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Research Paper

Simple models to predict grassland ecosystem C exchange and actual evapotranspiration using NDVI and environmental variables

Stephen J. Del Grosso[a,b,*], W.J. Parton[b], Justin D. Derner[c], Maosi Chen[b], Compton J. Tucker[d]

[a] USDA ARS PA SMSBR, 2150 Center Ave, Bldg. D, Suite 100, Fort Collins, CO 80526, USA
[b] Natural Resource Ecology Laboratory, Colorado State University, 1231 East Drive, Fort Collins, CO 80523, USA
[c] USDA-ARS High Plains Grasslands Research Station, 8408 Hildreth Road, Cheyenne, WY 82009-8899, USA
[d] NASA/GSFC, Mail Code: 610.9, Greenbelt, MD 20771, USA

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ABSTRACT

Semiarid grasslands contribute significantly to net terrestrial carbon flux as plant productivity and heterotrophic respiration in these moisture-limited systems are correlated with metrics related to water availability (e.g., precipitation, Actual EvapoTranspiration or AET). These variables are also correlated with remotely sensed metrics such as the Normalized Difference Vegetation Index (NDVI). We used measurements of growing season net ecosystem exchange of carbon (NEE), NDVI from eMODIS and AVHRR, precipitation, and volumetric soil water content (VSWC) from grazed pastures in the semiarid, shortgrass steppe to quantify the correlation of NEE with these driving variables. eMODIS NDVI explained 60 and 40% of the variability in daytime and nighttime NEE, respectively, on non-rain days; these correlations were reduced to 41 and 15%, respectively, on rain days. Daytime NEE was almost always negative (sink) on non-rain days but positive on most rain days. In contrast, nighttime NEE was always positive (source), across rain and non-rain days. A model based on eMODIS NDVI, VSWC, daytime vs. nighttime, and rain vs. non-rain days explained 48% of observed variability in NEE at a daily scale; this increased to 62% and 77%, respectively, at the weekly and monthly scales. eMODIS NDVI explained 50–52% of the variability in AET regardless of rain or non-rain days. A model based on eMODIS NDVI, VSWC, Potential EvapoTranspiration (or PET), and rain vs. non-rain days explained 70% of the observed variability in AET at a daily scale; this increased to 90 and 96%, respectively, at weekly and monthly scales. Models based on AVHRR NDVI showed similar patterns as those using eMODIS, but correlations with observations were lower. We conclude that remotely-sensed NDVI is a robust tool, when combined with VSWC and knowledge of rain events, for predicting NEE and AET across multiple temporal scales (day to season) in semiarid grasslands.

1. Introduction

Grasslands cover over 30% of the Earth's terrestrial surface (Adams et al., 1990; Reynolds et al., 2007), store large amounts of carbon (C) in soil organic matter strongly influence interannual variability in atmospheric carbon dioxide (CO_2) flux (Huang et al., 2016), and support rural economies through livestock grazing (Dunn et al., 2010). Recent analyses suggests that although water-limited, semiarid ecosystems account for only about 16% of global terrestrial NPP, they are responsible for about 29% of interannual variation in NPP, and drought is a primary driver (Huang et al., 2016). Consequently, it is important to improve understanding and better predict how key drivers, such as weather, drive the processes (photosynthesis, plant and microbial respiration) that control biomass production and net carbon flux in these systems. Net primary productivity (NPP) as well as net ecosystem exchange of carbon (NEE) in water-limited, semiarid grasslands are typically controlled by indices related to soil water (e.g., precipitation, soil water content, actual evapotranspiration) to a greater extent than other environmental controls (e.g., temperature, solar radiation). It is well established that NPP and NEE are correlated with normalized difference vegetation index (NDVI) and weather variables, particularly precipitation, at global scales (Del Grosso et al., 2008) and across the US Great Plains (Zhang et al., 2010; Gilmanov et al., 2005). Heterotrophic respiration also is limited by moisture in semiarid ecosystems and is particularly sensitive to rainfall events onto previously dry soil (Huxman et al., 2004).

Previously, Parton et al. (2012) presented empirical equations relating NEE observed in a shortgrass steppe grassland in Colorado, USA,

* Corresponding author at: USDA ARS PA SMSBR, 2150 Center Ave, Bldg. D, Suite 100, Fort Collins, CO 80526, USA.
E-mail addresses: steve.delgrosso@ars.usda.gov (S.J. Del Grosso), William.parton@colostate.edu (W.J. Parton), Justin.Derner@ars.usda.gov (J.D. Derner), compton.j.tucker@nasa.gov (C.J. Tucker).

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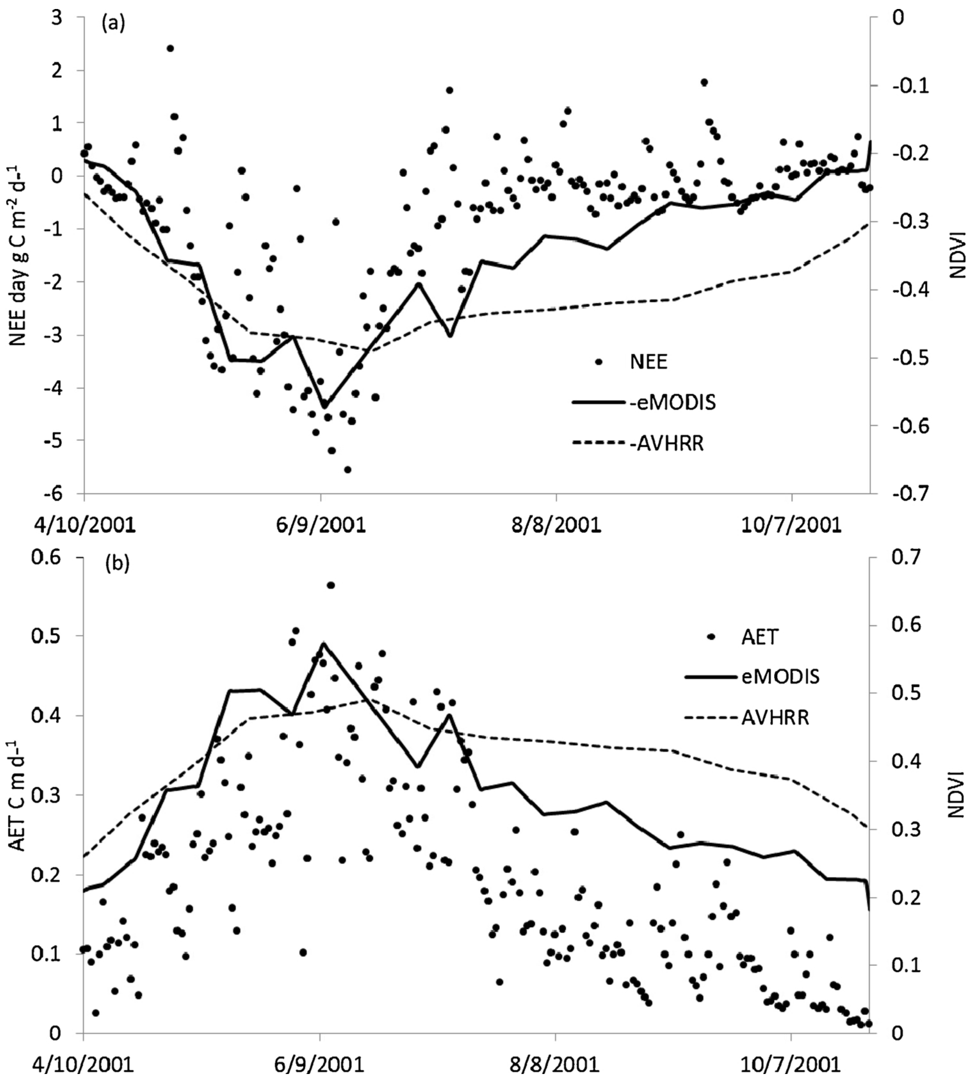

Fig. 1. Net ecosystem carbon exchange (NEE) (a) and actual evapotranspiration (AET) (b) with NDVI from eMODIS and AVHRR for shortgrass steppe during the 2001 growing season.

to soil water content, photosynthetically active radiation, live biomass, air temperature and relative humidity. Models based on these factors explained up to 65% of the variability in observed daytime NEE, but live biomass, which was the most important factor, relied on ground based measurements. In this paper we use flux tower data from shortgrass steppe pastures to demonstrate (1) that NEE is correlated with NDVI and soil water content, (2) that actual evapotranspiration (AET) is correlated with NDVI, soil water content, and potential evapotranspiration (PET), and (3) that precipitation events modify these relationships. We then develop and evaluate models to predict NEE and AET based on remotely-sensed NDVI from two satellite platforms, Moderate Resolution Imaging Spectroradiometer (eMODIS) and Advanced Very High Resolution Radiometer (AVHRR) combined with the weather related variables mentioned above. Lastly, we apply the model to quantify the importance of rain induced respiration on NEE and to compare the impact of increasing rainfall frequency, while keeping seasonal total constant, on NEE.

2. Materials and methods

2.1. Data sets used

NEE, AET and soil water content were observed at the USDA-ARS Central Plains Experimental Range (CPER), lat. 40° 50′ N. long. 104° 43′. The CPER, a Long-Term Agro-ecosystem Research (LTAR) network site, is about 12 km northeast of Nunn, Colorado, USA. Mean annual precipitation is 340 mm with 242 mm occurring during the spring and early summer growing season (April–August) and mean air temperatures are 15.6 °C in summer and 0.6 °C in winter. Vegetative basal cover ranges from 23% to 35% (Milchunas et al., 1989) and is comprised of a mixture of C4 and C3 perennial grasses, a sub-frutescent shrub (*Artemesia frigida*), forbs, and cacti, with the majority of the aboveground plant production coming from *Bouteloua gracilis* (C4 perennial grass). The CPER site, used as an experimental range since 1937, has been grazed by livestock during the past 150 years, with grazing by American Bison prior to European settlement in the 1850s.

Measurements were obtained from two consecutive grazing experiments at the CPER, one conducted from 2001 to 2003, and the other during 2004 to 2006. The earlier grazing study considered three grazing intensities (none, moderate, and heavy) while the latter only had moderate and heavy grazing (Morgan et al., 2016). Bowen ratio CO_2 energy balance (BREB) flux towers were used to infer NEE and AET. Remotely sensed 7-day 250 m resolution NDVI were calculated for the pastures using eMODIS data from the expedited Moderate Resolution Imaging Spectroradiometer (eMODIS) product (Jenkerson et al., 2010) and from bi-weekly 8-km AVHRR (Advanced Very High Resolution Radiometers) data (Tucker et al., 2005). Daily NDVI values for both eMODIS and AVHRR were inferred by linearly interpolating between days with consecutive observations. Volumetric soil water content (VSWC) was measured daily at 0–15 cm depth using calibrated water