GPP estimation over Heihe River Basin, China

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ABSTRACT

Gross Primary Production (GPP) is the sum of carbon absorbed by plant canopy. It is a key measurement of carbon mass flux in carbon cycle studies. Remote sensing based light use efficiency model is a widely used method to estimate regional GPP. In this study, MODIS-PSN was used to estimate GPP in Heihe River Basin. In order to better the model accuracy, maximum light use efficiency (ε_0) in MODIS-PSN is estimated using local observed carbon flux data and meteorological data. After adjustment of parameter ε_0, MODIS-PSN can correctly estimate GPP for major vegetation type in the Heihe River Basin. Then, yearly GPP over Heihe River Basin was estimated. The results indicated that about $1.4*10^{13}$g carbon enter terrestrial ecosystem through vegetation photosynthesis in the Heihe River Basin one year. In contrast, there is just $5.73*10^{13}$g carbon enter terrestrial ecosystem according to the standard MODIS GPP product, which is greatly underestimated GPP in the Heihe River Bain.

Keywords: Gross Primary Production; Eddy Covariance; Heihe River Basin; MODIS GPP Product

1 INTRODUCTION

Gross Primary Production (GPP) is a key variable in carbon cycle studies. It indicates carbon sequestration capability of vegetation. Heihe River Basin is the second largest inland river basin in China and it is located in arid region of Northwest China[1]. Estimation of GPP in this region can better understand carbon cycle of terrestrial ecosystem in arid region. Light use efficiency model is effective method to estimate regional GPP with remote sensing data. In recent years, a number of light use efficiency models were developed, such as GLO-PEM[2], VPM[3], EC-LUE[4], MODIS-PSN[5-6], C-Fix[7]. In these models, GPP is calculated with Photosynthetically Active Radiation (PAR) and light use efficiency, which is stressed by environmental factors (temperature, humidity, soil moisture, etc.). MODIS-PSN has been used to produce global GPP dataset with MODIS data by the Land Processes Distributed Active Archive Center (LP DAAC)[6]. It was reported that MODIS-GPP product is greatly lower than GPP observed with Eddy Covariance (EC) at a lot of ecosystems, such as temperate grassland ecosystem in Inner Mongolia[8], cropland in North China Plain and alpine meadow in Northwest China[9], subtropical coniferous plantation in southern China[10]. These great biases are resulted from erroneous model parameters in MODIS-PSN, especially maximum light use efficiency (ε_0) [8-10]. After using calibrated parameters, MODIS-PSN can correctly predict GPP[9-10]. Eddy Covariance (EC) can directly measure carbon flux over a footprint. GPP over the footprint can be estimated with meteorological data and carbon flux data[11]. GPP estimated with EC is comparable with that from remote sensing at spatial scale. Thus, it can be used to validate GPP estimated using remote sensing data and calibrate light use efficiency model.

In order to correct estimate GPP in the Heihe River Basin, key parameters in MODIS-PSN model were estimated using carbon flux data and meteorological data collected at four ground observation systems at first. Then regional grid climate data and latest land cover data were used to drive MODIS-PSN model. The estimated GPP was compared with standard MODIS GPP product at site scale and regional scale in this paper. The objectives of this study are: (1) to calibrate vital parameter in MODIS-PSN model with EC observed carbon flux data; (2) to estimate GPP over Heihe River Basin with MODIS-PSN.

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2 DATA

2.1 Meteorological data and carbon flux data

Carbon flux data and meteorological data from four stations (A'rou (AR) freeze/thaw observation station, Dayekou (DYK) Guantan forest station, Linze (LZ) inland river basin observation station and Yingke (YK) oasis station) in Heihe River Basin were collected. Figure 1 shows the location of the four stations. Time period of the data and surface type of each station are given in Table 1. The regional meteorological data with spatial resolution of 0.25° was downloaded from NASA Data Assimilation Office (http://ldas.gsfc.nasa.gov/gldas/GLDASdownload.php). In order to match the spatial resolution of MODIS data, this data was interpolated into 1km in spatial resolution.

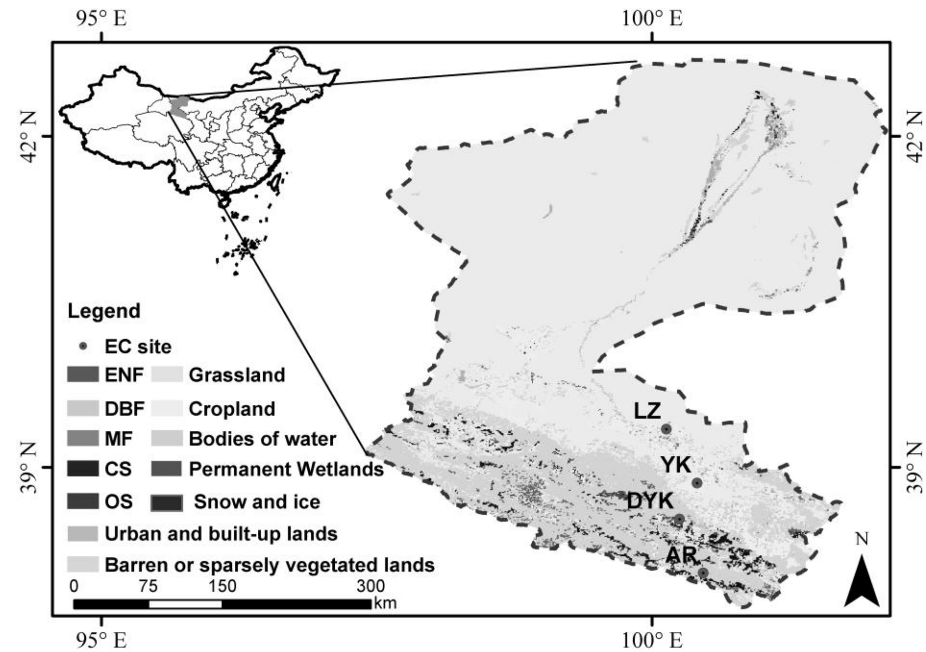


Figure 1 Location of the EC stations in the Heihe River Basin.(ENF: Evergreen needleleaf forest; DBF: Deciduous broadleaf forest; MF: Mixed forest; CS: Closed shrublands; OS: Open shrublands)

Table 1 Information of observation sites in the Heihe River Basin.

Station name	Vegetation type	Observing period
LZ	Cropland (Maize)	2008 (Jun-Sep),2009 (Jun-Sep)
YK	Cropland (Maize)	2008-2009
DYK	Evergreen needleleaf forest	2010
AR	Grassland	2008-2009

2.2 MODIS data and land cover data

MODIS reflectance product (MOD09A1) and MODIS GPP product (MOD17A2) were provided by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (lpdaac.usgs.gov) (https://wist.echo.nasa.gov/~wist/api/imswel come/). The land cover type data of the Heihe River Basin was provided by Ran[12]. There are 12 land cover types in the Heihe River Basin. Barren or sparsely vegetated lands covers 80.7 of the area of the Heihe River Basin, Grassland covers 13.9%, Cropland covers 2.3%, and other land cover types are smaller than 1%.

3 METHODOLOGY

In MODIS-PSN model, GPP is calculated according to Eq. (1):

$$GPP = PAR \times fAPAR \times \varepsilon_0 \times f(T\min) \times f(VPD) \quad (1)$$

where GPP [gC/m^2/d] is the gross primary production, PAR [MJ/m^2] is the photosynthetically active radiation, fAPAR [dimensionless] is the fraction of absorbed photosynthetically active radiation, ε_0 [gC/MJ APAR] is the maximum light use efficiency, Tmin [℃] is the minimum daily temperature and VPD [Pa] is the average vapour pressure deficit. f(Tmin) and f(VPD) are defined as follows:

$$f(T_{\min}) = \begin{cases} 0 & T\min < T\min_{\min} \\ \dfrac{T\min - T\min_{\min}}{T\min_{\max} - T\min_{\min}} & T\min_{\min} < T\min < T\min \\ 1 & T\min > T\min_{\max} \end{cases} \quad (2)$$

$$f(VPD) = \begin{cases} 0 & VPD > VPD_{\max} \\ \dfrac{VPD_{\max} - VPD}{VPD_{\max} - VPD_{\min}} & VPD_{\min} < VPD < VPD_{\max} \\ 1 & VPD < VPD_{\min} \end{cases} \quad (3)$$

$$fAPAR = 1.24 * NDVI - 0.168 \quad (4)$$

where Tminmin [℃], Tminmax [℃], VPDmax [Pa] and VPDmin [Pa] are species-specific parameters and can be obtained from the Biome Parameters Look Up Table (BPLUT) according to the vegetation code. The standard MODIS GPP product (MOD17A2) is calculated with MODIS-PSN model and based on the land cover type map (MOD12Q1 Land Cover Classification Type 2) which use classification scheme produced by the University of Maryland (UMD). fAPAR can be estimated with NDVI[4].

ε_0 is a very important parameter in MODIS-PSN model. ε_0 of the major vegetation types in the Heihe River Basin were estimated using local observation. ε_0 of ENF is calibrated with EC data at DYK site. The main crop types in Heihe River Basin are maize and wheat. According to Zhang's study, ε_0 of wheat is about 1.18gC/MJ APAR[9], and ε_0 of maize at YK station and LZ station is about 2.43 gC/MJ APAR, using the average of the two values as ε_0 for cropland in the Heihe River Basin. ε_0 at AR station was used for grassland. For DBF, MF, CS and OS, the default ε_0 were used. The default values were used for other parameters (see Table 2).

Table 2 Parameters for GPP estimation

Vegetation type	ε0(gC/MJ APAR)	Tmin_max (℃)	Tmin_min (℃)	VPD_max (Pa)	VPD_min (Pa)
ENF	1.13*/1.008	8.31	-8	2500	650
DBF	1.004	7.94	-8	2500	650
MF	1.116	8.5	-8	2500	650
CS	0.888	8.61	-8	3100	650
OS	0.774	8.8	-8	3600	650
Grass	1.35*/0.68	12.02	-8	3500	650
Croplands	1.81*/0.68	12.02	-8	4100	650

ENF: Evergreen needleleaf forest; DBF: Deciduous broadleaf forest; MF: Mixed forest; CS: Closed shrublands; OS: Open shrublands; * Calibrated parameter.

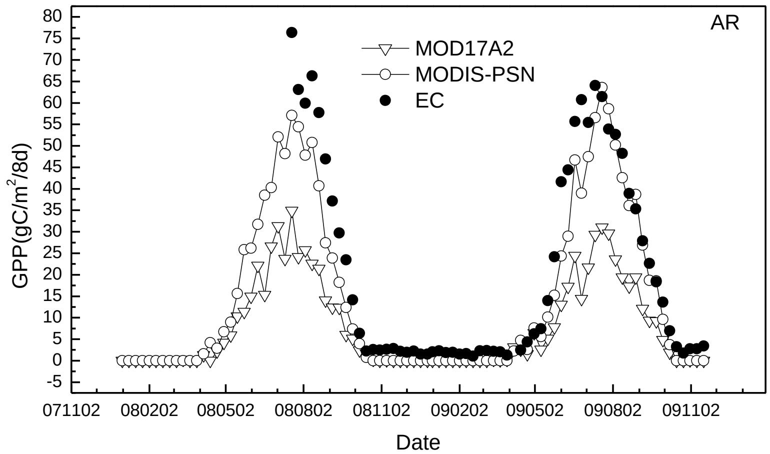
4 RESULTS

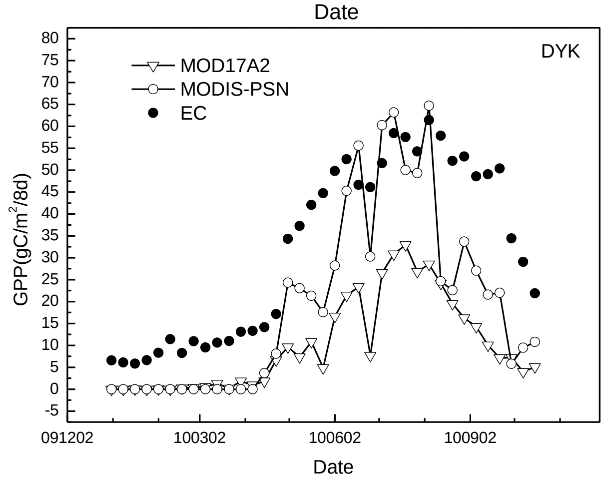
4.1 Validation of MODIS-PSN based on ground observation system

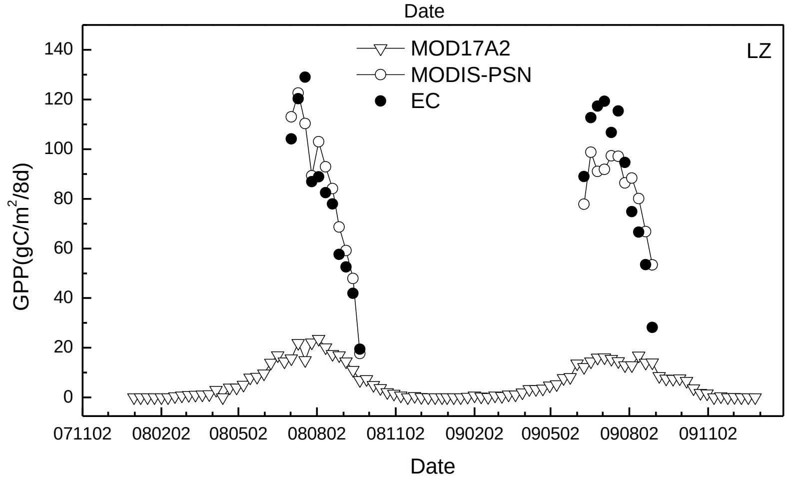
From Table3, Figure 2 and Figure 3, it is indicated that the MODIS GPP product greatly underestimated the GPP at the four stations. At AR station and DYK station, it was about 1/2 of GPP observed by EC, and 1/5 of GPP observed at YK and LZ station. The RMSE was up to 74gC/m^2/8d (see Table 3). When local observed meteorological data and calibrated ε_0 were used as inputs of MODIS-PSN, GPP was correct simulated at the four stations. The GPP predicted by MODIS-PSN was consistent with observed GPP. Both slope of linear regression and RMSE were improved (see Table 3).

Table 3 Slope in linear fit and RSME for MODIS GPP product and GPP estimated in this study at each site

	MOD17A2		MODIS-PSN	
Name	Slope	RMSE	Slope	RMSE
AR	0.41	19	0.86	8.2
DYK	0.35	25	0.69	16.1
LZ	0.17	74	0.96	15.9
YK	0.15	50	0.88	13







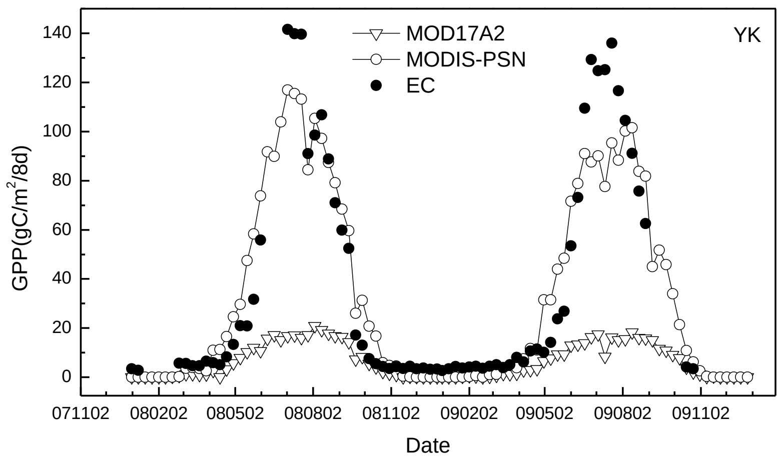


Figure 2 Comparison of GPP from MODIS GPP product (MOD17A2), MODIS-PSN and EC (GPP_EC) at AR station, DYK station, LZ station and YK station.

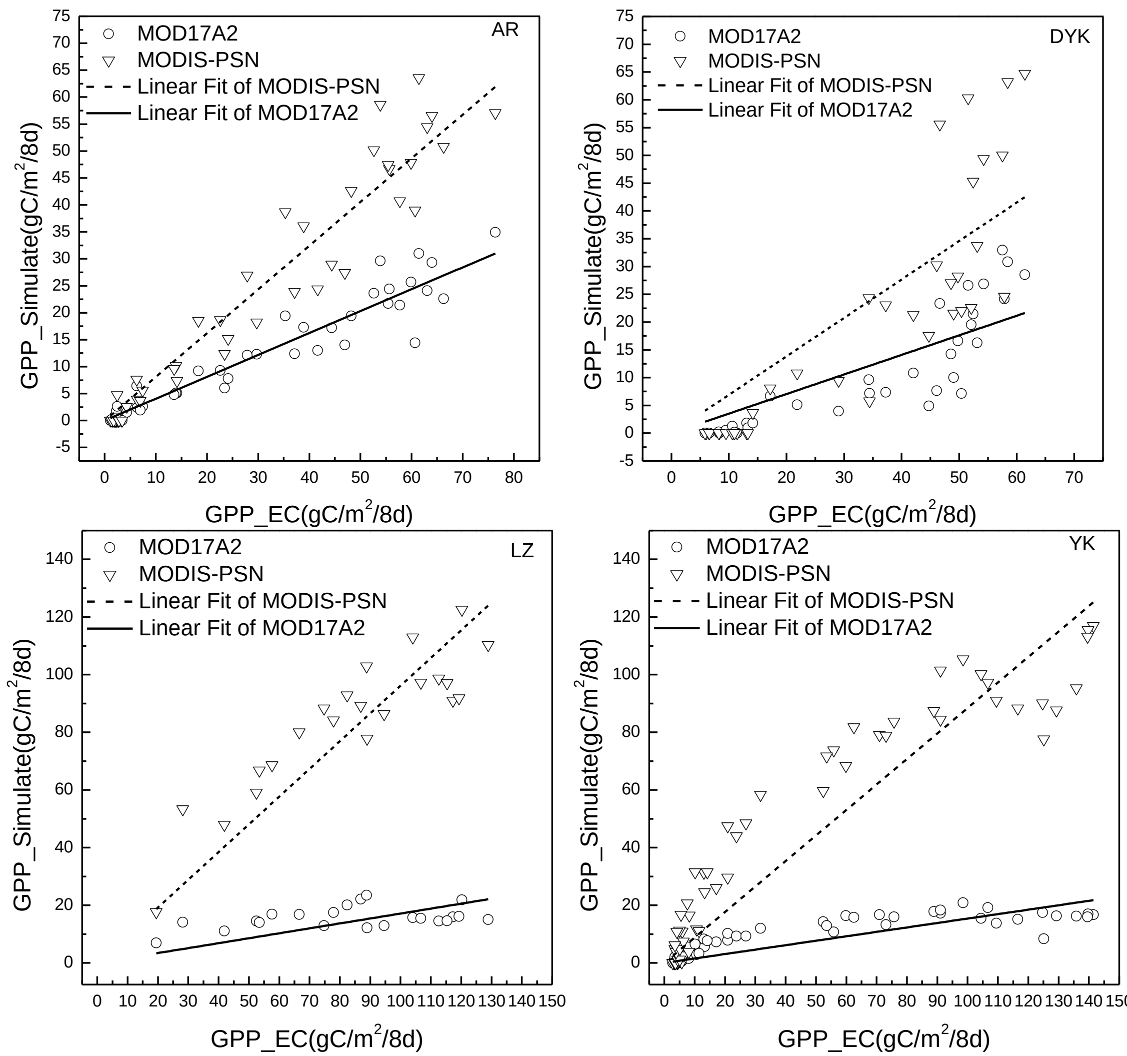


Figure 3 Scatter plot between simulating GPP (MODIS GPP and MODIS-PSN) and EC observing GPP at AR station, DYK station, LZ station and YK station. Intercept of linear fit was fixed equal to zero. Slope of linear fit was listed in Table 3.

GPP observed by EC at cropland (LZ and YK station) are much higher than GPP at grassland (AR station) and forest (DYK station) in the Heihe River Basin. However, in standard MODIS GPP product, GPP at the LZ and YK station are very close to GPP at AR and DYK station. GPP estimated in this study were consistent with GPP EC observed at the four stations. This indicates that MODIS-PSN model with estimated parameters can be used to predict regional GPP in the Heihe River Basin.

4.2 GPP of the Heihe River Basin

Figure 4 shows standard MODIS GPP product and GPP estimated in this study in Heihe River Basin. Generally, standard MODIS GPP product underestimated the GPP of this region. Maximum yearly integrated GPP of standard MODIS GPP product was 804gC/m^2/yr in 2008 and 802gC/m^2/yr in 2009, but the maximum value of GPP estimated in this study was 1648gC/m^2/yr in 2008 and 1631gC/m^2/yr in 2009 (see Table 4). In Heihe River Basin, the total GPP from standard MODIS GPP was $5.74*10^{12}$ gC/yr in 2008 and $5.72*10^{12}$ gC/yr in 2009, while that estimated from this study is $1.42*10^{13}$ gC/yr in 2008 and $1.37*10^{13}$gC/yr in 2009 (see Table 4).

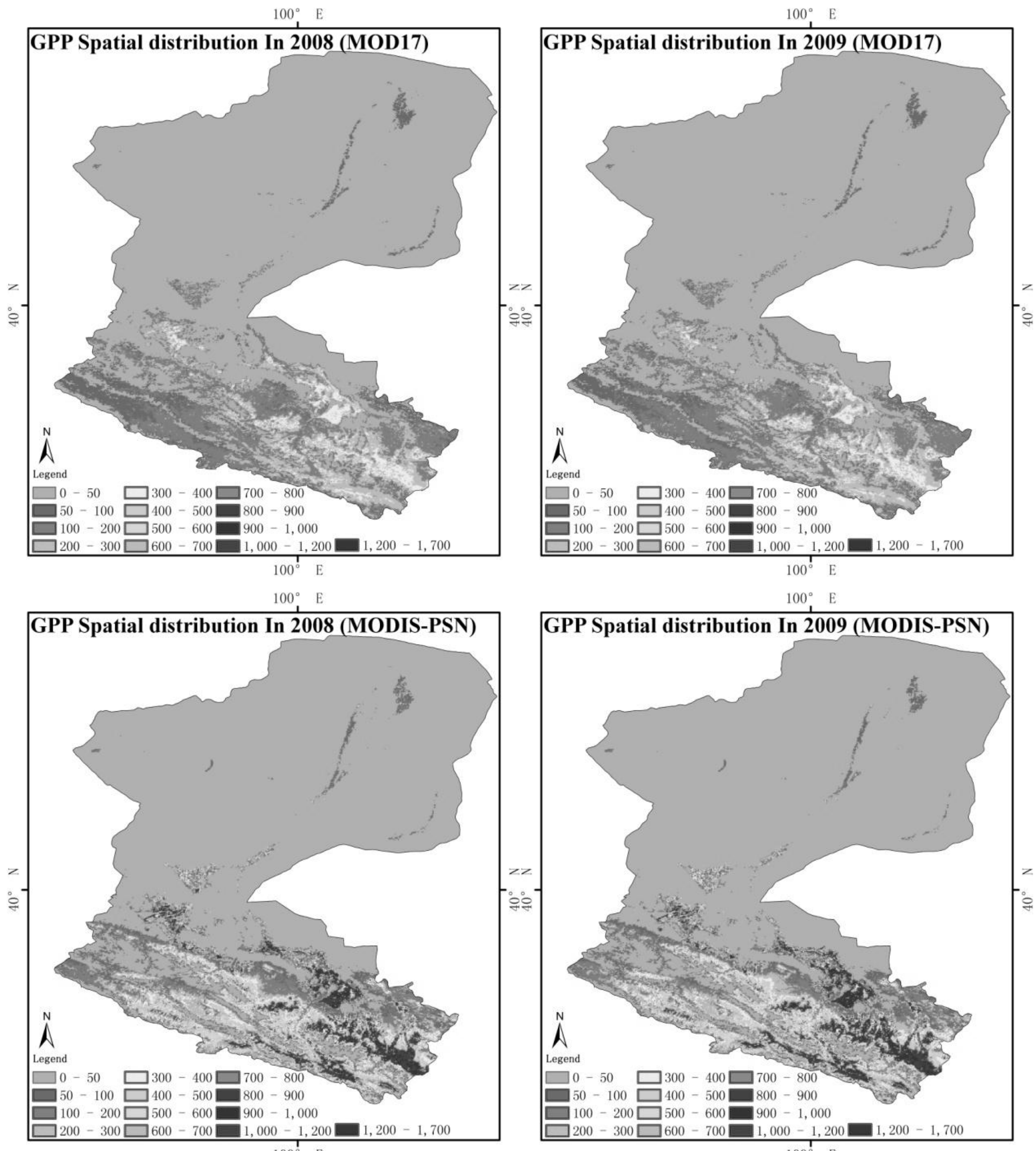


Fig. 4 Spatial distribution of GPP in Heihe River Basin

Table 4 Total GPP in Heihe River Basin.

Year	MOD17		MODIS-PSN	
	sum (gC/yr)	max(gC/m^2/yr)	sum(gC/yr)	max(gC/m^2/yr)
2008	$5.74*10^{12}$	804	$1.42*10^{13}$	1648
2009	$5.72*10^{12}$	802	$1.37*10^{13}$	1631

Not only the amount of GPP increased in GPP map estimated in this paper, but also the spatial pattern of GPP was different from the standard MODIS GPP product. For example, GPP of the cropland area was obviously higher than grassland in GPP map estimated in this study. From both of the GPP maps, it is can be know that GPP at upper and middle stream was much higher than GPP in lower stream in the Heihe River Basin.

5 DISCUSSION AND CONCLUSIONS

The ε_0 is a vital parameter in MODIS-PSN model. Systematic bias will be result from erroneous ε_0 in MODIS-PSN model. Some researchers found that there was a great bias between the standard MODIS GPP product and GPP observed by EC in some site, and that is mainly attribute to incorrect ε_0. The ε_0 at canopy scale is affected by a lot of factors, such as photosynthetic pathway, vegetation species, canopy structure, coverage and human manage. Thus, the ε_0 varies greatly in spatial. In this study, we estimated ε_0 of main vegetation types in the Heihe River Basin. From the site validation, it is indicated that predicting accuracy of MODIS-PSN model were greatly improved after using estimated model parameters. Then, regional GPP of Heihe River Basin was estimated.

At the whole Heihe River Basin, standard MODIS GPP is only one third of GPP estimated in this study. The difference between standard MODIS GPP and GPP estimated in this study mainly resulted from two aspects: (1) model parameter ε_0 which was adjusted for major type vegetation types; (2) vegetation type map which GPP is calculated based on. Standard MODIS GPP was estimated using MODIS product MOD12Q1. MOD12Q1 is not well validated in the Heihe River Basin. It is found that some pixels of MOD12Q1 are wrong. For example there is no Evergreen Broadleaf Forest in the Heihe River Basin, but MOD12Q1 contained this vegetation type. Thus, the more accurate vegetation type data was used in this study.

From this study, following conclusions can be drawn: (1) the default ε_0 in MODIS-PSN model is not correct for the major vegetation types in the Heihe River Basin. After used ε_0 estimated using local carbon flux data, the accuracy of MODIS-PSN can be improved obviously; (2) about $1.4*10^{13}$ g carbon per year enter terrestrial ecosystem through vegetation photosynthesis. GPP in upper and middle stream is much higher than that in downstream.

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