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A REMOTE SENSING APPROACH FOR ESTIMATING REGIONAL GRASSLAND CARBON DIOXIDE FLUX

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Abstract

Grasslands cover nearly 30% of the Earth's land surface and may be an important sink for atmospheric carbon dioxide (CO_2). CO_2 flux from semiarid grasslands could be mapped using sensors aboard orbiting satellites that measure surface reflectance and temperature. The relation between surface reflectance and temperature has been used to determine a Water Deficit Index (WDI) to estimate regional plant transpiration rates for a point in time. Given that transpiration and plant CO_2 uptake are linked through the photosynthetic process, it follows that the WDI would be related directly to CO_2 flux. Satellite images were acquired for a five-year period (1996-2000) during which transpiration and CO_2 flux were measured for a grassland site in the Walnut Gulch Experimental Watershed (WGEW). Based on this dataset, we determined the relations between 1) WDI and plant transpiration; 2) transpiration and plant CO_2 uptake; and 3) WDI and CO_2 flux. The results indicated that there was a slightly curvilinear relation between WDI and transpiration (R^2 = 0.73) and a strong linear relation (R^2 = 0.90) between CO_2 uptake and transpiration. Based on these results, an exponential relation between WDI and CO_2 flux was determined and validated with an independent data set at WGEW. The mean absolute difference between measured and WDI-derived CO_2 flux was 0.24 over a range of CO_2 flux values from –0.10 to 1.10 (mg m^{-2} s^{-1}). Negative and positive values indicated net CO_2 loss from the soil or net CO_2 uptake by plants, respectively. The WDI offers an operational, physically-based approach for estimating regional CO_2 flux in semiarid grasslands.

Introduction

Grasslands cover a significant portion of the Earth's surface and have been shown to function as a net sink for atmospheric carbon dioxide (CO_2) (Frank and Dugas, 2001). Carbon dioxide flux is commonly measured using Bowen ratio energy balance (BREB) and eddy covariance systems. These systems are able to obtain measurements spanning relatively small areas (several hundred meters). However, through the use of satellite sensors that measure reflectance and temperature, remote sensing can offer a means of mapping CO_2 flux from semiarid grasslands on a regional scale. Previous work has shown that the relation between surface reflectance and temperature can be used to determine a Water Deficit Index (WDI) to estimate regional plant transpiration rates for a point in time (Holifield et al., 2002). Transpiration and plant CO_2 uptake are inextricably linked through the photosynthetic process. Thus, it follows that the WDI would be related directly to CO_2

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flux. Consequently, the objectives of this study were to determine: 1) the relation between WDI and transpiration; 2) the relation between transpiration and plant CO_2 uptake; and thus 3) the relation between WDI and CO_2 flux.

Methods and Data Processing

The following subsections include a brief description of WDI, the study area and instrumentation, and a discussion of the procedures used in evaluating and determining the relations between WDI, transpiration, and CO_2.

WDI

The Water Deficit Index (WDI) approach uses a combination of surface reflectance, temperature, and meteorological data to estimate transpiration over large scale heterogeneous areas. The basic relation is defined as $WDI = 1 - T/T_p$ where T and T_p are actual and potential transpiration, respectively. A detailed account of the theory behind the WDI and its derivation is presented by Holifield et al. (2002). For objective 1, WDI was derived from a series of Landsat-5 Thematic Mapper (TM) and Landsat-7 Enhanced TM Plus (ETM+) satellite images acquired over a five year period (1996-2000). All images were selected and processed according to techniques outlined by Holifield et al. (2002).

Study Area and Instrumentation

The study took place in the grassland portion of the Walnut Gulch Experimental Watershed (WGEW) located in southeast Arizona. An area of approximately nine square kilometers, dominated by black grama (*Bouteloua eriopoda*), blue grama (*B. gracilis*), sideoats grama (*B. curtipendula*), bush muhly (*Muhlenbergia porteri*), and Lehmann lovegrass (*Eragrostis lehmanniana*) was examined.

A Bowen ratio energy balance (BREB) system located within the study area collected continuous 20 minute averages of carbon dioxide and vapor flux measurements (Emmerich, 2002). Each 20 minute collection was later processed to calculate evapotranspiration and CO_2 flux. For objective 2, data collected during the summer monsoon (15 August to 15 September) over the five year period were selected based on criteria reported in Holifield et al. (2002) and used to confirm the relation between CO_2 plant uptake and grassland transpiration.

Weekly reflectance and temperature measurements covering an 80 m radius surrounding the BREB system were made using a modified five-band Exotech radiometer. For objective 3, WDI values calculated from these measurements were used to validate the WDI / CO_2 flux relationship.

Results

In situ transpiration measurements collected from a BREB system were compared to WDI measurements derived by Landsat imagery. A curvilinear relation resulted:

$$(1\text{-}T / T_p) = -0.0492 + (0.0495 * e^{(3.0465wdi)}), \quad (1)$$

where wdi is the WDI derived from satellite imagery (Figure 1).

The next step was to confirm the assumed relation between CO_2 plant uptake and transpiration. The resulting linear relation was:

$$(1\text{-}T / T_p) = -1.2571x + 1.006, \quad (2)$$

where x is CO_2 plant uptake (Figure 2).

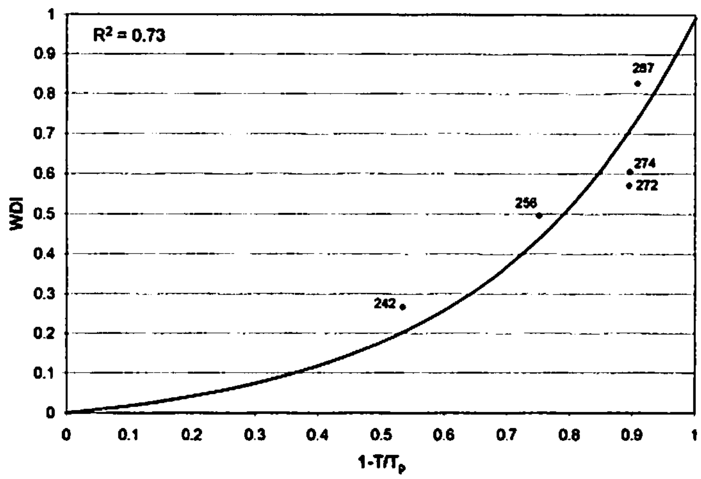

Figure 1. Comparison of satellite derived WDI and in situ transpiration measurements for 10/14/97 (DOY 287), 8/30/98 (DOY 242), 10/1/98 (DOY 274), 9/12/00 (DOY 256), and 9/28/00 (DOY 272).

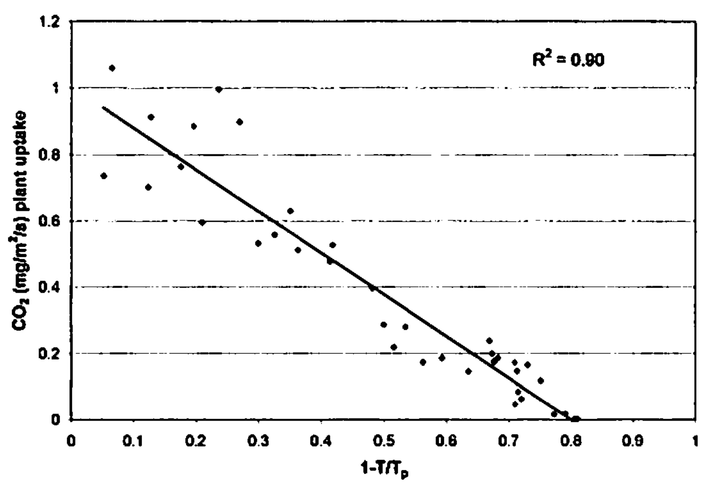

Figure 2. Comparison of CO_2 plant uptake and transpiration for the summer monsoon period of 15 August to 15 September for 1996-2000.

In the final step in our study, the two previous relations (Eq. 1 and 2) were used to determine the relation between WDI and CO_2 flux, where

$$CO_2 \text{ flux} = [\ln((wdi + 0.0492)/0.0495) - 2.3613] / -2.1945. \qquad (3)$$

An exponential relation between WDI and CO_2 flux was determined and validated with an independent data set collected at WGEW in 2002 (Figure 3). Due to unfavorable monsoon conditions and periodic instrumental difficulties, only three days were suitable for use for the validation (DOY 235, 263, and 268). The mean absolute difference between measured and WDI-derived CO_2 flux was 0.24 over a range of CO_2 flux values from -0.10 to 1.10 (mg m^{-2} s^{-1}). The relation shown in Figure 3 was then used to generate a ten-year series of Landsat images depicting point in time CO_2 flux over a 9 km^2 area. Four of these images are presented in Figure 4.

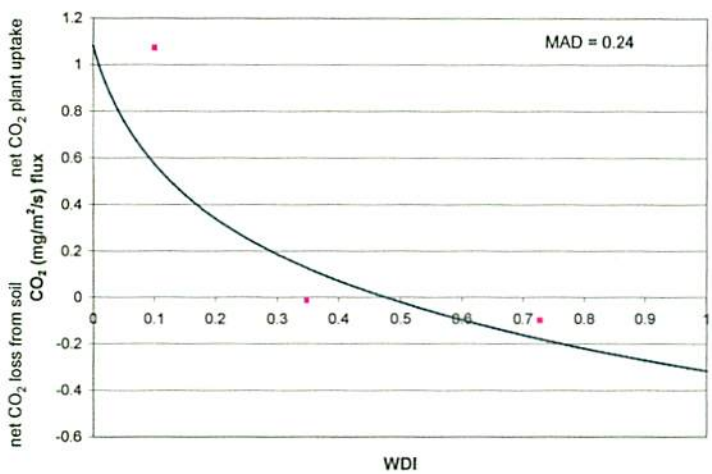

Figure 3. Comparison of CO_2 flux and WDI. Validation for the relation was performed using WDI data for 8/23/02 (DOY 235), 9/20/02 (DOY 263), and 9/25/02 (DOY 268).

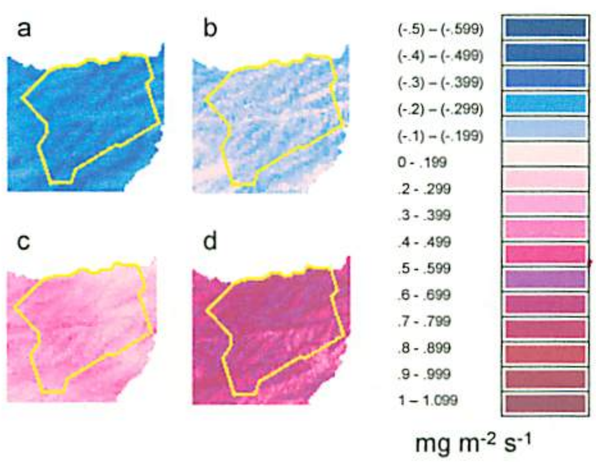

Figure 4. Landsat images of CO_2 flux (mg m^{-2} s^{-1}) over a 9 km^2 area for 9/30/92 (a), 9/17/93 (b), 8/30/98 (c), and 9/26/99 (d). Estimated plant available soil moisture for (a), (b), (c), and (d) were 0.71 mm, 3.54 mm, 12.70 mm, and 17.91 mm respectively. Negative values indicate net CO_2 loss from the soil. Positive values indicate net CO_2 uptake by plants.

Conclusions

The Water Deficit Index (WDI) derived from remote sensing was used to estimate large-scale carbon dioxide flux in semiarid grasslands and provide the ability to view spatial and temporal changes in CO_2 flux on a regional scale. The findings of this study also served to support a previous finding that semiarid grasslands serve not only as a sink, but as an important source of CO_2 (Emmerich, 2002). In the future, work to convert the WDI-derived CO_2 flux estimates from instantaneous to daily measurements has the potential to serve as a valuable tool in the ongoing effort to balance the global carbon budget.

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