The investigation between covariability of energy fluxes and CO_2 flux exchanges at Skukuza Kruger National Park by Eddy Covariance technique.

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Abstract.The contribution of the Kruger National Park South Africa ecosystem to Carbon uptake and emission is highly variable across the years due to perturbations in vegetation cover as driven by large herbivores and inter-annual climate variability. The quantification of the contribution from the savanna ecosystems to the global carbon budget is still highly uncertain. This can be accounted for by the unavailability of CO_2 measurements as well as changes in patterns of land use. This study explores the simultaneous changes in CO_2 flux exchanges and energy fluxes to understand the response of vegetation to climate variability. We have investigated the covarability between energy fluxes such as sensible heat flux, latent heat flux, and net radiation and CO_2 flux exchange by the Eddy Covariance technique at Skukuza Kruger National Park, South Africa. The patterns of the energy fluxes and net ecosystem exchange (NEE) during 1st January 2017 and 2018 show the ecosystem as a sink of Carbon with an average of -11,6177 $umol.m^{-2}.s^{-1}$ daytime, +4,6354 $umol.m^{-2}.s^{-1}$ nighttime, -8,3959 $umol.m^{-2}.s^{-1}$ daytime, +6,3479 $umol.m^{-2}.s^{-1}$ nighttime, respectively. CO_2 fluxes showed similar trends during the hydro-ecological year with an average of +0,8455 $umol.m^{-2}.s^{-1}$ and +0,1102 $umol.m^{-2}.s^{-1}$ annual increase from 2017 and 2018, respectively. While the energy flux increases with a decrease in carbon sink over that period from $H = 67{,}3488\ w/m^2$, $LE = 78{,}7404\ w/m^2$ and $R_{n\text{-}MET} = 86{,}4002\ w/m^2$ up to $H = 82{,}3075\ w/m^2$, $R_{n\text{-}MET} = 99{,}0331\ w/m^2$ and down LE = 40,4249 w/m^2 contribution of the change from 2017 dry year to 2018 wet year, respectively. The increase in energy fluxes and CO_2 flux exchanges shows connections that have large implications for the Skukuza area and its response to interannual variability.

1. Introduction

The global Carbon dioxide levels today are higher than at any point in the least the past 800,000 years. Human activities have increased the concentration of Carbon dioxide in the atmosphere, amplifying Earth's natural greenhouse effect. Carbon dioxide concentrations are rising mostly because of the fossil fuels that people are burning for energy. Fossil fuels like coal and oil contain carbon that plants pulled out of the atmosphere through photosynthesis over the span of many millions of years; human activities are returning that carbon to the atmosphere in just a few hundred years. Carbon is the fundamental component of all organic compounds. It is one of the primary elements of life, involved in the fixation of energy by photosynthesis. The biosphere includes a complex mixture of carbon compounds.

Which originate, transform, and decompose within this sphere. Plants absorb CO_2 during photosynthesis, which is active during the daytime. All living organisms always respire and release CO_2. Thus, Carbon-dioxide is produced and consumed in a cyclic manner. (Rebecca Lindsey et al.2020).
This paper explores the simultaneous changes in CO_2 flux exchanges and energy fluxes to understand the response of vegetation to climate variability. We have investigated the covarability between energy fluxes such as sensible heat flux, latent heat flux, net radiation, and CO_2 flux exchange by Eddy Covariance technique at Skukuza Kruger National Park, South Africa.

2. Methodology

The Carbon dioxide flux measurements using the Eddy Covariance technique generate a raw dataset with a very high temporal resolution (generally 10-20 Hz). The first step in the analysis of these data is to screen them for spurious values, perform various corrections, and then integrate the fluxes over periods of about 30 minutes. The Carbon fluxes from the atmosphere to the ground are given a negative sign and the ground to the atmosphere are given a positive sign, respectively. (Archibald SA, A Kirton, et al. 2008)

An Eddy covariance system was built at a site near Skukuza Camp in Kruger National Park, South Africa, in 2000, with meteorological measurements starting in January 2001, as the first flux measurements are used. The site required that the length of the tower be 22m long, 16 m of height measurements, 10 m vegetation height, (25.0197°S, 31.4969°E), lies at 365 m above the sea level, in an area with 547 mm/year of mean annual rainfall, which falls between November and April and the annual temperature ranges between 14.5 and 29.5 °C. (Scholes, R.; Gureja, N et al.2001)

Data was collected using LI-7500, the open-path analyser that measured in situ gas, instantaneous wind speed, CO_2 concentration, radiation, and latent and sensible heat flux measurements needed for computing the connection between energy fluxes and CO_2 flux exchanges. The turbulence (vertical) fluxes of the carbon dioxide, F_c (mmol m^{-2} s^{-1}), the sensible heat flux, H (W m^{-2}), and the latent heat flux, λE (W m^{-2}) for each time step (time scales, daily and diurnal patterns in various seasons, seasonal and inter-annual) were obtained from the flux tower at Skukuza. The eddy flux was calculated as:

$$F = \underline{\rho_a}\,\underline{W'S'} \qquad \text{General equation} \tag{1}$$

The eddy flux (F) was approximately equal to the mean air density multiplied by the mean covariance between deviations in instantaneous vertical wind speed and mixing ratio.

Carbon dioxide flux was presented as the mean covariance between deviations in instantaneous vertical wind speed and density of CO_2 in the air. (Grünwald T, Bernhofer C et al.2007, Mauder M, Foken T et al.2011)

$$F_C = \rho_a \underline{W'\rho_c'} \qquad \text{Carbon dioxide flux} \tag{2}$$

By analogy, sensible heat flux was equal to the mean air density multiplied by the covariance between deviations in instantaneous vertical wind speed and temperature; conversion to energy units were accomplished by including the specific heat term.

$$H = \rho_a c_p \ \underline{W'T_a'} \qquad \text{Sensible heat flux} \tag{3}$$

Latent heat flux was computed in a similar manner using water vapor and later converted to energy units.

$$\lambda E = \lambda \underline{W'\rho_v'} \qquad \text{Latent heat flux} \tag{4}$$

Where ρ_a was the density of dry air (kg m^{-3}) at a given air temperature, c_p was the specific heat capacity of dry air at constant pressure (J kg^{-1} K^{-1}), λ was the latent heat of vaporisation (J kg^{-1}), ρ_c was the molar density of CO_2 gas (mol m^{-3}) and ρ_v was the molar density of water vapour (mol m^{-3}). T_a was the air temperature derived from the sonic anemometer (K) and W was the vertical wind velocity component (m s^{-1}), and S'mixing ratios. Over bars denoted time averages and primes indicated fluctuations about the averages.

Energy closure balance was obtained using the energy budget represented by equation 5, parameters data was stored at the eddy covariance flux tower every 30 minutes. Energy balance closure was evaluated by statistical regression of turbulent energy fluxes (sensible and latent heat (LE)) against available energy (net radiation, less the energy stored) and by solving for the energy balance ratio, the ratio of turbulent energy fluxes to available energy.

$$H + \lambda E + Rn + G = 0 \qquad \text{Energy closure} \qquad (5)$$

3. Results and Discussion

Half-hourly fluxes were used to analyze Net ecosystem exchanges (NEE)(Figure 1). Previous studies defined a hydro-ecological year from 1 July to 30 June of the following year according to Archibald et al. 2009. We observed patterns of covariability during the hydro-ecological years(Figure 1) with mean of $(\boldsymbol{a})\boldsymbol{F_C}$ = -0,7349 *umol.m*$^{-2}$*.s*$^{-1}$, $(\boldsymbol{b})\boldsymbol{F_C}$ = -0,3185 *umol.m*$^{-2}$*.s*$^{-1}$, $(\boldsymbol{c})\boldsymbol{F_C}$ = -0,8454 *umol.m*$^{-2}$*.s*$^{-1}$ and $(\boldsymbol{d})$ $\boldsymbol{F_C}$ = +0,1102 *umol.m*$^{-2}$*.s*$^{-1}$ (d) is data bias because only values ending in January 2018 is used.

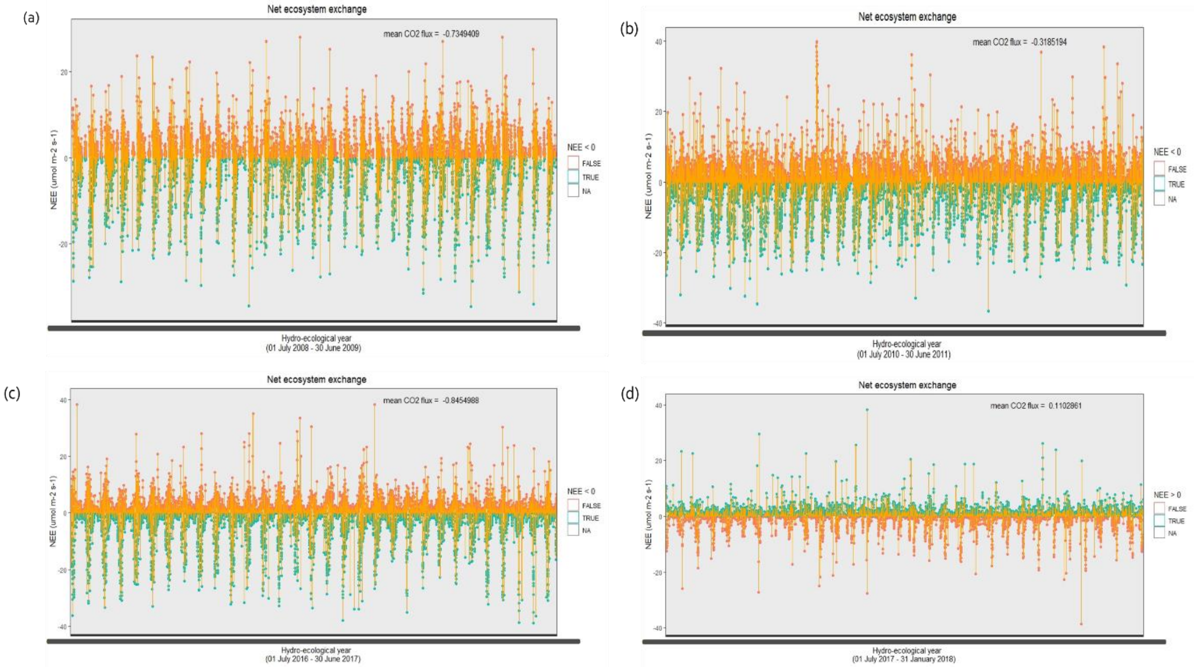

Figure 1 Net ecosystem exchange (NEE) for hydro-ecological years 2008/09, 2010/11, 2016/17 & 2017/18.

From the Figure 1 (a)-(c) the data shows that the Skukuza ecosystem during the years of study is a Carbon sink. This can be attributed to vegetation and availability of rain to grow vegetation during the years, although some of the years are regarded as dry/drought years. The ecosystem was still able to maintain its reservoirs.

The sensible heat flux (Figure 2) increases with a decrease in carbon sink over that period 2008/09, 2010/11,2016/17 and 2017/18 from **(a)** ***H*** = *49,1647 w/m*^{2}, ***(b) H*** = *58,5849 w/m*^{2}, ***(c)H*** = *67,3488 w/m*^{2} *and* ***(d) H*** = *82,3076 w/m*^{2}*, respectively.* Latent heat fluxes and CO_2 fluxes showed negative correlation (Figure 3) during the hydro-ecological years 2008/09,2010/11,2016/17 and 2017/18(data bias), respectively. While the latent heat fluxes mean measured were, **(a)** ***LE*** = *63,0990 w/m*^{2}, ***(b) LE*** = *50,5743 w/m*^{2} , ***(c) LE***= *78,7404 w/m*^{2} *and* ***(d) LE*** = *40,4249 w/m*^{2} . Interestingly, maximum CO_2 uptake occurs during periods of low soil moisture when green leaves are still present.

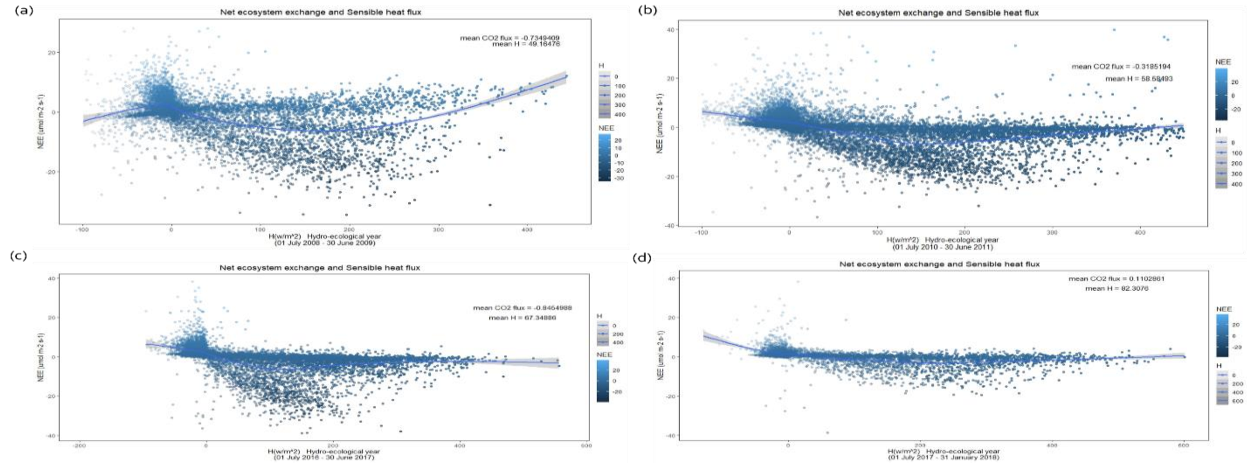

Figure 2 Net ecosystem exchange (NEE) and sensible heat flux(H) for hydro-ecological years 2008/09, 2010/11, 2016/17 & 2017/18.

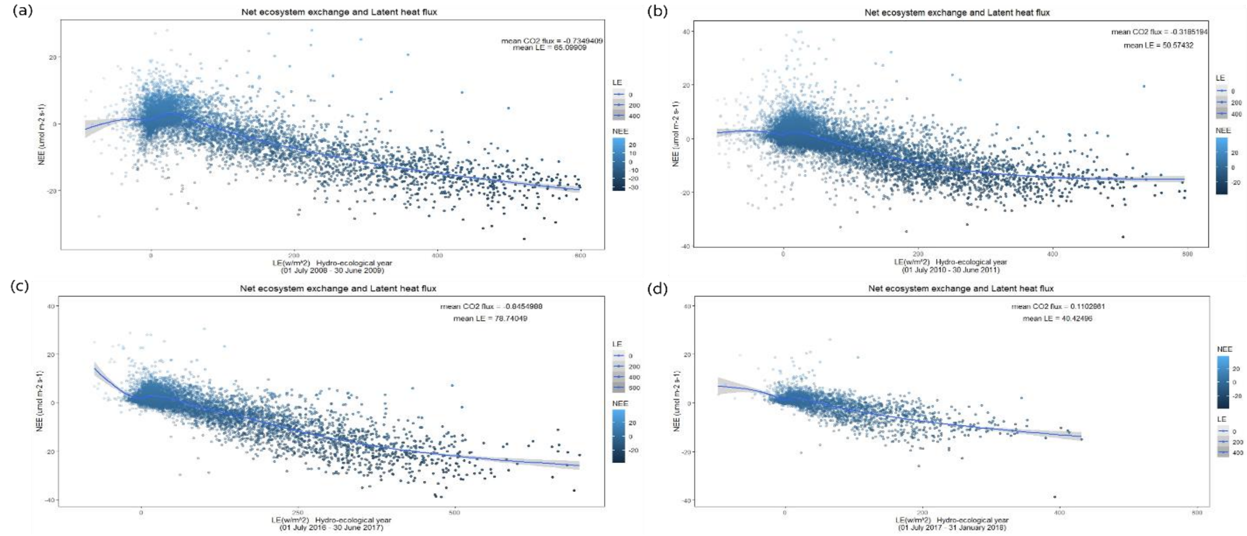

Figure 3 Net ecosystem exchange (NEE) and latent heat flux (LE/ λE) for hydro-ecological years 2008/09, 2010/11, 2016/17 & 2017/18.

The pattern shown in Figure 2 and Figure 3 indicates the relation between NEE and sensible heat flux and NEE and latent heat flux. The correlation curving towards the negative. This shows that with an increase in energy flux of sensible heat over the years, the Skukuza ecosystem is impacted negatively. The curve is moving towards average if this uptake is continuous, it may end up becoming a source of Carbon in the future.

The patterns of the energy fluxes and NEE (Figure 4), during 1st January 2017 and 2018 shows average of -11,6177 umol.m^{-2}.s^{-1} daytime, +4,6354 umol.m^{-2}.s^{-1} night-time, -8,3959 umol.m^{-2}.s^{-1} daytime, +6,3479 umol.m^{-2}.s^{-1} night-time, respectively. CO_2 fluxes showed similar trends during the hydro-ecological years with average of +0,8455 umol.m^{-2}.s^{-1} and +0,1102 umol.m^{-2}.s^{-1} increase from 2017 and 2018,respectively. While the energy flux increases with a decrease in carbon sink over that period from H = 67,3488 w/m^2, LE = 78,7404 w/m^2 and Rn = 86,4002 w/m^2 up to H = 82,3075 w/m^2, Rn = 99,0331 w/m^2 and down LE = 40,4249 w/m^2 contribution of the change from dry year to wet year for 2017 and 2018, respectively. However, to quantify and understand the patterns for analyses we used hydro-ecological years instead of a day.

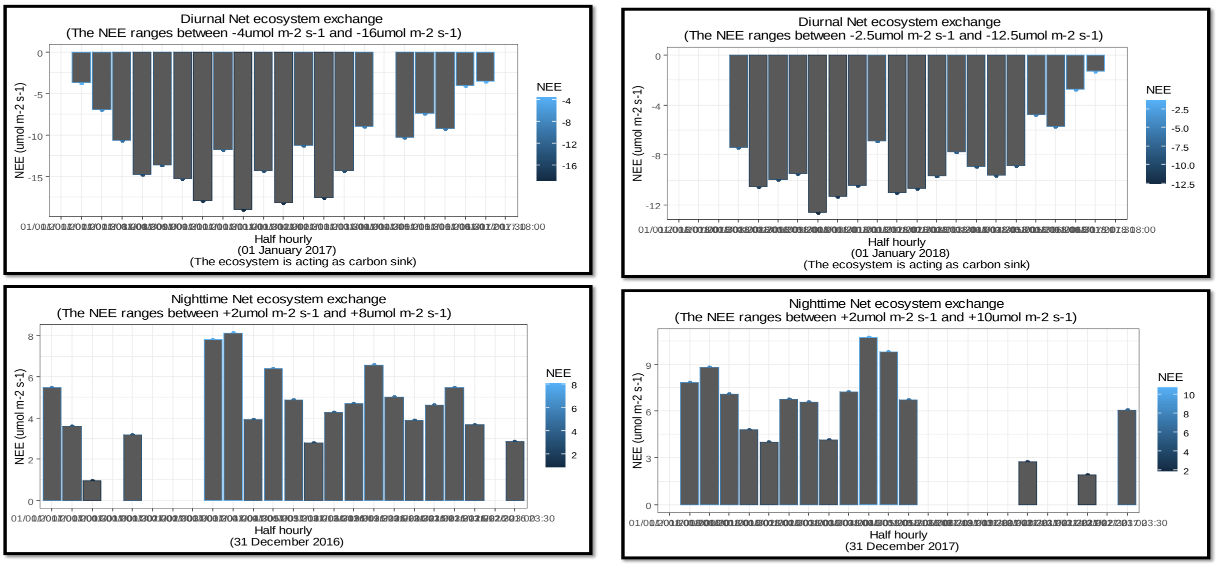

Figure 4 Comparison of Net ecosystem exchange (NEE) during diurnal of 01 January 2017 and 01 January 2018.

The energy balance closure was 74% (Figure 5). Generally, a 100% energy budget closure is not achieved for EC systems, and an average closure of approximately 80% is often observed. Several reasons for the lack of 100% including different sampling scales of the sensors; energy storage; measurement errors; and heterogeneity of the land surface resulting in advective fluxes and transport of large eddies which cannot be measured with the Eddy Covariance method.

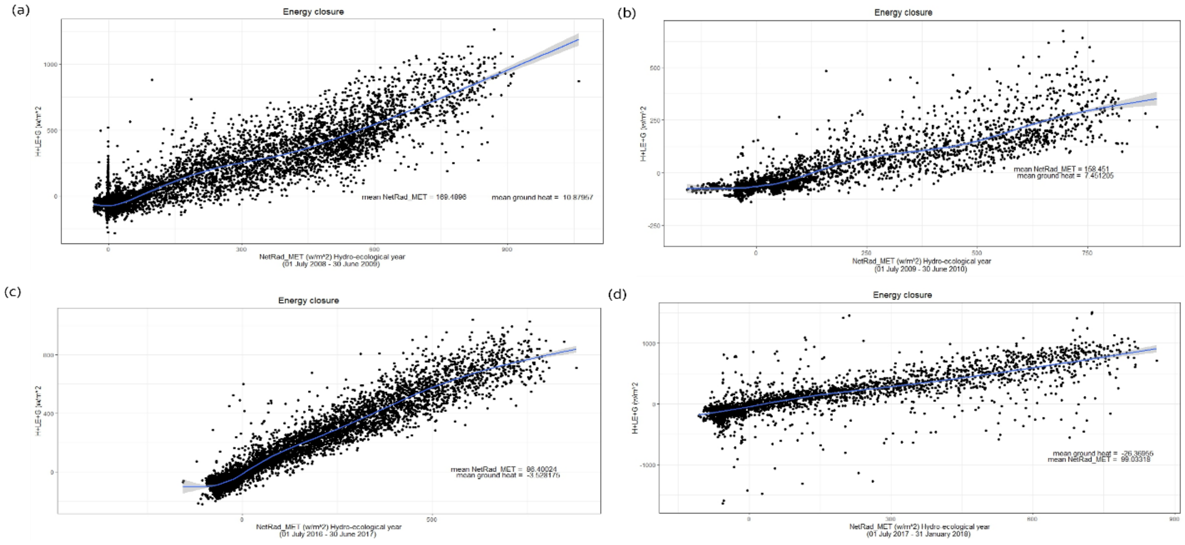

Figure 5 Energy closure with the sum of sensible heat flux (H), latent heat flux (LE) and soil heat flux (G) against net radiation.

Since the Skukuza flux tower is a LI-Cor 7500 open path gas analyzer, it has problem with energy closure. This issue can be resolved by looking at closure residual. The energy closure must approach zero. While closure residual is determined with:

$$\text{Closure Residual} = (Rn + G) - (H + \lambda E) \qquad (6)$$

4. Conclusion

The general conclusion is that there is a covariability between energy fluxes and CO_2 flux exchanges which is a positive covariance. The increase in energy has large implications to the Skukuza area and its response to interannual climate variability. The covaribility can be attributed to perturbations in vegetation cover as driven by large herbivores and interannual climate variability. Further studies are necessary to fully understand the covariability between the energy fluxes and the CO_2 flux exchanges with other flux station in different footprint and use of seasonal data. The Skukuza is a carbon sink but vegetation response to climate variability in this study is shifting to becoming average/source of carbon.

5. Acknowledgement

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