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Vegetation primary production estimation at maize and alpine meadow over the Heihe River Basin, China

Xufeng Wang[a,b,*], Mingguo Ma[a], Guanghui Huang[a], Frank Veroustraete[c], Zhihui Zhang[a,b], Yi Song[a,b], Junlei Tan[a]

[a] Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100049, China
[c] Flemish Institute for Technological Research, B-2400 Mol, Belgium

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ABSTRACT

The accurate estimation of Gross Primary Production (GPP) is an important issue in carbon cycle studies. In this study, GPP dynamic of two typical vegetation in Heihe River Basin (alpine meadow in the upper stream and maize in middle stream) were estimated using Eddy Covariance (EC) and Vegetation Photosynthesis Model (VPM). Yearly GPP observed by EC at alpine meadow is 853 gC/m^2/yr, which is only half of GPP of the value 1567 gC/m^2/yr at maize field. This is mainly attributed to irrigation, fertilization and high light use efficiency at maize field. More than 80% carbon fixed by photosynthesis is release to atmosphere through ecosystem respiration at alpine meadow and at maize field 60%. The maximum light use efficiency of maize is 2.66 gC/MJ ARAR, while it is 1.6 gC/MJ ARAR at alpine meadow. VPM can correctly simulate seasonal dynamic and magnitude of GPP at both of the two sites. GPP values predicted by VPM were 872 gC/m^2/yr at alpine meadow site and 1246 gC/m^2/yr at maize site. The determination coefficients were as large as 0.9 at the alpine meadow site and 0.93 at the maize site. Average GPP value at each season predicted by VPM is very close to that observed by EC.

1. Introduction

Heihe River Basin which is located in northwest arid area of China is composed of three typical ecosystems: alpine ecosystem in upper stream, human controlled agro-ecosystem in the middle stream and Gobi and Desert ecosystem in the lower stream. Vegetation productivity is sensitive to climate change. Gross Primary Production (GPP) is the rate of carbon fixation through vegetation photosynthesis. GPP is a key measure of carbon mass flux in carbon cycle studies. GPP is generally estimated using models because it is difficult to measure GPP directly (Chapin et al., 2002). GPP in arid and semiarid region in northwest China was rarely reported in previous work.

Satellite remote sensing is widely used to estimate temporal and spatial patterns of GPP with high spatial and temporal resolution. The GPP is a function of the amount of Photosynthetically Active Radiation (PAR), the fraction of PAR absorbed by the plant canopy (*f*APAR) and environmental factors (e.g., temperature, soil moisture and vapour pressure deficit) in the Production Efficiency Model (PEM). The Vegetation Photosynthesis Model (VPM) (Xiao et al., 2004a) is a satellite-based GPP model. The main characteristic of the VPM is that *f*APAR is estimated using the Enhanced Vegetation Index (EVI) rather than the Normalised Difference Vegetation Index (NDVI), which is used in many other satellite-based GPP models. Another characteristic of the VPM is that it makes use of the Land Surface Water Index (LSWI), which is easier to measure than Vapour Pressure Deficit (VPD) and soil moisture content (SMC) for large-scale simulations, to simulate the impact of water on GPP. The VPM has been validated for many ecosystems, such as evergreen needle leaf forest (Xiao et al., 2004a, 2005), alpine meadow, swamp and shrub ecosystems (Li et al., 2007), winter wheat-maize double cropping systems (Yan et al., 2009), temperate grass ecosystems (Wu et al., 2008), and temperate deciduous broadleaf forests (Xiao et al., 2004b).

Eddy Covariance (EC) is an accurate method to measure vertical mass fluxes of CO_2 and water vapour as well as energy fluxes. It enables the direct measurement of the net ecosystem exchange (NEE) of CO_2 for a footprint that is related to the tower height, atmospheric stability and wind speed and direction. GPP can be calculated from daytime NEE values measured using EC and daytime ecosystem respiration (ER) values. A regressed relationship between nighttime NEE values and nighttime temperature has

* Corresponding author at: Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China.
Tel.: +86 931 4967259.
E-mail address: wxfgis2002@sina.com (X. Wang).

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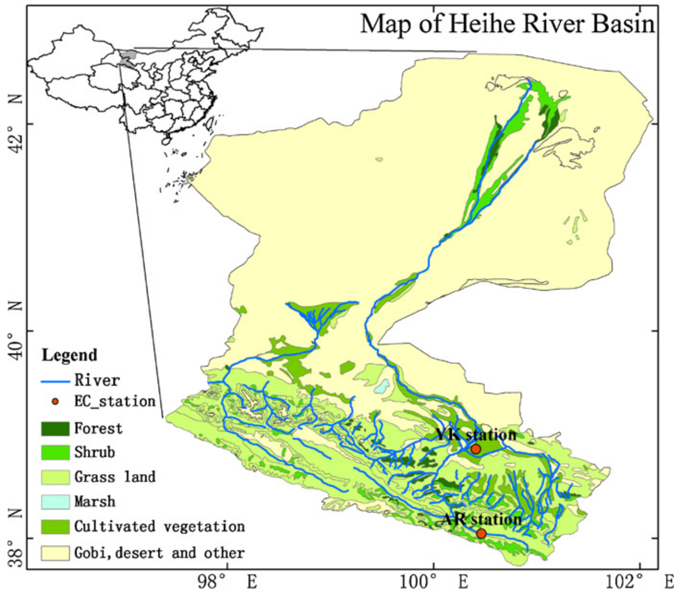

Fig. 1. Locations of the YK and AR stations in the Heihe River Basin.

been established when GPP is zero; daytime ER is estimated using this relationship and the daytime soil temperature (Georg et al., 2005; Suyker et al., 2005; Desai et al., 2008).

There were three objectives for this study: (1) to assess the carbon budget of typical ecosystem in the Heihe River Basin; (2) to estimate parameter of VPM for two main ecosystems in Heihe River basin and (3) to validate VPM in alpine meadow site and irrigated maize field.

2. Data

2.1. Study sites

The Heihe River Basin is the second largest inland river basin in China. It is located between 97°24′–102°10′E and 37°41′–42°42′N and covers an area of approximately 128,900 km^2. Elevation in the Heihe River Basin ranges from 5000 m in the south to 1000 m in the north (Ma and Veroustraete, 2006). In the upper stream of Heihe River Basin, the vegetation ecosystems are primarily natural ecosystems; in the middle stream of Heihe River Basin, there are many artificial oases; and the downstream Heihe River Basin is mainly covered by the Gobi and desert (Lu et al., 2009). Alpine meadow covers the largest vegetation area in the upper stream, which is located in the cold region (Li et al., 2001). In the middle stream, crops are some of the main vegetation types. We chose the A'rou (AR) freeze/thaw observation station, which is in an area of alpine meadow in the upper stream, and the Yingke (YK) oasis station, which is in an area of irrigated farmland in the middle stream. The field observation systems at these two experiment sites are stations that were constructed as part of the Watershed Allied Telemetry Experimental Research (WATER) project. Fig. 1 shows the positions of the YK station and the AR station.

The AR station (E100°27′, N38°02′, 3032 m) was constructed in July 2007. Seasonally frozen soil is widely distributed in this region. Yearly average temperature was −1 °C in 2008 and −0.3 °C in 2009. Yearly integrated rainfall was 449.4 mm in 2008 and 450.5 mm in 2009. The observation variables included the following: wind speed and direction (measured at heights of 2 and 10 m), air temperature and humidity (measured at heights of 2 and 10 m), air pressure, rainfall, the four components of radiation, soil temperature and moisture profiles (measured at depths of 10, 20, 40, 80, 120 and 160 cm), and EC (measured at a height of 3.15 m). The EC measurements have been taken since June 2008, and the other measurements have been taken since July 2007 (Li et al., 2008, 2009).

Table 1
Parameters of the Van't Hoff equation and percentage of nocturnal data accepted.

	$R_{ref,10}$	Q_{10}	R^2	Nocturnal data accepted
YK2008[a]	0.024	2.39	0.48	22.8%
YK2009[a]	0.022	2.59	0.55	22%
AR2008[a]	0.043	3.11	0.63	26.8%
AR2009[a]	0.037	3.45	0.61	28.8%

[a] Figures after the station acronym are the year observations are acquired. $R_{ref,10}$ [mgC/m^2/s]; Q10 [dimensionless].

The YK station (E100°25′, N38°51′, 1519 m) was constructed in November 2007. During 2008 and 2009, the primary crop in the area was maize. Yearly average temperature was 7 °C in 2008 and 7.8 °C in 2009. Yearly integrated rainfall was 67.4 mm in 2008 and 68.7 mm in 2009. The observation variables included the following: wind speed and direction (measured at heights of 3 and 10 m), air temperature and humidity (measured at heights of 3 and 10 m), air pressure, rainfall, the four components of radiation, soil temperature and moisture profiles (measured at depths of 10, 20, 40, 80, 120 and 160 cm), and EC (measured at a height of 2.81 m). All of the measurements have been taken since November 2007 (Li et al., 2008, 2009).

2.2. EC data processing and GPP estimation

EC data measured at the YK and AR stations from 2008 to 2009 were collected. Components of the wind vector and temperature were measured using a three-dimensional sonic anemometer (CSAT3, Campbell Inc., USA). Water vapour density and CO_2 density were measured using an open-path, infrared gas analyzer (Li-7500, LiCor Inc., USA). The sampling frequency was 10 Hz. The energy balance ratio is approximately 87% at AR station and 86% at YK station (Wang et al., 2009).

Data quality control processes were applied to raw 10 Hz EC data to obtain half-hourly flux data. The processing steps included despiking, coordinate rotation, time lag correction, frequency response correction and WPL correction (Zhang et al., 2010). Half-hourly flux data were excluded if the sensor variance was excessive, if there was rainfall or if the instruments malfunctioned. During the night, the quality of flux data was often inferior because of a weak turbulent mixing at a low friction velocity (u^*). Thus, nighttime (downward shortwave radiation <1 W/m^2) half-hourly data flux values were excluded if the friction velocity was lower than a specific threshold. The threshold was 0.15 m/s for the YK station and 0.1 m/s for the AR station (Zhu et al., 2006; Richardson and Hollinger, 2007). More than 70% nocturnal data was rejected at the two stations (see Table 1). To obtain complete daily estimate of CO_2 exchange, data gaps were filled using the following method. Missing NEE values during the day were estimated using the Michaelis–Menten equation (see Eq. (1)), which begins from a hypothesis that the relationship between NEE and PAR is nonlinear. The coefficients of the Michaelis–Menten equation were determined based on monthly data. Missing night time NEE values were estimated using the Van't Hoff equation (see Eq. (2)), which can be used to represent the night time NEE values as a function of temperature. When PAR and temperature data were missing, the gaps were filled with the average value of the variable for the same time periods over the adjacent 10 days. Big gaps (>1 day) were not filled PAR and temperature data of the two sites is given in Fig. 2.

GPP can be estimated from the NEE values measured with EC. The nighttime NEE is considered to be equal to ER, and the daytime NEE is equal to the difference between GPP and the daytime