
- T-Slots 15S 4 Hole Inside Corner Gusset (Quantity 4)
- T-Slots 5/16-18" x 11/16" FBHSCS & Economy T-Nut (Quantity 66)
- T-Slots 15S 8 Hole Joining Plate (Quantity 2)
- T-Slots 1" Single Horizontal Base (Quantity 4)
- Synflex 250' 1300 Tubing Coils (Quantity 2)
- Legris Connector Male Elbow, 90 Degree, ¼ Inner diameter (Quantity 1)
- High Temperature Silicone Foam Rubber Bulb Seal, 3/4" Overall Width, 9/16" Overall Height, Black (Quantity 1)

- 18-8 Stainless Steel Hex Head Cap Screw, 5/16"-18 Thread, Length 2" (Quantity 13)
- Type 18-8 Stainless Steel Flat Washer, 5/16" Screw Size, 0.344" Inner Diameter, 0.750" Outer Diameter (Quantity 13)
- Type 18-8 Stainless Steel Nylon-Insert Locknut, 1/4"-20 Thread Size, 7/16" Wide, 5/16" High (Quantity 8)
- Stainless Steel Tee Nut Insert for Wood, Type 18-8, 5/16"-18 Thread Size, Length 0.375" (Quantity 4)
- Clippard Spherical Rode End, 5/16-24" Thread, 17SER (Quantity 1)
- Legris flow control (Quantity 2)
- 1" Outer Diameter x 0.120" Wall Steel Round Tube, Length 20" (Quantity 1)
- High-Strength PVC Sheet, 24" x 24" x 1/4" (Quantity 1)
- SMC Clevis Bracket (Quantity 1)
- SMC Double-Acting Air Cylinder, 0.4375" Rod Size, 1.5" Bore Diameter, 12" Stroke Length, Double End Mount (Quantity 1)

The construction of an automated flux chamber began by cutting a 15" diameter Irrigation PVC Pipe into two different sections to build the base and lid (Figure 2.2).

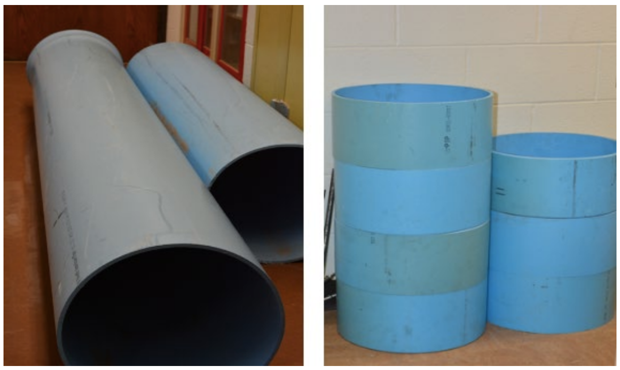


Figure 2.2 PVC Cylinder before and after cutting into sections for base and lid of automated flux chambers

The lid was built by gluing together the 15" diameter Irrigation PVC Pipe of length 2" to a 15" diameter PVC aerobie previously cut from the High-Strength PVC Sheet (Figure 2.3).

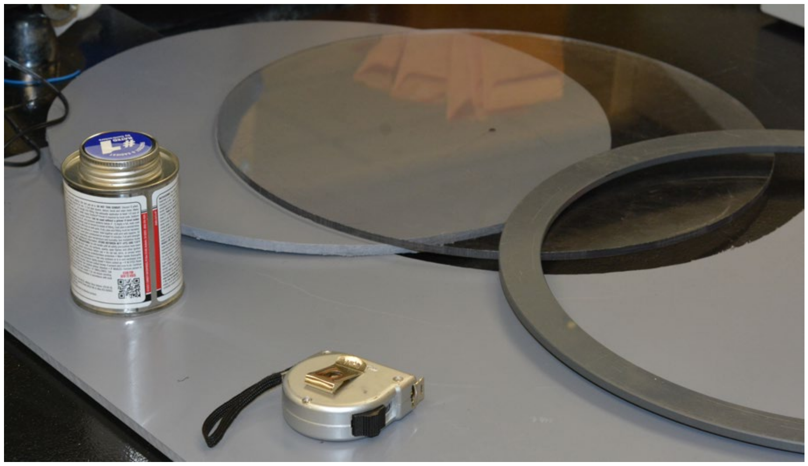


Figure 2.3 Construction of the lid PVC aerobie using silicone rubber bulb seal

A High Temperature Silicone Foam Rubber Bulb Seal was also glued to the PVC pipe for the lid to seal properly. The top of the lid had a Legris Connector Male Elbow to allow a Synflex Tube to connect to permit for the passage of CO_2. A closed system of tubing inside of the lid allowed the CO_2 to return to the automated flux chamber. The assembled lid was connected to 1.5" x 1.5" T-Slotted Extrusion of length 20.15" by using the 18-8 Stainless Steel Hex Head Cap Screw of length 2" along with the Type 18-8 Stainless Steel Nylon-Insert Locknut (Figure 2.4).

Figure 2.4 Lid assembly illustrating the connection of T-slot extrusions to the PVC aerobie

The base was constructed by attaching two 1.5" x 3" T-Slotted Extrusions of length 30.75" and two 1.5" x 3" T-Slotted Extrusions of length 15.25" to the PVC pipe using four Stainless Steel Tee Nut Inserts (Figure 2.5).

Figure 2.5 Attaching PVC Pipe to T-slot extrusions to build the base of the chambers

The T-Slotted extrusions were connected to each other by using the T-Slots 15S 8 Hole Inside Corner Gusset. A lid was attached to the base of the automated flux chamber by connecting 1.5" x 3" T-Slotted Extrusion of length 30.75"of the base to two vertical 1.5" x 3" T-Slotted Extrusion of length 15.25" and to the 1" Outer Diameter x 0.120" Wall Steel Round Tube by using the T-Slots 1" Single Horizontal Base. A SMC Double-Acting Air Cylinder (piston) was attached to the base of the automated flux chamber by using a SMC Clevis Bracket.

The top part of the piston was attached to a 1.5" x 1.5" T-Slotted Extrusion of length 20.15" using a Clippard Spherical Rode End which allowed the piston to slightly rotate its position when the lid was either lowered or raised. This was an extremely important component which allowed the lid to open and close without any restrictions of the piston (Figure 2.6).

Figure 2.6 Attachment of the air cylinder to the lid and base of the automated flux chamber

The construction of a first prototype automated flux chamber allowed me to change some original components that at the end were not used and allowed me to tweak and tinker as the prototype was constructed. The remaining five chambers were then constructed in bulk after the first automated flux chamber was developed and finalized (Figure 2.7), using the same design implementation, measurements, components, and materials. The operation of all six is identical.

Figure 2.7 Assembly of all six automated flux chambers at The Jornada LTER site

2.2 Electronics and assembly of CO_2 automated flux chambers

This section includes a list of electronic instruments used, and brief outline of the process for connecting all the automated flux chambers together allowing them to work in sequence.

- Campbell Scientific CR1000 Datalogger (Quantity 1)
- Campbell Scientific SDM-CD16AC Relay Controller (Quantity 1)
- Viair 150 PSI High-Flow Air Compressor including a pre-wired pressure switch (Quantity 1)
- SMC Solenoid Valve (Quantity 6)
- KNF Air Pump (Quantity 1)
- Parker Hannifin Miniature Pump (Quantity 3)
- Omega Engineering Mass Flow Sensor (Quantity 1)
- Licor Li-840A CO_2/H_2O Gas Analyzer (Quantity 1)
- Omega Engineering Relative Humidity/Temperature Transmitter (Quantity 1)
- SMC Direct operated two port valve (Quantity 12)
- Renogy 100-Watt 12 Volt Monocrystalline Solar Panel (Quantity 5)
- Interstate Batteries 12 Volt 100Ah Sealed Large Deep Cycle Battery (Quantity 5)
- Morningstar Prostar 30 Amp 12/24 Volt Solar Charge Controller (Quantity 3)
- Polyphaser Voltage Suppressor (Quantity 3)

Following completion of the automated flux chambers, I performed testing in the laboratory. The opening and closing mechanism were initially tested in the prototype chamber. The SMC Double-Acting Air Cylinder was firstly connected to a SMC Solenoid Valve and this was connected to a Nitrogen Cylinder just for testing purposes (Figure 2.8).

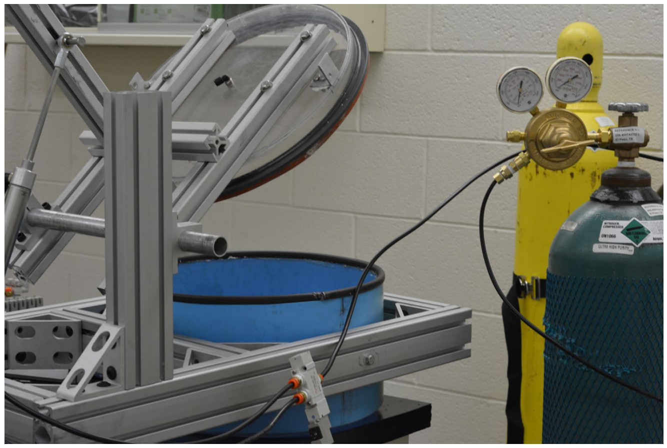


Figure 2.8 Laboratory testing of opening/closing mechanism of an automated flux chamber

The next step was to connect all the automated flux chambers together to the Viair 150 PSI High-Flow Air Compressor. The Air Compressor was connected to six independent SMC Solenoid Valves which allowed the passage of regulated air. The Campbell Scientific SDM-CD16AC Relay Controller which was controlled by the Campbell Scientific CR1000 Datalogger turned the SMC Solenoid Valves on/off when it was programmed to do so allowing for the lids to be raised or lowered in sequence (Figure 2.9).

Figure 2.9 Connecting and testing the six automated flux chambers at the Green Roof of the Biology Building at UTEP.

The automated flux chambers were powered with Solar energy. Two of the Renogy 100-Watt 12 Volt Monocrystalline Solar Panels were connected to two 12 Volt 100Ah Sealed Large Deep Cycle Batteries in parallel. The entire array was 12 Volts and with the help of the Solar Charge Controller allowed the Viair 150 PSI High-Flow Air Compressor to work without interruption for 24 hours. Two different solar panels and batteries were connected in series to create an array of 24 volts. With the help of the Solar Charge Controller it allowed the SMC Solenoid Valves and SMC Direct operated two port valve which required 24 Volts to work properly (Figure 2.10).

Figure 2.10 Controllers, polyphasers and two port valves interconnected to control the airflow of the automated flux chambers.

The remaining Renogy 100-Watt 12 Volt Monocrystalline Solar Panel was connected to a single 12 Volt 100Ah Sealed Large Deep Cycle Battery. With the help of a Solar Charge Controller this array was used to power all the brain electronic equipment such as the Campbell Scientific CR1000 Datalogger, Campbell Scientific SDM-CD16AC Relay Controller, KNF Air Pump, Omega Engineering Relative Humidity/Temperature Transmitter, Omega Engineering Mass Flow Sensor, Licor Li-840A CO_2/H_2O Gas Analyzer and the Parker Hannifin Miniature Pumps (Figure 2.11). All the electronic equipment was protected against lighting by grounding all the components and a Polyphaser Voltage Suppressor was used to protect the equipment and batteries against thunder.

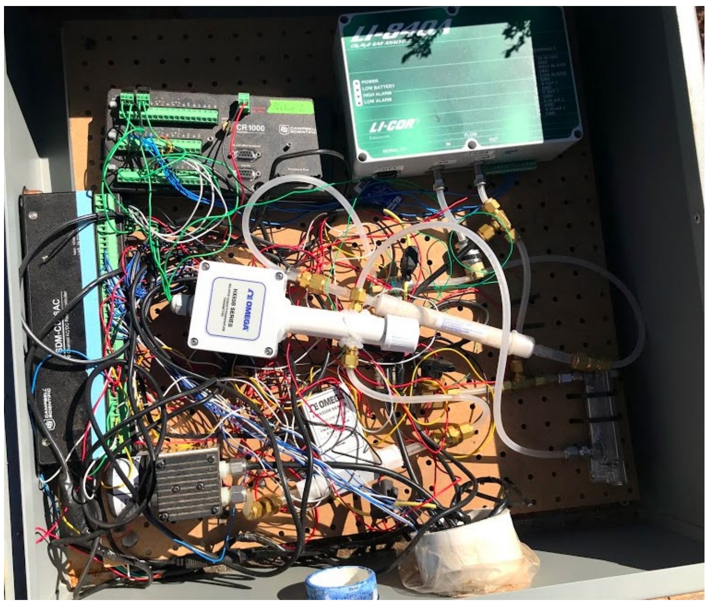


Figure 2.11 Brain electronic components which controlled the overall function of the automated flux chambers

2.3 Site Information and CO_2 automated flux chambers installation

The field site was located at The Jornada Experimental Range (32.581956, -106.635025) near Las Cruces, New Mexico. The Mean Annual Temperature is 15 °C and the Mean Annual Precipitation is 247 mm per year (Bird et al., 2002). The dominant plant species at The Jornada

LTER site are black grama (*Bouteloua eriopoda),* creosote bush (*Larrea tridentata*), mesquite (*Prosopis glandulosa*) and tarbush (*Flourensia cernua*).

The soil parent material consists of limestone and igneous alluvium. The carbonate content in the form of calcite at The Jornada LTER site affects the soil morphology and its classification (Havstad et al., 2006). Soils at The Jornada LTER site contain caliche layers with stage IV and V carbonates preserved in deep soil layers exposed by water or wind erosion. The total soil carbon at a shrubland near to our study site is 1.51-5.82 wt%. The soil organic carbon is 0.41-0.43 wt% and the soil inorganic carbon is 1.10-5.39 wt% at 0-48 cm depth. Caliche is ~ 45 wt% calcite (Nyachoti et al., 2017).

Weather data is also recorded at the site, including air and soil temperature, incoming radiation, wind speed among other environmental factors. Soil moisture is recorded using time domain reflectometry (TDR) sensors installed near the Eddy Covariance Tower. These probes collect signals transmitted into a medium such as soil water and the analysis of the reflected signal particularly their magnitude, shape and sign provide a complete image of the transmitting medium (Dwevedi et al., 2017). TDR sensors offer a cost-effective way of estimating soil moisture in a large area such as The Jornada LTER site. These sensors measure air and soil (open and shrub) temperature, rain, moisture and wind speed in proximity to the Eddy Covariance Tower. The Eddy Covariance Tower measures fluxes every 30 minutes obtained from the Infrared Gas Analyzer (Licor Li-7500) and sonic anemometer (CSAT3-SONIC CSI) installed at the tower. The average footprint of the Eddy Covariance Tower is estimated to be at 370 meters using footprint models (Jaimes, 2014).

I installed the automated flux chambers in a flat area close to the Eddy Covariance Tower. The site soil texture is firm enough to allow for minimum maintenance of the automated flux chambers and they were installed in a strategic location to avoid flooding during intense precipitation events (Figure 2.12).

Figure 2.12 The Jornada LTER installation site of automated flux chambers

The automated flux chambers were tested for two months at the Green Roof located on the top of the Biology Building at The University of Texas at El Paso prior to deployment in the field. The automated flux chambers were installed at The Jornada LTER site in June 2018. Once in the field it took three weeks to fully get the automated flux chambers operational and with the appropriate equipment for weather hazards such as rain, dust and thunderstorms and animal disturbances (Figure 2.13). The Viair 150 PSI High-Flow Air Compressor, SMC Solenoid Valves, SMC Direct operated two port valves, Solar Charge Controllers, Polyphaser Voltage Suppressor and Deep Cycle Batteries were enclosed in a 130 Gallon Polyethylene Outdoor Deck Box. The electronic equipment was enclosed inside a Weather Resistant Enclosure. The collar of the automated flux chambers was installed on top of the soil. The site where the automated chambers were installed is a shrubland and the dominant species is creosote bush (*Larrea tridentata*). The collars were placed near six different creosote bushes.

Figure 2.13 Weather resistant enclosures for electronic equipment at The Jornada LTER

2.4 CO_2 automated flux chambers operation

The automated flux chamber opaque lids close in sequence every hour for a duration of four minutes. The instruments recorded carbon dioxide concentration values every ten seconds from a Licor Li-840A CO_2/H_2O Gas Analyzer. The flow of air starts when the first automated flux chamber lid closes and a KNF Air Pump pulls the gathered air into a closed flow system ending back at the same automated flux chamber. This allows for a slow and steady accumulation of CO_2 inside the automated flux chamber allowing the carbon dioxide to increase while the lids are closed.

An Omega Engineering Mass Flow Sensor was connected to the KNF Air pump and measured the average flow rate of the carbon dioxide. The flow rate of the system was 7 L/min with 0.5 L/min going through the IRGA. Water vapor content and temperature of the sample also were recorded by an Omega Engineering Relative Humidity/Temperature Transmitter which was connected to the flow sensor.

All the recorded data points which include CO_2 concentration of the air passing through the system, internal pressure recorded from the Licor, air flow average obtained from the Mass flow sensor, Water Vapor Content and Temperature from the Humidity/Temperature Transmitter were sent to a Campbell Scientific CR1000 datalogger which stored the information from every automated flux chamber as it was averaged every ten seconds. The automated flux chambers were operational from January 13 to April 30, 2019. Figure 2.14 shows the different processes that were required for the automated flux chambers to work efficiently.

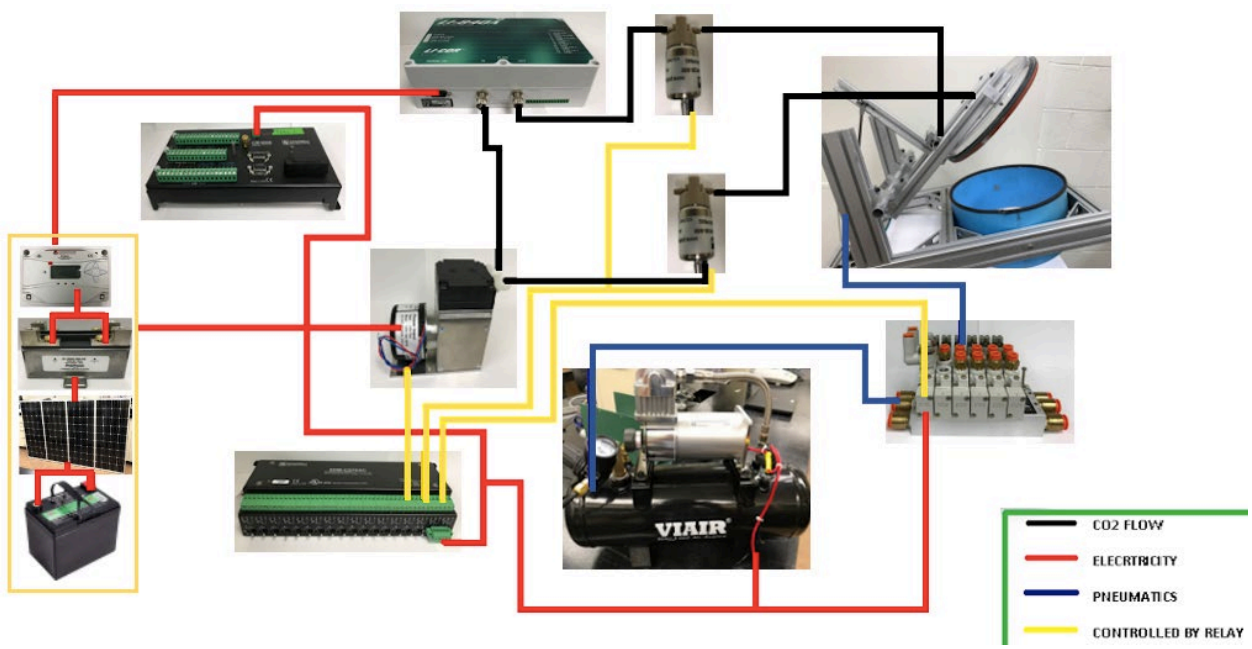


Figure 2.14 Automated flux chambers operations diagram. It includes CO_2 flux pathway in black, electricity pathway in red, pneumatics pathway in blue and relay-controlled pathway in yellow.

2.5 Removal of creosote bush

Two creosote bushes and their roots were manually removed on January 25, 2019 from automated flux chamber 2 and automated flux chamber 5 (Figure 2.15). The removed bushes were near the automated flux chambers; therefore, my hypothesis is that removal of shrubs and roots would reduce the CO_2 fluxes that were recorded.

Figure 2.15 Automated flux chamber 2 before and after removal of creosote bush

2.6 Data analysis and statistics

Data from the automated flux chambers were collected on an hourly basis from January 23 to April 30, 2019. A total of 12,827 data points for 5 automated flux chambers were recorded since the data of chamber 6 was omitted due to technical problems. The data were analyzed using the programming language R (R Development Core Team, 2018). The data from the five automated flux chambers was assembled into columns in a single data file along with environmental data containing air and soil temperature, photosynthetically active radiation (PAR), wind speed and soil moisture obtained from the eddy covariance tower. Environmental factors such as temperature, moisture and precipitation were compared to the cumulative CO_2 fluxes from five automated flux chambers.

Relationships between CO_2 flux from the five automated flux chambers and soil temperature were examined by fitting exponential curves from 5 to 25 °C. Temporal trajectories were summarized using local regression (loess, span = 0.75). Most models use a 1.5 to 2.0 for the increase of soil respiration per 10 °C. Q10 is the factor by which soil respiration increases by 10 °C (Meyer et al., 2018). I got the exponent values from the temperature exponential fits object Q10 = exp(10*a).

Correlations between moisture and CO_2 flux were also compared but regression was not attempted since there was no clear association between the CO_2 flux and soil moisture content. A time series between cumulative CO_2 flux from the five automated flux chambers and precipitation was compared.

For the creosote bush removal experiment, a Welch two sample *t*-test was performed before and after removal of the creosote bushes on January 25, 2019 from automated flux chamber 2 and 5. A time series comparison between the ecosystem respiration from the eddy covariance tower and the cumulative CO_2 from the automated flux chambers was performed. Reco_U50 is the NEE flux data measured from the eddy covariance tower, U* filtered and gap-filled using the R package ReddyProc. U* filtered is an approach to minimize bias associated with horizontal and vertical advective forces in an eddy covariance tower (Van Gorsel et al., 2009). U50 indicates that data was filtered with the 50th percentile related to U* filter. I used a linear regression to examine the relationship between the tower and chamber data. Workflow documentation is valuable for this project and a data download guide is available as well as all the codes used to analyze such data in the programming language R.

RESULTS

3.1 CO_2 flux trends over time

At the beginning of the measurement period on January 13, 2019, during the winter season, when the temperatures were cold at the site, CO_2 fluxes were as low as 0.1 µmol m^{-2} s^{-1} (Figure 3.1). As the temperature warmed up, CO_2 fluxes increased up to 0.8 µmol m^{-2} s^{-1}. In the middle of March 2019 there was a peak in the CO_2 flux as there was a rainfall event during that time. In coordination with this particular rainfall event, I compared hourly CO_2 efflux from the eddy covariance tower and the automated flux chambers (Figure 3.2). I saw a decline in CO_2 flux from both the eddy covariance tower and the automated flux chambers after the precipitation event. I think this is due to CO_2 absorbed by the soil by pedogenic carbonates.

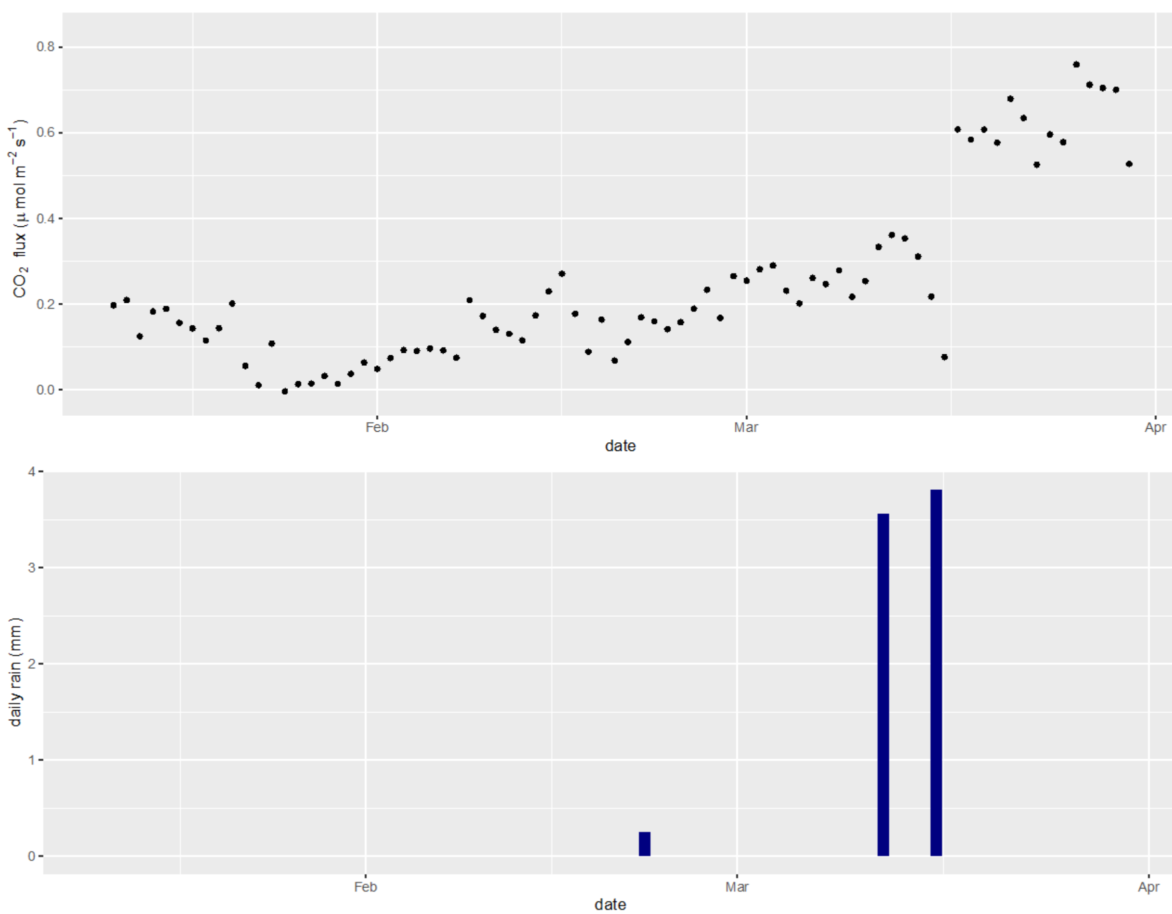


Figure 3.1 Comparison of cumulative CO_2 fluxes from five automated flux chambers and daily rainfall for the period of 13 January - 30 April 2019. Positive values indicate a release of CO_2 from the soil to the atmosphere. There is a peak in CO_2 in the middle of March which correlates with a precipitation event.

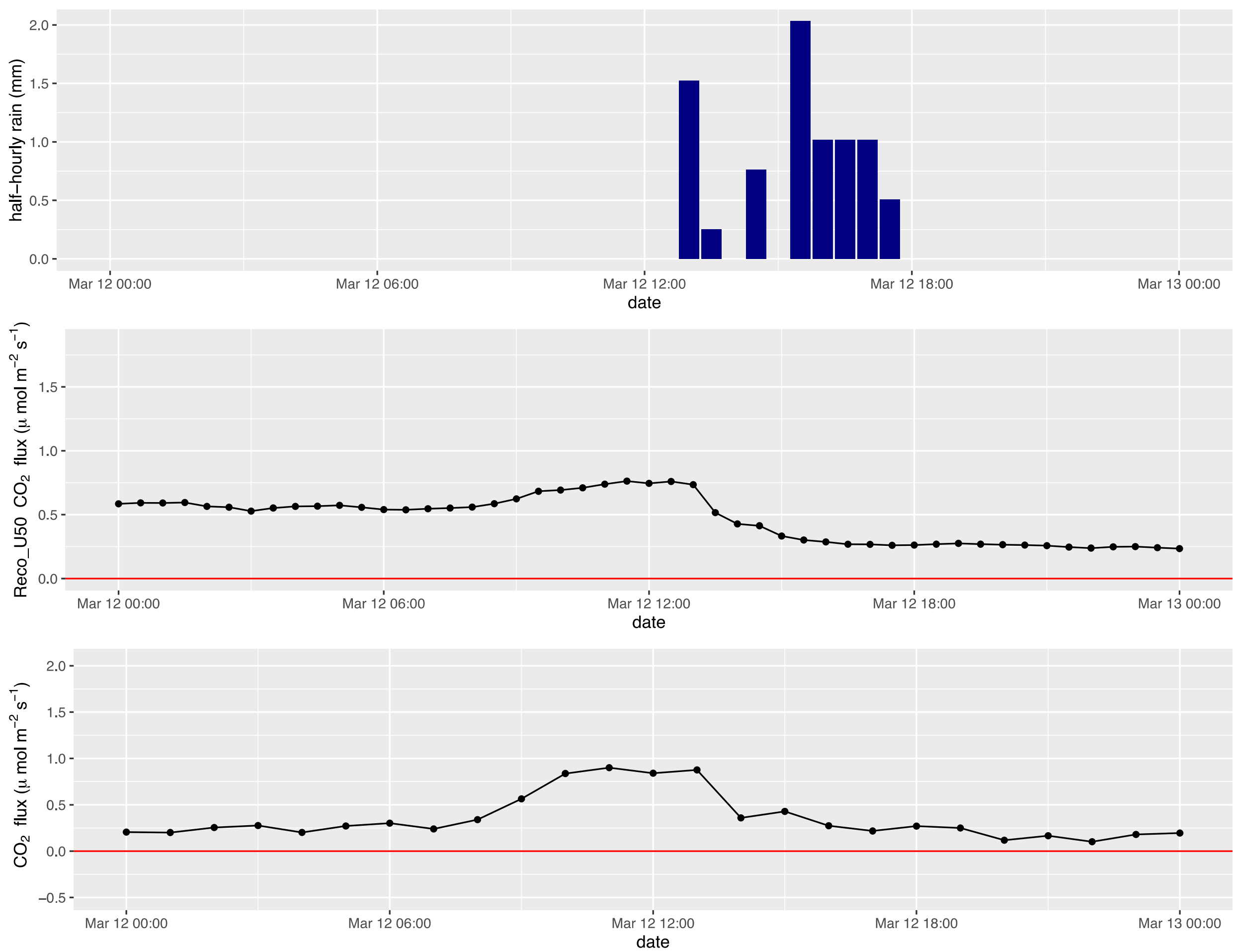


Figure 3.2 Hourly CO_2 efflux from eddy covariance tower and five cumulative automated flux chambers along with hourly rainfall. The period of recorded measurements was taken on March 12, 2019 in coordination with a big rainfall event.

3.2 Relationships with environmental conditions

Relationship with temperature

Increases in air temperature were associated with increases in CO_2 flux for each of the individual automated flux chambers (Figure 3.3). This association was most noticeable in automated flux chamber 1. Automated flux chambers 2 to 5 had a similar increase in CO_2 flux as temperature increased. Q10 was 2 for these data. The exponential curves show an increase in CO_2 from 5 to 25 °C. The data was color coded ranging from blue indicating nighttime hours to red indicating daytime hours. Over the course of the day from nighttime to daytime, the CO_2 flux from the automated flux chambers increased as the temperature increased.

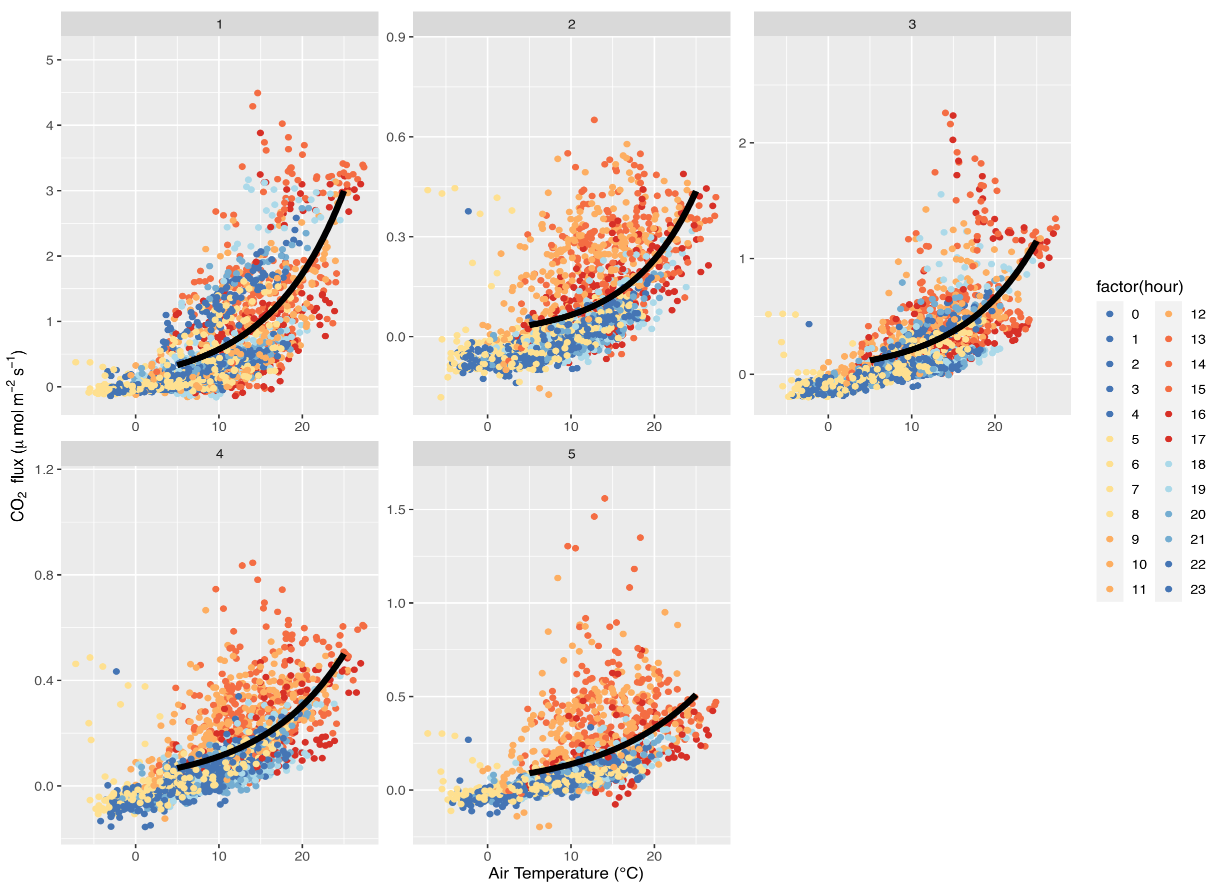


Figure 3.3 Correlations between CO_2 fluxes from five automated flux chambers and air temperature from 13 January - 30 April 2019. Exponential curves were fitted from 5 to 25 °C. Black lines are exponential fits. Positive values indicate an increase in CO_2 as air temperature increases. The data was color coded ranging from blue indicating nighttime hours to red indicating daytime hours.

Relationship with humidity and precipitation:

As soil moisture increased there was not the same type of association with increase in CO_2 fluxes (Figure 3.4). However, I note that the Time Domain Reflectometry (TDR) sensors on site did not capture good moisture data over the course of the study period due to missing values from instrument failure (Figure 3.5). During my initial testing of the automated flux chambers on the UTEP Biology Building Green Roof, the soil of the automated flux chambers was artificially wet with water and the CO_2 from each of the automated flux chambers increased noticeably, suggesting that moisture and precipitation play an important factor in the activity that microbes, roots and plants play in the soil.

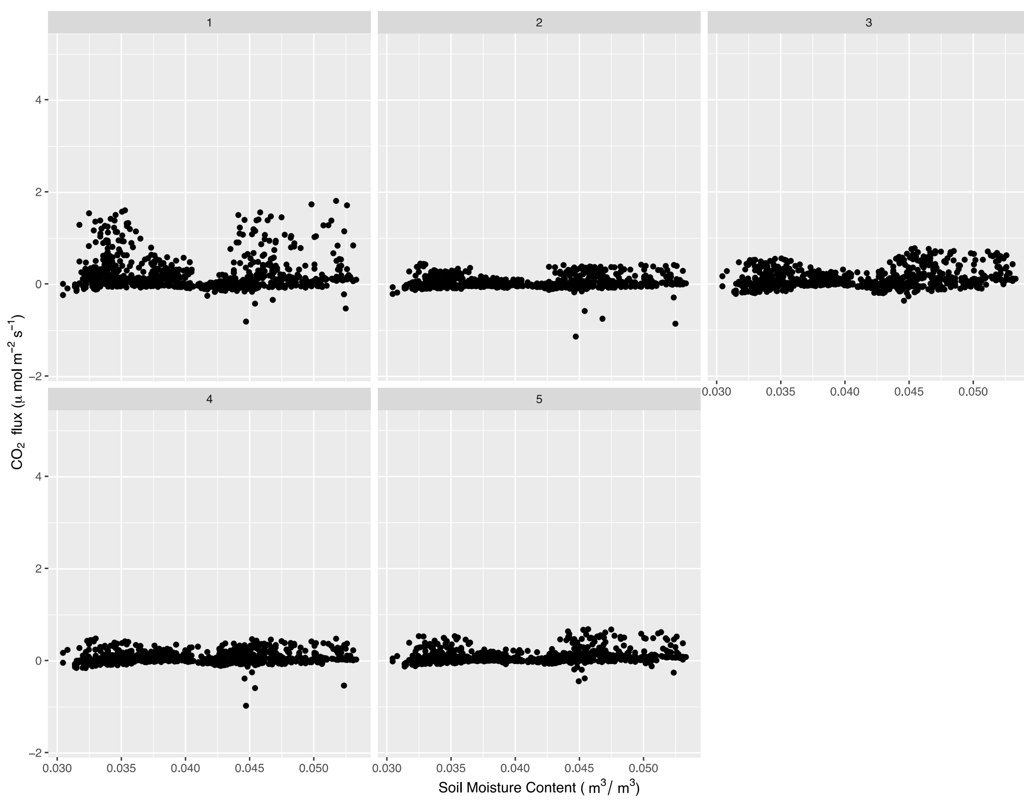


Figure 3.4 Correlation between individual CO_2 fluxes from five automated chambers and soil moisture content. A linear regression was not possible since there was no significant correlation between both CO_2 flux and Soil Moisture Content.

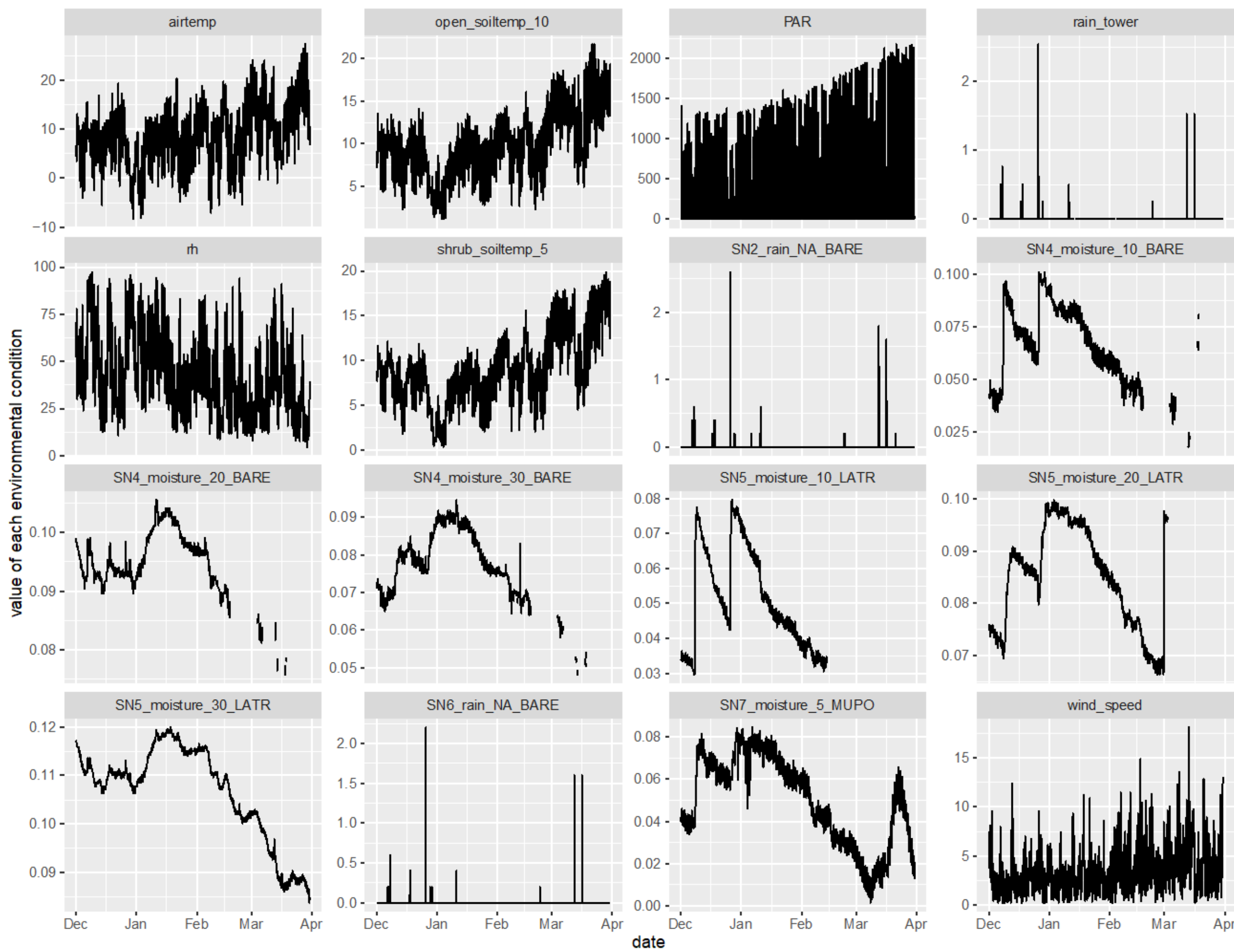


Figure 3.5 Weather data of eddy covariance tower from January 12 to March 31, 2018. Different sensors in the tower measure air and soil (open and shrub) temperature, rain, moisture and wind speed. No data was recorded using time domain reflectometry (TDR) sensors therefore the soil moisture data from those graphs are not shown.

Night-time uptake

The graph below shows an increase in CO_2 flux when temperatures get hotter starting at sunrise in the mornings to sunset in the evenings (Figure 3.6). This is noticeable at around 12 pm when the temperature during the day is the hottest and the sun is at its highest point. Additionally, during the night, there was on some days an uptake of CO_2 from the soil.

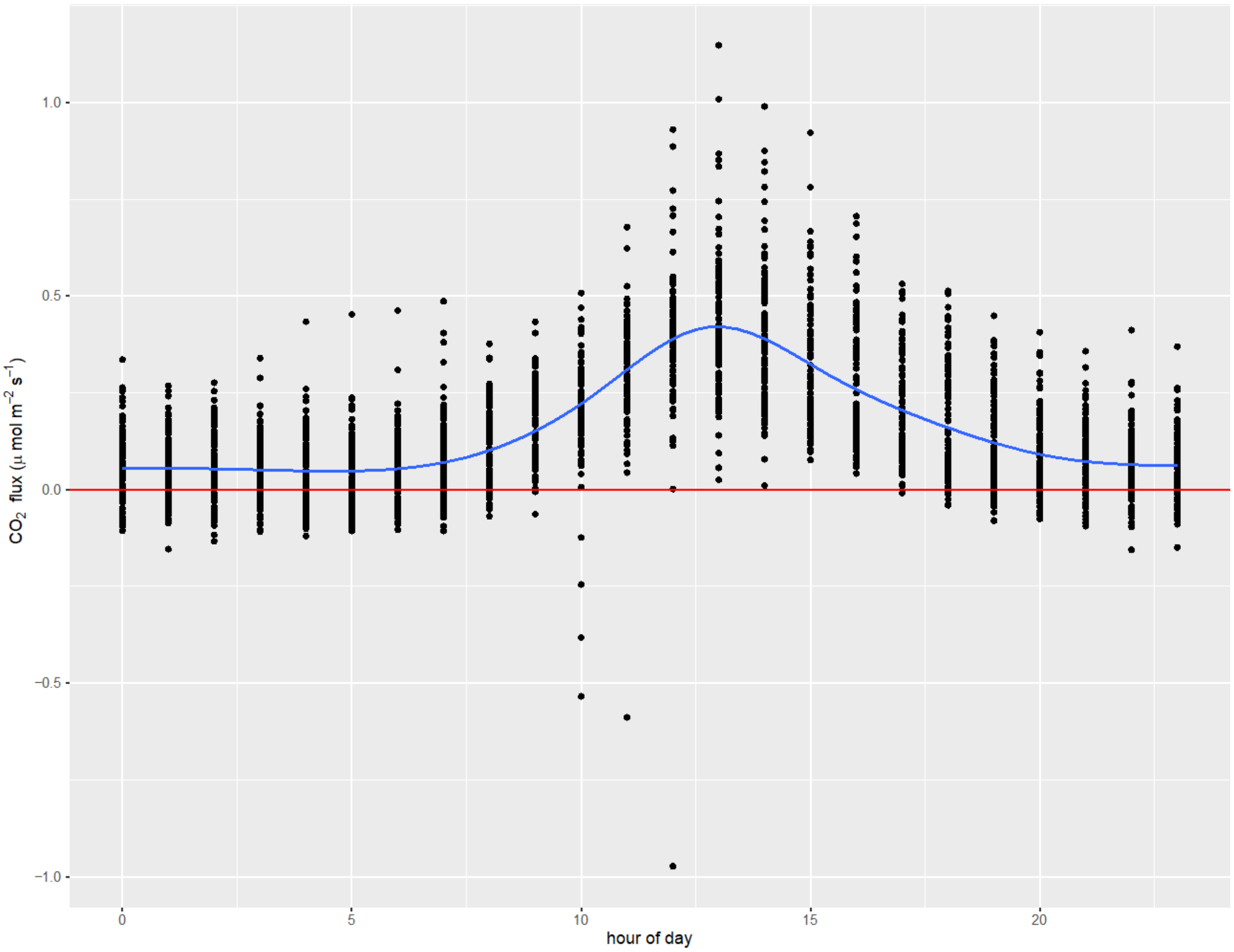


Figure 3.6 24-hour average uptake of CO_2 of five automated flux chambers. A local polynomial regression fitting (loess) was used, with span = 0.75 and degree 2. Positive values indicate a release of CO_2 from the soil to the environment. Negative values indicated an uptake of CO_2 by the soil.

I further examined when this night-time uptake occurs. I saw an increase in CO_2 flux uptake at midnight from the months of February to May (Figure 3.7). It did not happen every night consistently. As an example, automated flux chamber 4 clearly demonstrates that CO_2 flux decreases at night during the length of an hour at a consistent rate (Figure 3.8).

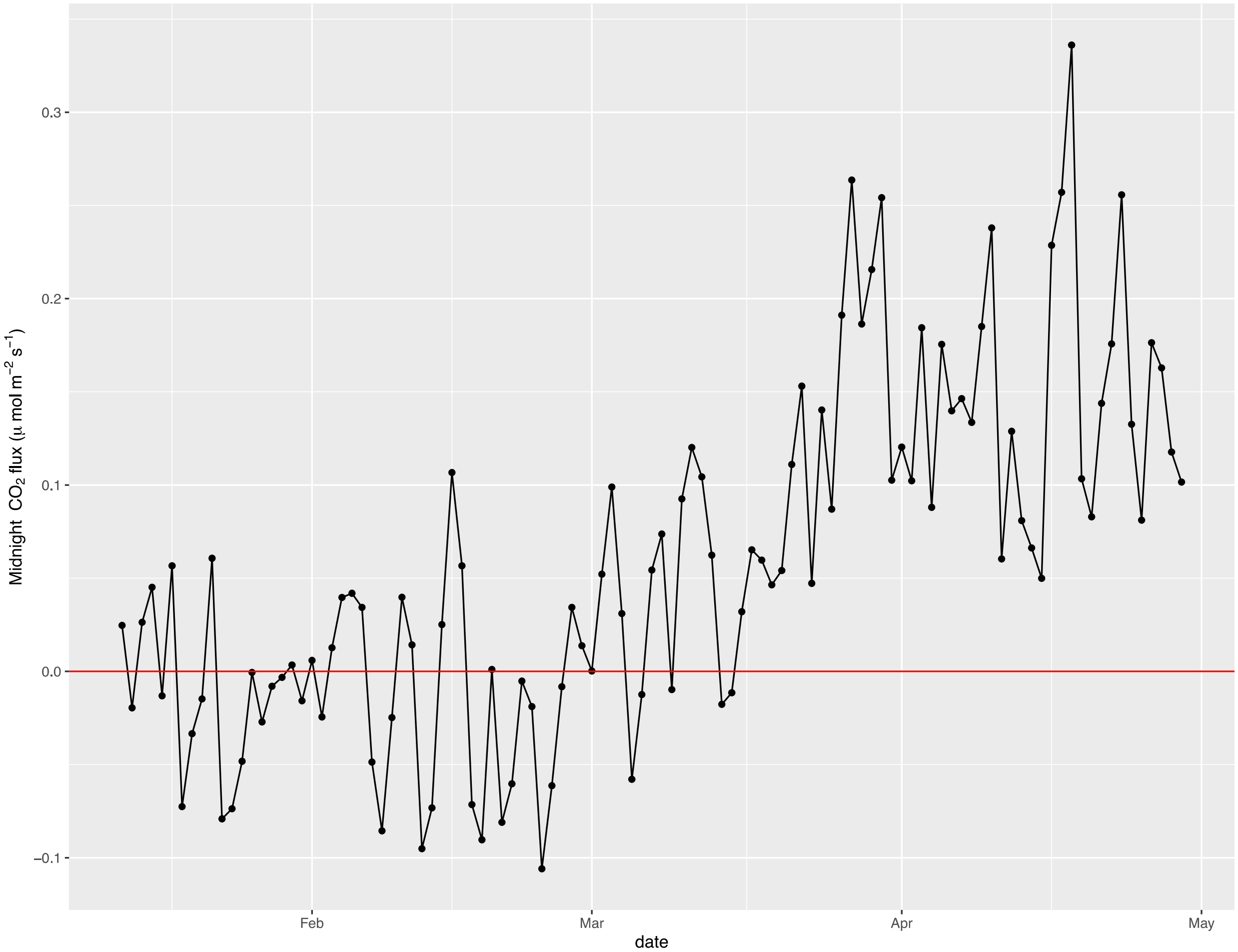


Figure 3.7 Midnight CO_2 flux patterns for automated flux chamber 4 daily for the period of 13 January - 30 April 2019. Positive values indicate a release of CO_2 from the soil to the environment. Negative values indicate an uptake of CO_2 by the soil.

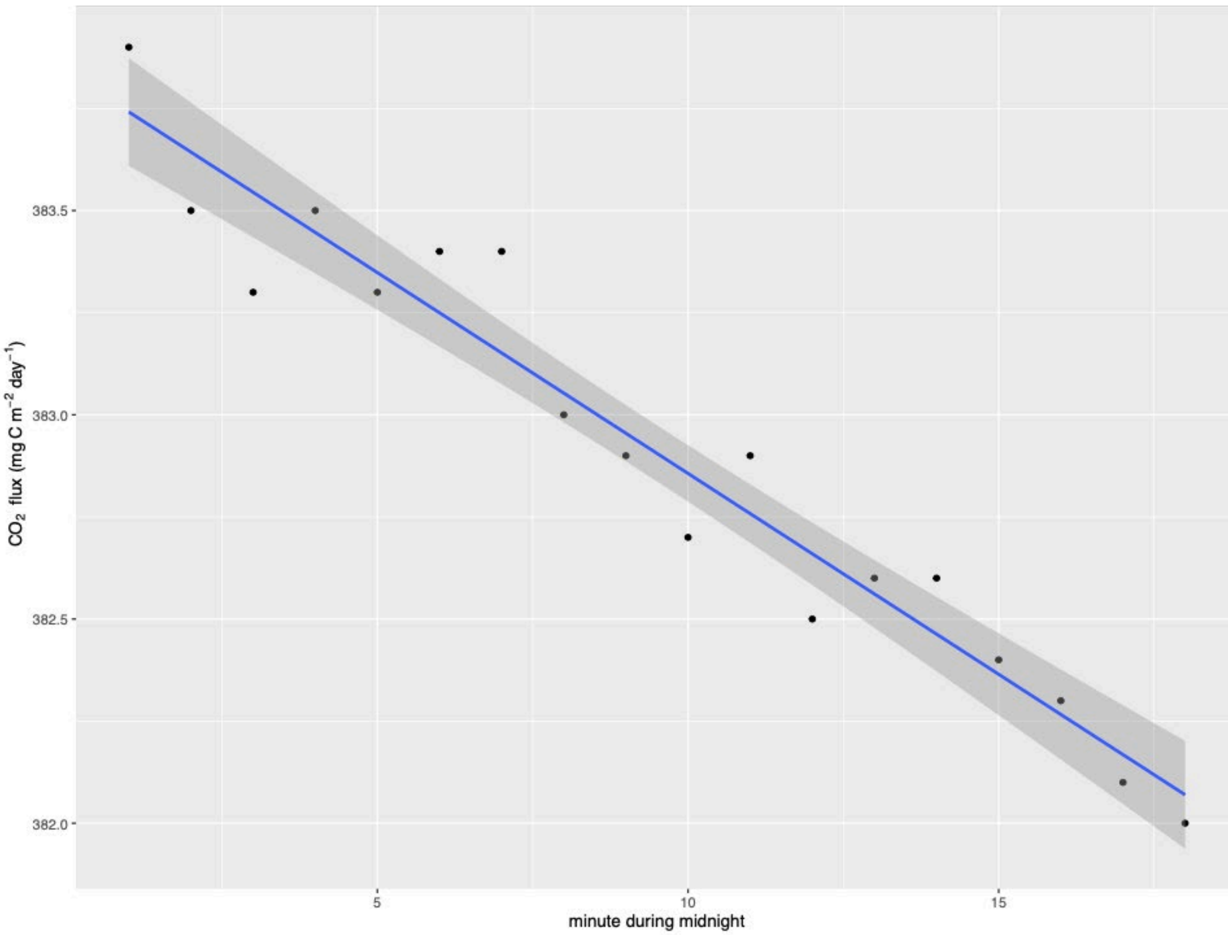


Figure 3.8 Hourly negative CO_2 flux pattern for automated flux chamber 4. A regression line in blue was fitted to the scatterplot. R-squared is 0.94 and the slope of the plot is -10. Shaded part shows uncertainty in the slope and intercept. The standard error is 232.50. There is a continued decrease in CO_2 throughout the day.

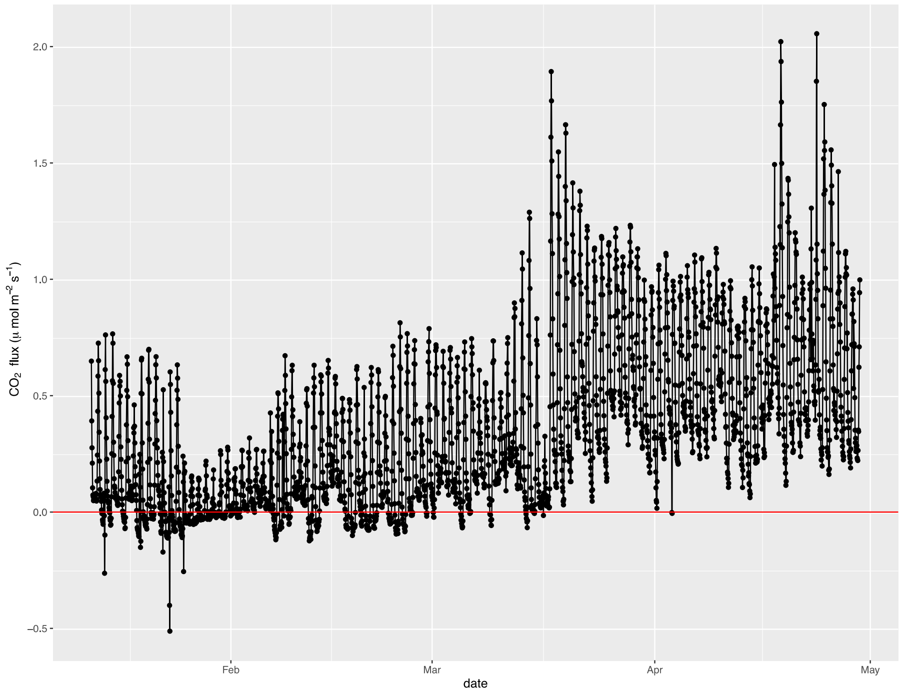
3.3 Impact of shrub removal

I observed no evidence of reduction in CO_2 emissions with the removal of the creosote bushes on automated flux chamber 2 and automated flux chamber 5 on January 25, 2019 (Table 3.1). Opposite to what was hypothesized, there continued to be a slight increase in CO_2 flux in both of the chambers. I expected to see a significant reduction of CO_2 when the creosote bushes were removed since I hypothesized plants and roots played a major impact on the overall source of CO_2 from the soil to the atmosphere. When comparing automated flux chambers 2 and 5 to automated flux chambers 3 and 4, Table 3.1 shows an extremely wide confidence interval of -158 to 168, indicating it is too small of a sample size. While not definitive due to the sample size, there is no clear evidence for reduction based on shrub removal. Additionally, there was substantial chamber to chamber variation. In particular, the automated flux chamber 1 value of 267 mg C m^{-2} day^{-1} indicates that particular shrub was very active compared to the other shrubs.

Table 3.1 Individual CO_2 flux emissions before and after removal of creosote bushes on automated flux chambers 2 and 5. All numbers are in units of mg C m^{-2} day^{-1}. The before period is January 13- to 25, the after period is February 3 to 28.

Automated Chamber	CO_2 before removal of bush (mg C m^{-2} day^{-1})	CO_2 after removal of bush (mg C m^{-2} day^{-1})	CO_2 difference (mg C m^{-2} day^{-1})
1	250	516	267
2	58.5	63.8	5.32
3	159	128	-31.2
4	77.1	89.4	12.3
5	132	118	-13.7

3.4 Comparison of flux data from Eddy Covariance Tower and automated flux chambers



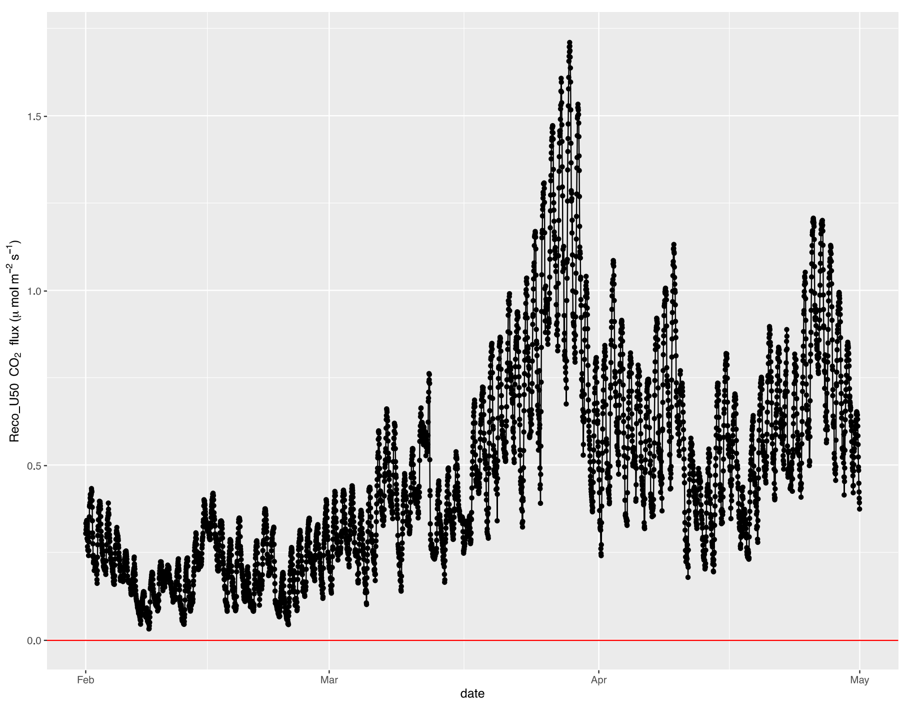


Figure 3.9 Comparison of Eddy Covariance Tower CO_2 flux (first graph) and cumulative CO_2 automated flux chamber measurements (Second graph) from 1 February to 30 April 2019. Positive values indicate a release of CO_2 from the soil to the environment. Negative values indicate an uptake of CO_2 by the soil.

The Ecosystem Respiration (R_{eco}) over the months of February to April 2019 of the Eddy Covariance Tower (Figure 3.9) showed an overall release of CO_2 from the soil to the atmosphere but during some instances for example in January showed an uptake of CO_2 by the soil. The automated flux chambers measurements showed a release of CO_2 to the atmosphere without any uptake by the soil. The order of magnitude between the two graphs are similar. The R_{eco} is higher, though it also includes aboveground respiration.

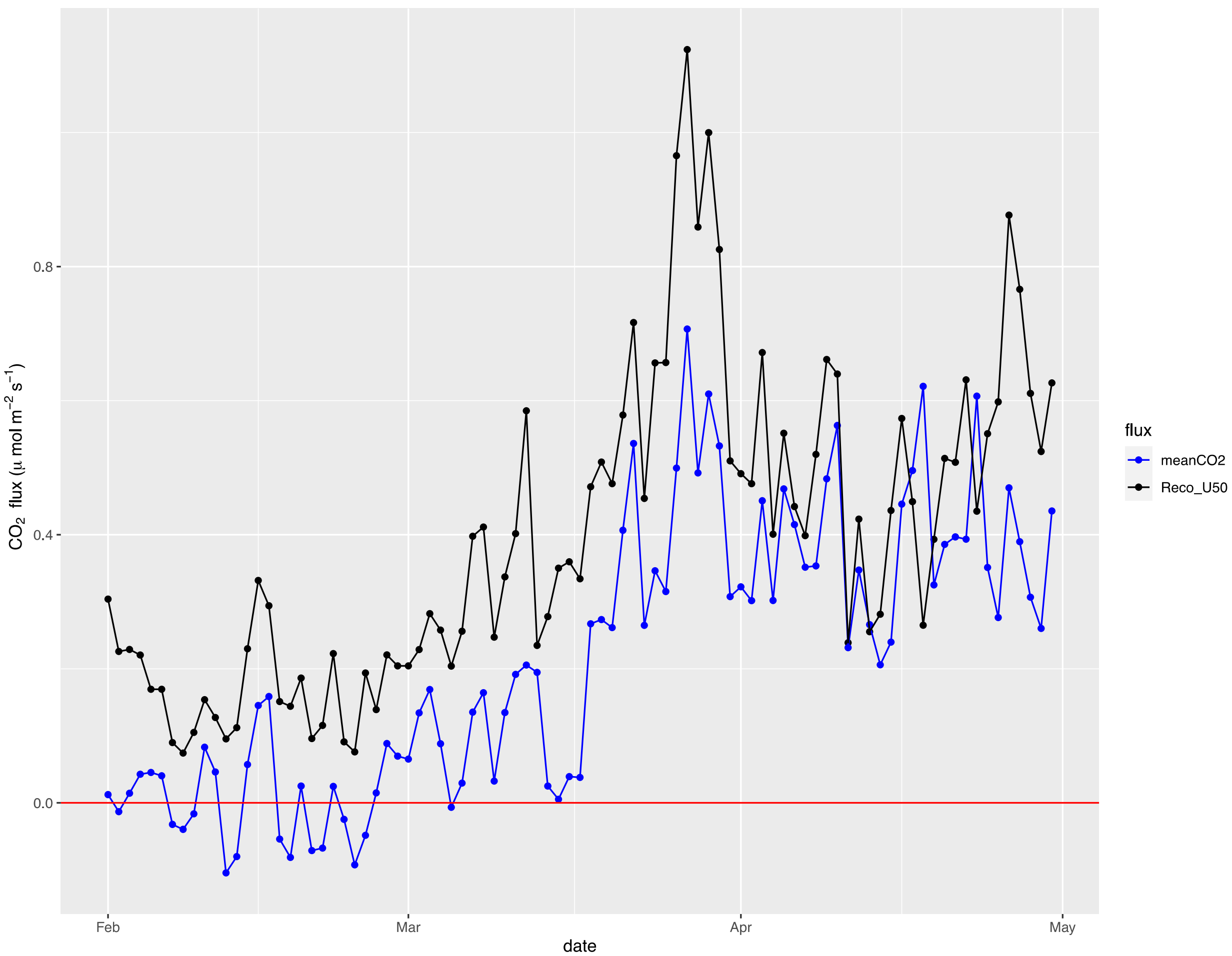


Figure 3.10 Midnight values for comparison of Eddy Covariance Tower Ecosystem Respiration and cumulative CO_2 automated flux chamber measurements. For Ecosystem respiration from the eddy covariance tower, R_{eco}_U50 was used. Both plots are close to each other and seem to overlay in the month of April.

When comparing nighttime values (here, all midnight values), the Eddy Covariance Tower R_{eco} and CO_2 fluxes from the automated chambers show a strong association (Figure 3.10). No photosynthesis is interfering with the signal obtained from both measurements at that time of day. There is a peak of CO_2 during the middle of March that was associated with the rainfall event. During the month of April both plots seem to overlay on top of each other.

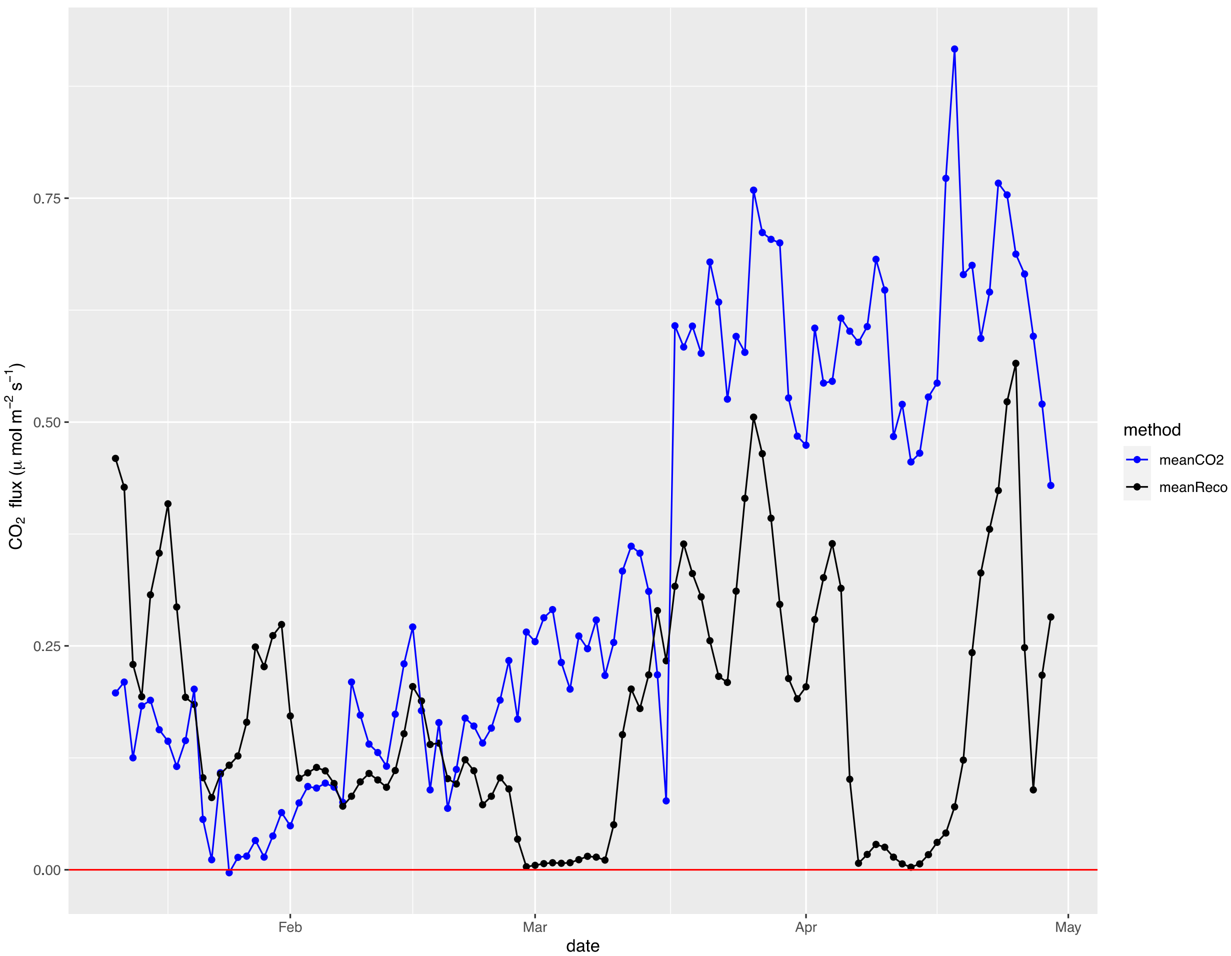


Figure 3.11 Comparison of daily averages of Eddy Covariance Tower Ecosystem Respiration and cumulative CO_2 automated flux chamber measurements. For Ecosystem respiration from the eddy covariance tower, R_{eco}_U50 was used.

I went ahead and compared the daily averages of CO_2 flux from the eddy covariance tower and the automated flux chambers (Figure 3.11). Photosynthesis is not interfering with these measurements. Both plots are close to each other in the beginning of the measurement period in January and February but as the season changes from winter to spring both trends come apart especially during the month of April.

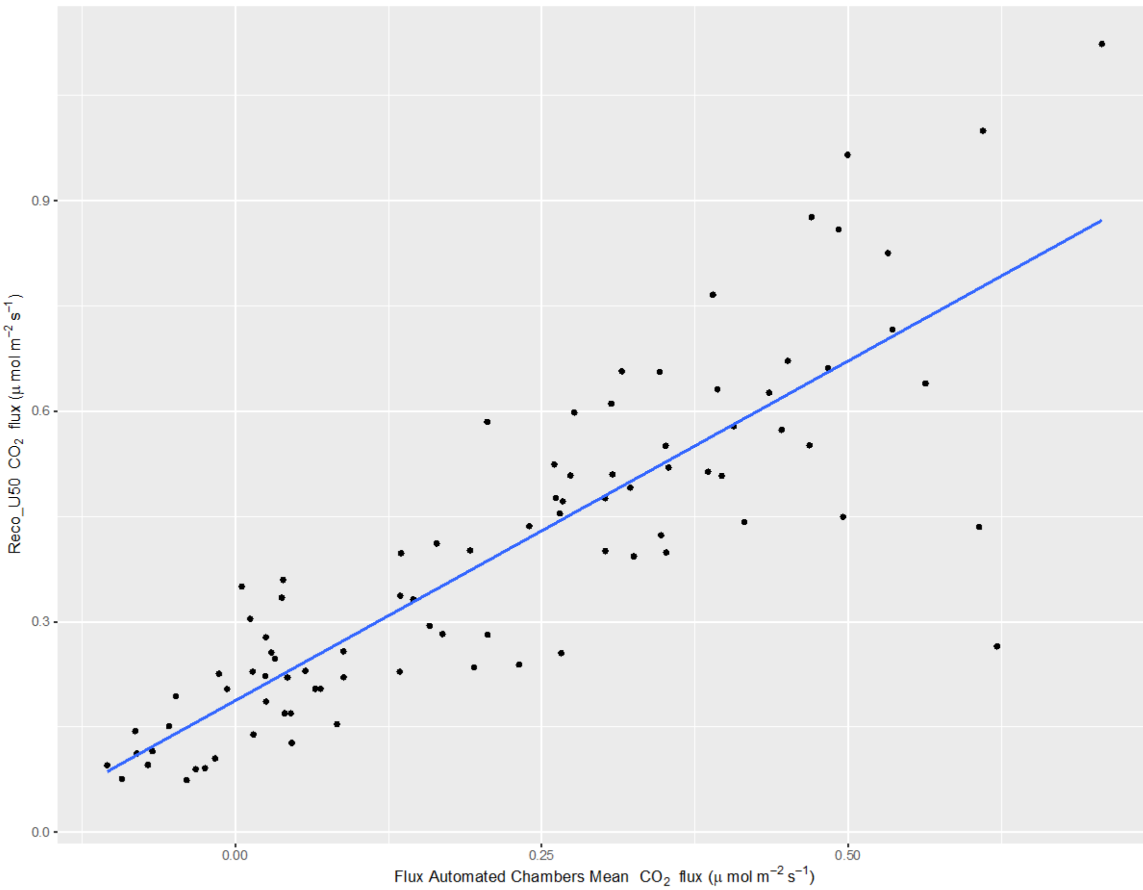


Figure 3.12 Midnight scatterplot comparing the Eddy Covariance tower and the Automated flux chambers. R-squared is 0.73 and the slope of 0.97 indicates a 1:1 relationship between both sources of measurement.

Figure 3.12 indicates the eddy covariance tower and automated flux chambers match at midnight. The slope of 0.97 indicates a close to 1:1 relationship between the two measurement techniques.

DISCUSSION

4.1 CO_2 automated flux chamber design

Building – improvements and changes, impact on functionality

The automated flux chambers underwent several improvements to the design in contrast to the automated flux chambers designed by Ed Grote (Darrouzet-Nardi et al., 2015). The position of the pistons in the automated flux chambers allowed the lids to be pneumatically lowered with more precision and the automated flux chambers needed fewer mechanical adjustments to recalibrate. T-slots were also implemented to the core structure of the automated flux chambers to make them more resistant to the tough environmental conditions found in the desert. It also allowed the automated flux chambers to be recalibrated with ease and allow minimal invasive intrusions. Individual SMC Direct operated two port valves were used instead of a 10-position manifold valve used by Ed Grote. This allowed for the automated flux chambers to be individually connected to the intake of CO_2 from the collars and allowed the CR1000 datalogger to individually switch on/off the valves making the programming simple and easy to modify if needed. It also allowed for a quick fix by just replacing individual valves which is cheaper in cost the replacing the 10-position manifold valve.

Recommendations for future improvements on the automated flux chambers

I recommend building a prototype and testing it in the field for a few months until the automated flux chambers are fully functional and getting data on a consistent and efficient basis. The prototype can have improvements made *in situ* to make it more efficient over time. I recommend installing and test the electronic equipment in situ when the prototype is deployed.

Subsequent automated flux chambers and the different electronic components needed for its assembled function can be added over time to make the system as complex as needed. A future improvement I recommend is to make the lid of the automated flux chambers easy to fix and install in case of malfunction. With an increase in technological advances, the piston would rely on electricity and not on an air compressor for its function.

4.2 Investigation of soil CO_2 fluxes at The Jornada Experimental Range

General

Soil respiration is one of the most difficult factors in CO_2 fluxes to the atmosphere to research. It is complex to separate heterotrophic respiration from autotrophic respiration. Automated flux chambers have been widely used in forest and grassland ecosystems (Jassal et al., 2012; Heinemeyer et al., 2011; Liu et al., 2006; Gilmanov et al., 2007; Edwards, 1975) but not as much has been done to study the influence of CO_2 in a desert environment. My results indicate CO_2 flux went up over course of spring season due to temperature increase but there was substantial variation among the different automated flux chambers due to the position they had and the influence of the shrubs on the soil.

At night-time, I saw both an uptake and release of CO_2 from the soil as the CO_2 flux values go below and above 0. As an example, there was an hourly negative CO_2 flux pattern at chamber 4. In April both trends from the Eddy Covariance tower and the auto-chambers are closer to each other but the trend from the eddy covariance tower is higher because it includes aboveground respiration. When the creosote bushes were removed, autotrophic respiration did not clearly contribute as much as expected to soil respiration. The goal of my study was to investigate belowground autotrophic respiration and if any environmental factors such as temperature and humidity affected the rates of CO_2 flux.

Environmental associations with soil respiration

Temperature is an important factor in determining if carbon is a sink or source in dryland ecosystems (Darrouzet-Nardi et al., 2015). There was a significant increase in CO_2 as temperature increased with the change of season from winter to summer. In figure 3.3, I saw an increase in CO_2 flux in each of the automated flux chambers. This may be due to an increase in temperature, which allows the microbes and plants in the soil to be more active. In modeling carbon dynamics, the temperature sensitivity of heterotrophic respiration is crucial but variable (Meyer et al., 2018). Several studies indicate that temperature plays an important role in the increase of CO_2 flux (Garrett & Cox, 1973; Edwards, 1975). One of those studies states there is in increase in CO_2 flux in the afternoon/evenings when the temperature is hotter compared to mornings when the temperature is colder (Barron-Gafford et al., 2011).

The daily variations of CO_2 flux are driven by soil temperature (Ouyang & Zheng, 2000). To test how daily variations, affect soil temperature, exponential curves were fitted to the temperature graphs for each of the automated chambers. I saw an increase of CO_2 flux when temperatures were between 5 and 25 °C. This may be due to microorganisms having a suitable environment to thrive, not too cold or hot for them to carry on their daily activities and reproduce. Q10 was 2 meaning soil respiration doubled as 10 °C increased. As shown by the color code data, over the course of the day from nighttime to daytime, the CO_2 flux from the automated flux chambers increased as the temperature increased. Temperature is an environmental factor that, in my results, appeared strongly correlated with soil respiration and NEE throughout winter and spring.

Soil moisture makes an important contribution in the activity of microbes and plants in the soil. Moisture in the soil created in the morning dissolves the calcium carbonate contained in the soil and this allows CO_2 to increase. I think dew caused by humidity played a minor effect on CO_2 flux activity. I did not see a significant increase in CO_2 flux in association with changes in humidity in figure 3.4. There may be a threshold value which limits the effect soil moisture has on soil respiration, but it is dependent on the site being studied (Xu et al., 2004). The TDR probes on site didn't record moisture data due to instrument failure.

Soil biogeochemistry in arid ecosystems is dependent on precipitation events. A novel study suggests monsoon storms can induce heterotrophic activity in microbes, but they are not large enough to evoke autotrophic activity in shrubs (Sponseller, 2007). However, in my testing of the automated flux chambers on the Green Roof located on the UTEP Biology Building, I artificially wetted the soil and a huge increase in CO_2 was observed. I saw a peak on the cumulative CO_2 over time as there was a rainfall event around March 15 which caused the sudden increase in Figure 3.1. It is believed that as soil gets wet, microbes become more active, this leads to an increase in CO_2 (Rastogi et al., 2002). In Figure 3.2, I did not see an increase in CO_2 flux as the soil got wet during the rainfall event, it decreased. I think this is due to the carbonate dissolution and precipitation reactions as well as soil water CO_2 solubility. This allowed the CO_2 to be absorbed by the soil and therefore a decrease in CO_2 efflux shown in the graph.

Comparison of CO_2 flux data from Eddy Covariance Tower and CO_2 automated flux chambers

Concurrent measurements from the Eddy Covariance Tower allow for a comparison of my small-scale measurements with larger-scale estimates of ecosystem respiration (R_{eco}). The major difference between these data types is that the automated flux chambers measure only the output of the soil and shrub roots, if present, whereas R_{eco} includes output from the above-surface portions of the shrubs, in addition to other vegetation. One of my objectives was to compare the carbon flux at a landscape level with small-scale automated flux chambers measurements. My results showed that the measurements between the two techniques were very similar, adding confidence to both measurements. A study comparing NEE exchange of CO_2 in cotton and wheat fields in China similarly concluded there is an agreement between eddy covariance tower measurements and automated flux chambers at a daily, annual, seasonal scale (Wang et al., 2013). Data from the automated flux chambers are slightly higher compared to the Eddy Covariance Tower measurements because the automated flux chambers were positioned below shrubs. March is when vegetation activity starts to increase (Huenneke & Schlesinger, 2006); therefore, there would be greater CO_2 flux from both sources as shown in Figure 3.9.

In Figure 3.3, I observed substantial differences in CO_2 fluxes among the automated flux chambers. The CO_2 flux of automated flux chamber 1 was always high, but the mechanisms causing this higher rate were unclear. Possibilities include the position of the automated flux chamber relative to the creosote bush, position of high-density clusters of roots, or belowground airflow patterns, or the structure of pedogenic carbonates underneath any individual automated flux chamber.

The comparison of the Eddy Covariance Tower and auto-chamber CO_2 flux data in Figure 3.10 showed me that both numbers can be compared since they are the same magnitude and the trends between both measurements are similar during midnight when no photosynthesis is present to alter the signal of measurements. I saw a peak in the middle of March in both measurements indicating that both measurements respond to moisture. I can compare the Eddy Covariance Tower and auto-chambers measurements and use them to investigate how they contribute to NEE and compare their values to NPP. Since both the eddy covariance tower and auto-chambers measurements data points match, maybe it's not the soil respiration part that appears wrong. There might be other issues, to investigate, especially belowground production, and in particular root production. It is difficult to do research on belowground NPP. There are a lot of errors and bias in data collection, calculations and processing of promising methods such as minirhizotron, root ingrowth technique and isotope labeling (Milchunas, 2012). There is also a lack of data on root function and biomass.

Different environmental factors such as temperature, precipitation and humidity play an essential role in the uptake and release of CO_2. Temperature makes microbes more active and therefore a greater activity of the creosote bush next to the automated flux chamber is expected. I think humidity and precipitation also plays a major role in CO_2 flux activity, but we didn't capture as many moisture events as needed to fully characterize this effect.

At night I observed some amount of uptake of CO_2 from the soil as the CO_2 flux values dipped below 0. A similar study in which automated flux chambers were used in a forest environment, saw a peak in CO_2 at night during moist periods (Heinemeyer et al., 2011). Another study also found similar results in which there was a peak in CO_2 at night due to an increase in moisture at night and hot soil temperature at the beginning of night (Rastogi et al., 2002).

At midnight there is a similar pattern in CO_2 flux from both the Eddy Covariance Tower and the auto-chambers. At the beginning of April, the trends seem to be closer to each other suggesting plants were not as active during that month. The CO_2 flux from the tower is higher due to the plants contributing to the total ecosystem respiration. There is an increase in CO_2 as the weather gets warmer and there is a peak in the middle of March. Both Figure 3.1 and Figure 3.10 show that peak at the same point in time. I think it's due to a precipitation event which occurred around March 15 and this allowed the soil particles to be more active causing an increase in CO_2 flux shown by both the automated flux chambers and the eddy covariance tower.

In Figure 3.10 the eddy covariance tower trend is below zero which indicates CO_2 is taken up by the soil. I think these unexpected sinks of CO_2 absorbed by the soil are due to pedogenic carbonates. There are a number of intervals in the graph when organic carbon processes cannot explain the sinks of CO_2 to the soil. These processes might be due to carbonate dissolution and precipitation reactions as well as soil water CO_2 solubility (Mills et al 2019). Another mechanism which is suggested by this paper is the temporary adsorption of CO_2 to soil minerals. At the end of the measurement period in the month of April both trends get close to each other, I believe this is due to the plants in the area beginning to be more active especially due to the mesquite plants leafing out at that time.

Both the trends of the eddy covariance tower and automated flux chambers in Figure 3.11 are close to each other in the months of January and February due to plants being not as active during the winter.

Shrub removal

The removal of creosote bushes from automated flux chamber 2 and automated flux chamber 5 did not cause a significant reduction of CO_2 as hypothesized. Basically, CO_2 stayed the same indicating there is an influence from elsewhere. Soils act as a host for both organic and inorganic carbon such as soil organic matter and pedogenic carbonates. I believe there is another factor which may be calcium carbonate contained in the soil. An incubation study indicated that 13% of the total carbon efflux in the Mojave Desert is contributed to the dissolution of carbonate (Stevenson & Verburg, 2006). A recent study conducted in five agricultural soils with different $CaCO_3$ content indicated that 35% of total carbon efflux may be contributed to the dissolution of carbonate (Bertrand et al., 2007). During precipitation events calcium carbonate dissolves and this allows CO_2 to increase (Salomons & Mook, 1986). I also think the microbes in the soil and the different processes and mechanisms which act in between the soil particles affect the rates of CO_2 (Thomas & Hoon, 2010). Soils contain three times as much carbon as above-ground plant biomass making them the dominant terrestrial sink for carbon (Manning, 2008). During dry conditions, the removal of creosote bushes did not greatly affect the CO_2 flux from the automated flux chambers. It stayed the same since not much plant and microbial activity was present. For future experiments, I would expect to see a higher CO_2 efflux from the soil on a wet season as the plants would be more active and as the soil gets wet, more soil processes become active and CO_2 would be considerable higher and more interesting to measure.

4.3 Implications for future experiments

The next step is to test the influence of respiring bacteria versus the presence of pedogenic carbonates in the soil. It would be interesting to record how much the dissolution/precipitation of pedogenic carbonates influence the rate of CO_2 flux released to the environment. This could be measured with stationary automated flux chambers as the ones deployed during this experiment in combination with isotopic analyses of CO_2. Although my results indicate that roots aren't dominantly controlling the rates of CO_2 flux during my measurement period at The Jornada LTER site, I consider pedogenic carbonates, temperature and humidity with a more substantial amount of rainfall would affect at a major rate the uptake and release of CO_2. It would be also beneficial to study the different microbes involved in the soil particles and how much each of them contributes to soil respiration.

This project didn't generate all the answers, but it did generate some great questions for future experiments. Some of these questions are why is chamber 1 CO_2 flux higher when comparing it to the other five chambers? Why is there night-time CO_2 uptake from the soil when no photosynthesis is present from the plants? What explains temporal trends in the comparison of the eddy covariance tower and automated flux chambers measurements?

CONCLUSION

My results indicate five major findings:

1. CO_2 flux went up over course of spring season due to temperature increase as the desert got hotter. This involved microorganism being more active in the soil. This means there was a positive correlation with temperature. This was demonstrated with Figure 16 as CO_2 increased over a three-month period as temperature increased.

2. There was substantial variation among the different automated flux chambers. Automated flux chamber 1 was consistently high in CO_2 flux. This might be due to its location where it was installed, with greater carbonate activity. The other automated flux chambers were not as high and were more consistent with each other.

3. At midnight, I can see both an uptake and release of CO_2 from the soil as the CO_2 flux values go below and above 0. No photosynthesis was interfering with this analysis and both the eddy covariance tower data and auto-chambers data seem to match. When I compared the trends of CO_2 from the Eddy covariance tower and from the auto-chambers there is a match between both data points. In the month of April both trends from the Eddy Covariance tower and the auto-chambers are closer to each other.

4. Although preliminary, autotrophic respiration did not clearly contribute as much as expected to soil respiration. When I removed the creosote bushes from the soil, the data did not change as expected, it remained the same. Therefore, plants and especially its roots may not be an instantaneous control over soil respiration, I believe other factors such as temperature, humidity and pedogenic carbonates play a major role. I believe pedogenic carbonates in deserts and how it affects soil respiration should be studied more in the future.

Taken together, my findings suggest that soil respiration is influenced by environmental factors such as humidity and temperature more than belowground autotrophic respiration. Moving forward, different types of soil respiration measurements can be compared to each other to investigate which biotic and abiotic factors contribute to Net Ecosystem Exchange on a landscape level.

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