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Adaptive data-driven models for estimating carbon fluxes in the Northern Great Plains

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Abstract

Rangeland carbon fluxes are highly variable in both space and time. Given the expansive areas of rangelands, how rangelands respond to climatic variation, management, and soil potential is important to understanding carbon dynamics. Rangeland carbon fluxes associated with Net Ecosystem Exchange (NEE) were measured from multiple year data sets at five flux tower locations in the Northern Great Plains. These flux tower measurements were combined with 1-km^2 spatial data sets of Photosynthetically Active Radiation (PAR), Normalized Difference Vegetation Index (NDVI), temperature, precipitation, seasonal NDVI metrics, and soil characteristics. Flux tower measurements were used to train and select variables for a rule-based piece-wise regression model. The accuracy and stability of the model were assessed through random cross-validation and cross-validation by site and year.

Estimates of NEE were produced for each 10-day period during each growing season from 1998 to 2001. Growing season carbon flux estimates were combined with winter flux estimates to derive and map annual estimates of NEE. The rule-based piece-wise regression model is a dynamic, adaptive model that captures the relationships of the spatial data to NEE as conditions evolve throughout the growing season. The carbon dynamics in the Northern Great Plains proved to be in near equilibrium, serving as a small carbon sink in 1999 and as a small carbon source in 1998, 2000, and 2001. Patterns of carbon sinks and sources are very complex, with the carbon dynamics tilting toward sources in the drier west and toward sinks in the east and near the mountains in the extreme west. Significant local variability exists, which initial investigations suggest are likely related to local climate variability, soil properties, and management.
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Keywords: Carbon flux; Grassland ecosystems; Northern Great Plains; Data-driven models; Piece-wise regression models; Net Ecosystem Exchange

1. Introduction

Grassland systems, faced with large-scale agricultural conversions, are some of the most altered systems in the world (Butcher, 2004; White et al., 2000; WRI, 2000). Rangelands make up 40% of the Earth's surface (WRI, 2000) within which temperate grasslands contain about 18% of global carbon reserves (Burke et al., 1997). As future demands on ecosystems increase, the value of ecosystem services, including carbon mitigation and ecosystem health will also continue to increase (Costanza et al., 1997).

This study describes an adaptive data-driven piece-wise regression methodology to estimate Net Ecosystem Exchange (NEE) at 10-day time steps during the growing season. These estimates are summed and added to winter flux estimates to create 1-km resolution maps of annual carbon fluxes for the ecoregion. An analysis of the spatial patterns and responses

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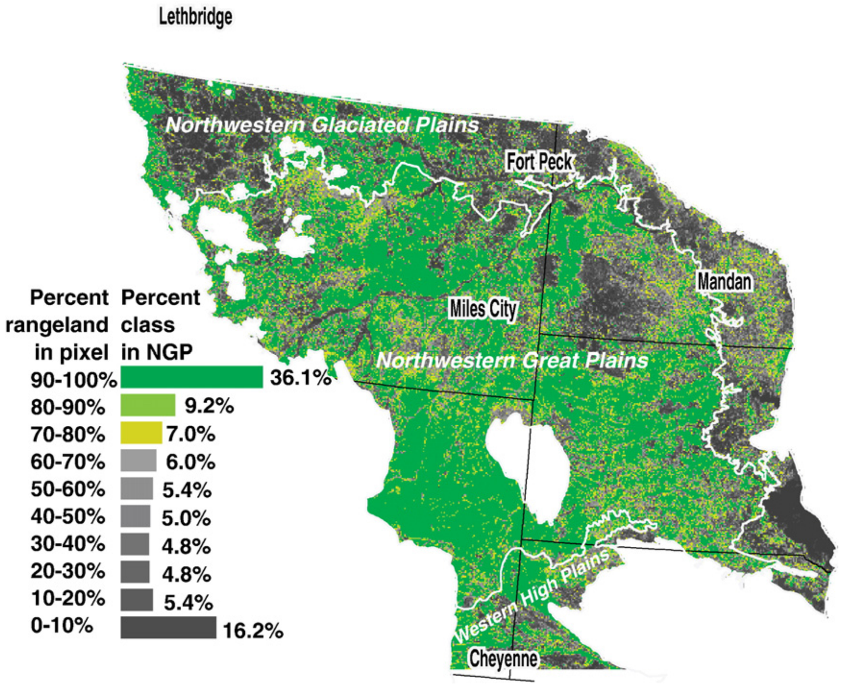

Fig. 1. Distribution of grass and shrub lands in the Northern Great Plains. The boundaries of the ecosystems are in white. The locations of the five flux towers are shown.

through time will lead to a better understanding of climatic variability and land management practices on the Net Ecosystem Exchange of carbon.

The Northern Great Plains grassland ecosystem for this study (see Fig. 1) includes the Northwestern Glaciated Plains, Northwestern Great Plains and the Western High Plains north of 41° N latitude (CEC, 1997; McMahon et al., 2001; Omernik, 1987). The Northern Great Plains comprises a transition from moister and more intensive agricultural regions to the east to dryer lands dominated in the south and west by native grasslands, where agriculture is controlled by access to irrigation. The boundary between the Northwestern Great Plains and the Western High Plains marks the transition between blue grama-buffalo grass (*Bouteloua gracilis*) and winter wheat (*Triticum aestivum*) to the south and mostly wheatgrass–needlegrass (*Pascopyrum smithii*–*Stipa spp*.) and spring wheat to the north (EPA, 2005). How will Northern Great Plains rangelands respond to predicted increases in winter precipitation and drier summer conditions and increased weather variability (Wigley, 1999) or the introduction of new varieties of drought resistant crops (Higgins et al., 2002) within this highly variable and responsive ecological system? Methodologies described in this paper will assist in identifying how these causal variables are reflected in changing carbon dynamics.

Micro-meteorological flux towers improve our understanding of ecosystem responses to climate and quantify carbon dynamics locally at great detail. Continental (Wofsy & Harriss, 2002) and international programs (Cihlar et al., 2003) have prioritized the scaling up of localized flux tower measurements to identify, monitor, and understand carbon sink and source areas. The relationships between grassland CO_2 and spectral vegetation indices (e.g., Bartlett et al., 1990; Churkina et al., 2005; Gilmanov et al., 2005; Wylie et al., 2004) provide opportunities for scaling up localized tower measurements to larger geographical areas.

Carbon absorbed and released as a result of biological activity needs to be summed throughout the ecoregion to quantify biological carbon sinks and sources. However, carbon fluxes can only be directly measured for approximately 1-km fetch areas, and the cost of direct measurement limits the number of locations that can be measured. The key to understanding ecosystem carbon dynamics lies in discovering robust relationships between detailed knowledge collected at representative local sites and spatial data that describe the entire ecoregion.

Two complementary approaches are possible to quantify the relationships between flux tower measurements and spatial data. The first approach is to define theoretical biophysical models of carbon dynamics, to adapt these models to available spatial data, and to calibrate and validate the models using flux tower measurements. The second approach, described in this paper, is to develop data-driven models at the flux towers using tower measurements and spatial data measurements at the tower. These data-driven models are evaluated in regard to known vegetation physiology and are then applied across the ecosystem.

This paper describes (1) the spatial and tower data, (2) the development of a data-driven model, (3) techniques to assess the robustness of the model, and (4) the results of applying the model to estimate NEE across the entire ecoregion. The spatial variables must be able to quantify carbon fluxes in a manner that can be justified given known physical characteristics of carbon dynamics. To achieve robust estimates, the spatial distribution of the flux towers and the years sampled at the towers must adequately sample the variability of the environmental extremes in the