Estimating Regional Daytime Net Carbon Dioxide Flux using Remotely Sensed Instantaneous Measurements

Chandra D. Holifield, William E. Emmerich, M. Susan Moran, Ross Bryant, Charmaine L. Verdugo

Abstract

Atmospheric carbon dioxide (CO_2) is steadily increasing as a result of the world's increasing use of fossil fuels and wood biomass. However, the impact of increases in CO_2 on the global carbon cycle is unclear. Semiarid grasslands comprise a large portion of the world's rangeland ecosystem and may play a significant role in the carbon cycle. In a previous study, regional estimates of instantaneous net CO_2 flux were obtained by using a Water Deficit Index (WDI) derived from satellite imagery over a five-year period (1996-2000) covering a grassland site in the Walnut Gulch Experimental Watershed (WGEW). In this study, a linear relationship (R^2 = 0.95) was found to exist between instantaneous and daytime net CO_2 flux estimates, where daytime is the period from 6 a.m. to 6 p.m. This linear relationship was used to convert instantaneous estimates of net CO_2 flux to daytime estimates, and maps depicting spatially distributed daytime net CO_2 flux were generated for WGEW. Remote sensing offers a viable means of obtaining regional estimates of daytime net CO_2 flux in semiarid grasslands.

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Keywords: carbon dioxide (CO_2) flux, semiarid grasslands, remote sensing, Water Deficit Index (WDI)

Introduction

A large portion of the earth's surface contains semiarid grasslands. However, the role these grasslands play in the carbon cycle is unclear. Studies are being conducted around the world in an effort to answer this question. Unfortunately, many of these studies are being conducted on a small scale (a few hundred square meters), when larger, regional scale measurements are most important for examining the global carbon cycle. With its potential for larger scale and global coverage, remote sensing could be a useful tool in determining the role played by semiarid grasslands in the global carbon cycle.

A remote sensing derived measurement of plant transpiration, the Water Deficit Index (WDI), has been used to estimate instantaneous net CO_2 flux on a regional scale (Holifield et al. 2003). Further, studies have shown that daily plant evapotranspiration (ET) can be estimated from an instantaneous ET measurement using the direct relationship that exists between plant ET and incoming solar radiation (R_s) (Jackson 1983, Zhang and Lemeur 1995). Given that CO_2 uptake by plants is tied to transpiration, it follows that an estimation of daytime (6 a.m. to 6 p.m.) net CO_2 flux can be obtained from a measure of instantaneous net CO_2 flux. However, in light of the fact that the aforementioned studies were conducted in fully irrigated environments and semiarid grassland systems are seldom irrigated, a different approach must be employed. Thus, the objectives of this study were to convert instantaneous net CO_2 flux estimates from a semiarid grassland site to daytime estimates; and to generate maps depicting spatially distributed estimates of grassland daytime net CO_2 flux.

Methods

The following subsections include a brief description of the study area and instrumentation, the criteria used in data selection for the conversion of instantaneous net CO_2 flux to daytime estimates, and the procedure used to generate spatially distributed maps of daytime net CO_2 flux.

Study area and instrumentation

The study took place in the Walnut Gulch Experimental Watershed located in southeast Arizona. The study area was comprised of a grassland area of approximately nine square kilometers, dominated by black grama (*Bouteloua eriopoda*), sideoats grama (*B. curtipendula*), blue grama (*B. gracilis*), Lehmann lovegrass (*Eragrostis lehmanniana*), and bush muhly (*Muhlenbergia porteri*). Continuous 20 minute averages of carbon dioxide and water vapor flux measurements were collected by a Bowen ratio energy balance (BREB) system located within the study area (Emmerich 2003).

Data selection criteria

Data covering the monsoon season (1 July to 31 October) over a five-year period (1996-2000) were used for this study. All data were selected based on an incoming solar radiation (R_s) curve to indicate clear days. Days showing clear morning and cloudy afternoon conditions were also selected. Days that had an occurrence of precipitation were eliminated.

For each day, the 11 a.m. measurement was selected for use as the instantaneous CO_2 flux measurement due to its concurrence with Landsat Thematic Mapper (TM) overpasses. The flux measurements from 6 a.m. to 6 p.m. were summed and used as the actual daytime net CO_2 flux for each day.

Calculation of daytime net CO_2 flux

A two-year (1996-1997) data set consisting of 41 days was used to examine the relationship between instantaneous and daytime net CO_2 flux. A three-year data set (1998-2000) composed of 69 days was used for validation of the relation. The resulting equation from that comparison was applied to Landsat imagery to generate spatial maps of daytime net CO_2 flux.

Results and Discussion

Semiarid grassland CO_2 fluxes tended to deviate from the expected relation that exists between plant ET and R_s. Figure 1a illustrates an R_s curve over the course of a cloud-free day. Plant ET would have a very similar curve under cloud-free conditions with unlimited water availability (Jackson 1983). Due to its link with transpiration, CO_2 plant uptake was expected to have the same curve. However, in water limited conditions this was not the case. Figure 1b shows the variability that occurred due to differences in water availability. The trend in CO_2 flux observed in the morning proved to be an indicator of the flux trend for the day.

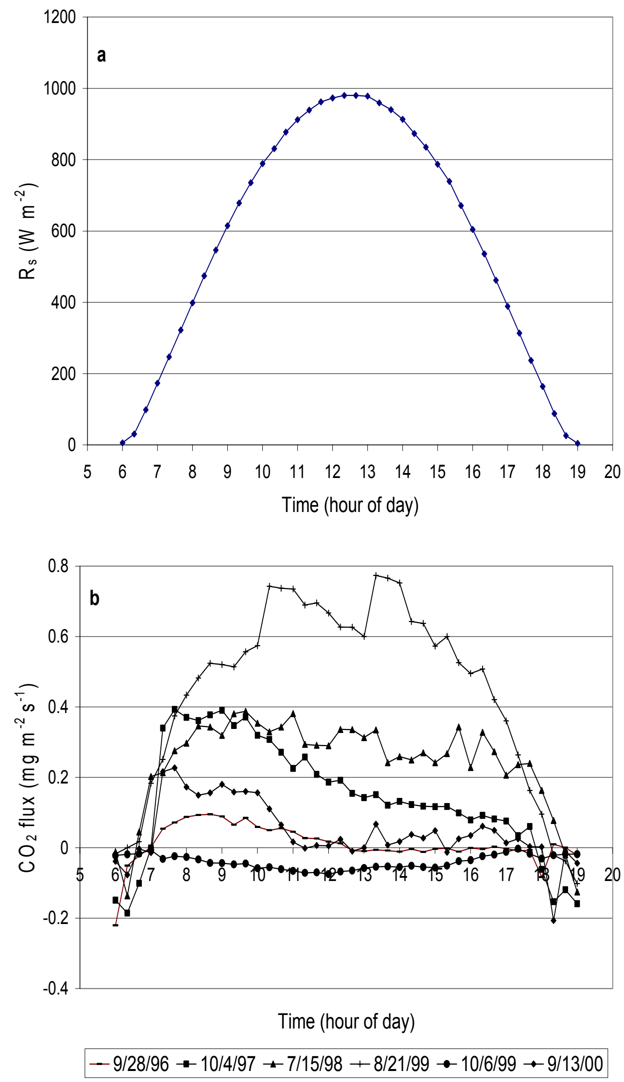

Figure 1. (a) Illustration of incoming solar radiation (R_s) from 6 a.m. to 6 p.m. under cloud-free

conditions. (b) Measurements of net CO_2 flux for cloud-free days with varying plant water availability. The relation between daytime and instantaneous net CO_2 flux (Figure 2) indicated a strong ($R^2 = 0.95$) linear relationship. The resulting equation was validated using data from 1998-2000, where

$$CO_{2d} = 29.338(CO_{2i}) - 0.2461 \quad (1)$$

and CO_{2d} is daytime net CO_2 flux (g m^{-2} $(12\ hrs)^{-1}$) and CO_{2i} is instantaneous net CO_2 flux (mg m^{-2} s^{-1}) (Figure 3). The RMSE for negative flux values, defined here as a net loss from the ecosystem, and positive flux values were 0.37 and 1.44 respectively.

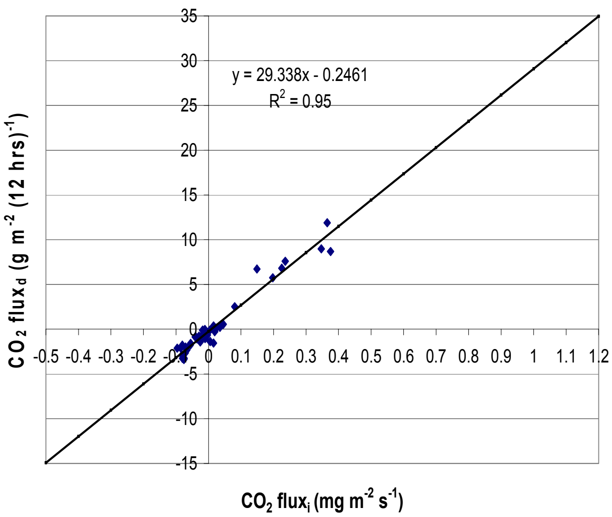

Figure 2. Comparison of daytime and 11 a.m. instantaneous net CO_2 flux for 1996 and 1997 on clear days. Negative flux values indicate net CO_2 loss from the soil. Positive values indicate net CO_2 uptake by plants.

Analysis was done to determine what happens to net CO_2 flux when a day has a clear morning, but clouds appear in the afternoon (Figure 4). This scenario is more typical of atmospheric conditions during the monsoon growing season. The relationship remained linear when the flux was negative. This was apparently due to the fact that soil moisture is the limiting factor when negative net CO_2 flux occurs. As a result, it made no difference whether sky conditions were clear or cloudy because the water limitation dominated. However, when the flux was high and positive, the relationship became slightly curvilinear. When flux is positive, water is generally not a limiting factor. In these instances, R_s becomes the limiting factor. Thus, when cloudy conditions occur, net CO_2 flux begins to decrease due to the fact that plants are forced to limit photosynthesis, decreasing CO_2 plant uptake.

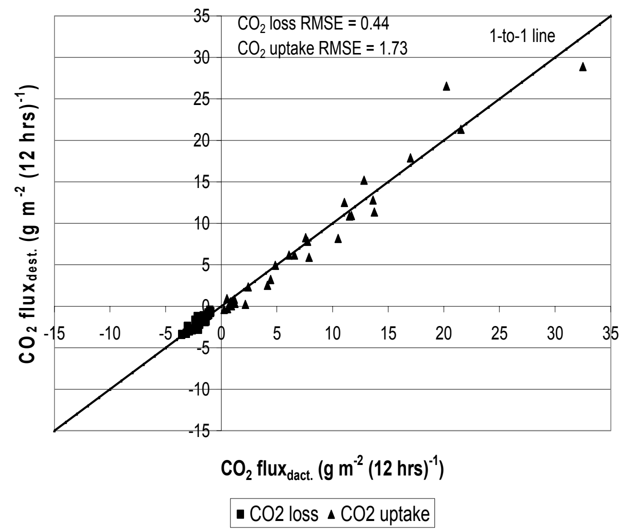

Figure 3. Comparison of estimated and actual daytime net CO_2 flux. Data from clear days in 1998, 1999, and 2000 were used for validation of the relation between daytime and instantaneous flux. Negative and positive flux values indicate net CO_2 loss and uptake, respectively.

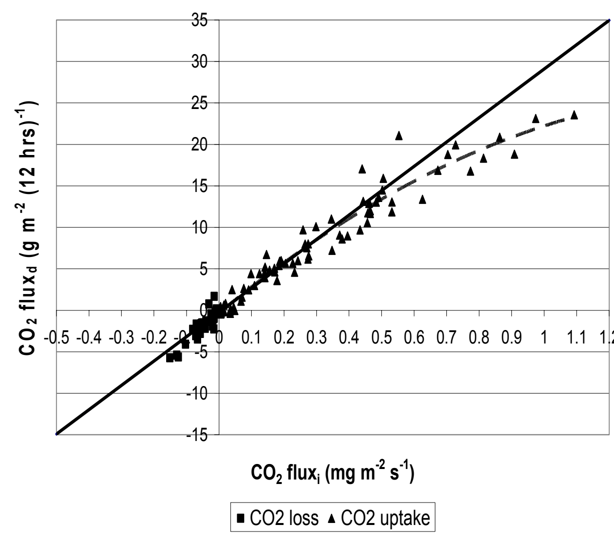

Figure 4. Comparison of daytime and 11 a.m. instantaneous net CO_2 flux for days with clear mornings and cloudy afternoons. Negative and positive flux values indicate net CO_2 loss and uptake, respectively.

Consequently, when Equation 1 was applied using the instantaneous flux values for these days, the result was an overestimation of daytime net CO_2 flux

(Figure 5), with RMSE of 0.70 and 2.00 respectively for negative and positive flux.

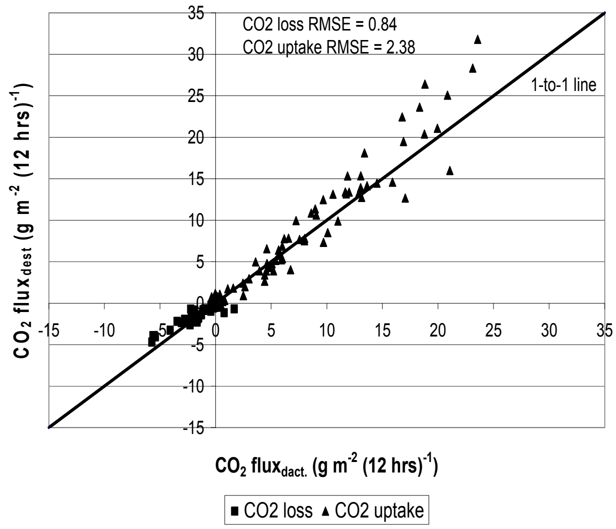

Figure 5. Comparison of estimated and actual daytime net CO_2 flux for days with clear mornings and cloudy afternoons. Negative and positive flux values indicate net CO_2 loss and uptake, respectively.

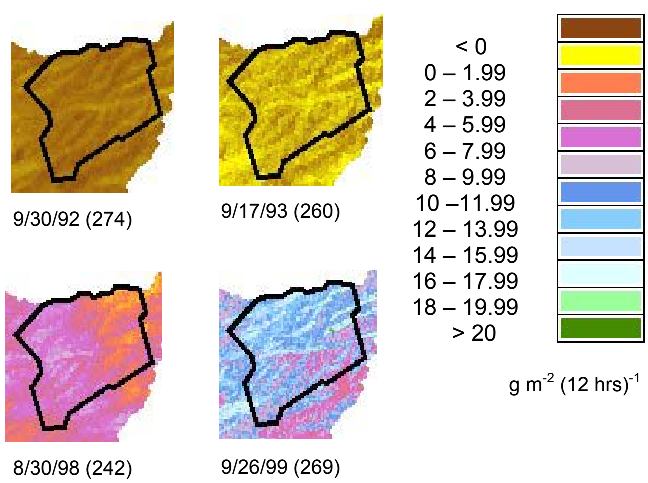

Figure 6. Landsat images of daytime net CO_2 flux (g m^{-2} (12 hrs)$^{-1}$) over a 9 km^2 area for 9/30/92 (DOY 274), 9/17/93 (DOY 260), 8/30/98 (DOY 242), and 9/26/99 (DOY 269). Negative values indicate net CO_2 loss from the soil. Positive values indicate net CO_2 uptake by plants.

Equation 1 was applied to Landsat satellite images of instantaneous net CO_2 flux created using a relation developed by Holifield et al. (2003) between net CO_2 flux and the WDI to generate spatially distributed maps of daytime net CO_2 flux (Figure 6). Each map reflected the impact made by precipitation or lack thereof, and the resulting plant responses. The DOY 274 image was taken during an extremely dry time period and the result was an overall negative flux measurement for the day. The DOY 242 image illustrated the spatial differences that existed due to a somewhat localized storm that had passed through a few days before the image was taken. Higher values of CO_2 uptake by plants were seen along the left portion of the image. This coincided with the storm path. The DOY 269 image reflected the fact that 1999 was a very wet year. Soil moisture was adequate to support high levels of transpiration and thus, high levels of CO_2 plant uptake (10 to 20 g m^{-2} (12 hrs)$^{-1}$).

Conclusions

In this study, instantaneous net CO_2 flux measurements were converted to spatially distributed, large-scale estimates of daytime net CO_2 flux. This conversion was possible because the 11 a.m. instantaneous flux measurement was found to be indicative of daytime flux in environments where water is a limiting factor. Consequently, a linear relationship was found to exist between instantaneous and daytime net CO_2 flux in semiarid grasslands. However, on days when water is not limiting and R_s is limited by cloud cover, overestimation of daytime flux is likely to occur. Nonetheless, this study showed it was possible to obtain reasonable large-scale, spatially distributed estimates of daytime net CO_2 flux for semiarid grasslands and serves to illustrate the promise of this potential tool in determining the role played by semiarid grasslands in the carbon cycle.

Future work could be focused on combining these daytime net CO_2 flux measurements with modeled or measured nighttime net CO_2 flux estimates to determine total daily net CO_2 flux. The ultimate goal would be to determine the seasonal patterns of daily net CO_2 flux and annual net CO_2 flux in semiarid grasslands.

Acknowledgments

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