**Estimating gross primary productivity in two different vegetation types using data from CO2 eddy flux tower sites and MODIS images**

Cheng Meng & Li Pan

# **Objectives**

Accurate estimates of the terrestrial gross primary product (GPP) are critical for understanding the global carbon cycle and predicting future climate change. Currently, a variety of GPP data products are available based on different models, when GPP estimates are validated against eddy correlation variance data, however, the performance of different models varies widely. How to obtain a generally approved, accurate, and simple GPP estimation model is the current challenge and innovation. In this project, we use Vegetation Photosynthesis Model (VPM) to estimate GPP. The VPM model is based on the improved light use efficiency (LUE), satellite remote sensing, and the eddy covariance (EC) technique, employing a state-of-the-art vegetation index (VI) gap-filling and smoothing algorithm to generate an accurate GPP estimate value. This project takes MODIS remote sensing data and flux tower data as input, and obtains the parameters required by the VPM model through a series of calculations and conversion, and the output is the seasonal dynamic and interannual change of GPP within a MODIS pixel where the Ameriflux sites are located. This project expects to obtain a satisfactory performance when validated against flux tower GPP estimates and provide another accurate GPP estimate method for regional to global carbon cycle studies.

# **2. Significance**

Ecosystem-scale vegetation photosynthesis, also known as gross primary productivity (GPP), is the first step for CO2 to enter the biosphere from the atmosphere. Accurate estimation of the gross primary product (GPP) of terrestrial vegetation is of great significance for understanding the global carbon cycle and predicting future climate change. Over the past few decades, the eddy covariance technique has estimated GPP at different sites, this method is based on the height of each site tower and weather conditions, however, has limitations in the study of the carbon cycle at large regional and global scales. The GPP estimated model based on the LUE model is currently the most commonly used method, which uses remote sensing data and is suitable for research on large regional and global scales.

Here, we select one of the LUE models: the VPM model, to estimate the GPP of different sites of various landscapes and vegetation, using eddy flux data from Ameriflux tower sites to compare the estimated GPP based on the VPM model to explore whether the output of this model has satisfactory performance. We will use linear fitting analysis to compare the results from different and compare with MOD17A2 product. Then discuss the difference.

# **3.Data Source**

## 3.1 Study area

In this study, we will select two different vegetation types, one is a classic deciduous broadleaf forest called Harvard forest. Another is a savanna called Tonzi ranch savanna. All these two sites are located in the US.

### 3.1.2 The Harvard forest site

The first study site, a deciduous broadleaf forest (US-Ha1, 45.5378°N, 72.1715°W, 340 m asl). Most of the surrounding area was cleared for agriculture for more than 100 years. The site has been regrowing since before 1900 and is now predominantly red oak and red maple with patches of mature hemlock stand and individual white pine. The Lands dominated by woody vegetation with a percent cover more than 60%. Mean annual temperature is 6.62 ℃ and mean annual precipitation is 1071 mm in this site. The site is warm summer continental with significant precipitation in all seasons. Detail descriptions of the site can be found on the AmeriFlux website (https://ameriflux.lbl.gov/sites/siteinfo/US-Ha1).

### 3.1.3 The Tonzi Ranch Savanna site

Another study site, The Tonzi Ranch site (Ton, 38.4309˚N, 120.9960˚W, 177 m asl) is a woody savanna dominated by blue oak (Quercus douglasii, 40% of total vegetation) and grey pine trees (*Pinus sabiniana*). The understory species including purple false brome (*Brachypodium distachyon*), smooth cat's ear (*Hypochaeris glabra*), and rose clover (*Trifolium hirtum*). The site has a mediterranean climate with dry and hot summer and wet, mild winter. The mean annual temperature is 15.8˚C and mean annual precipitation is 559 mm in this site. Detail descriptions of the site can be found on the AmeriFlux website(https://ameriflux.lbl.gov/sites/siteinfo/US-Ton).

## 3.2. MODIS data

**MODIS surface reflectance and vegetation indices***.* In this project, the 8-day MOD09A1 data product produced by the CEOM data center is used. The CEOM data center has hosted hundreds of terabytes of MODIS data and products for the world from 2/2000 to the present, identified poor quality observations in MODIS, and interpolated gaps. The data can be downloaded on the website([www.ceom.ou.edu/moids](http://www.ceom.ou.edu/moids)).

**MOD17A2 GPP product***.* MOD172H is cumulative 8-days composite with a resolution of 500 meters. The "Gpp" band is the cumulative value of gross primary production over 8-days, and this data is used in this project to compare the results of the VPM model. The data can be downloaded on the Google earth engine website (https://earthengine.google.com/platform/).

### 3.3. CO2 eddy flux data from AmeriFlux tower sites

CO2 flux data for the Harvard Forest and Tonzi savanna can be downloaded from the AmeriFlux data portal (http://ameriflux.ornl.gov/). In this project, we selected TA (air temperature), PPFD (photosynthetic photon flux density), and GPP. Since PPFD cannot be generated at night, daytime is defined as the moment when PPFD is greater than 0. Then in the daytime range, the daily average of TA for every 8-days average, the daily sum of PPFD and GPP for every 8-days average is calculated, respectively.

# **4. Methods**

### 4.1 Vegetation Photosynthesis Model

The VPM model uses the product of light use efficiency (LUE, ), and absorbed photosynthetically active radiation by chlorophyll () to estimate GPP as follows (Fig. 1):

where is calculated as a product of photosynthetically active radiation () and the fraction of absorbed by chlorophyll ():

The is calculated as a linear function of EVI, and have been validated using the solar-induced chlorophyll fluorescence data in previous studies:

Light use efficiency () is affected by air temperature and water:

where is the apparent quantum yield or maximum light use efficiency (μmol CO2/μmol PPFD), and and can be calculated as follow:

where the , and is the maximum, minimum and optimum daytime air temperature for photosynthesis activities. Tmax and Tmin are biome-based and can be set as 40℃ and -1℃ in deciduous broadleaf forest, and 48℃ and 1℃ in savanna, respectively. For Topt, we used a site-specific optimum air temperature for photosynthesis activities. Topt\_sy values were defined as the average air temperature of the observations with EVI equal or higher than 95% of the maximum EVI during the growing season. Site-specific optimum air temperature (Topt\_s) was calculated as multi-year mean Topt\_sy for each site. is the largest value of LSWI during the thermal growing season within five years.

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Fig.1 Datasets and workflow of VPM to calculate GPP. MODIS: Moderate Resolution Imaging Spectroradiometer; EVI: enhanced vegetation index; LSWI: land surface water index. Tdaytime: daytime air temperature; ɛ0: maximum light use efficiency; Topt: optimum temperature for photosynthesis; Tmax: maximum temperature for photosynthesis; Tmin: minimum temperature for photosynthesis; LSWImax: maximum LSWI during the growing season. Tscalar: temperature limitation for photosynthesis; PAR: photosynthetically active radiation; Wscalar: water limitation for photosynthesis; fPARchl: fraction of PAR absorbed by chlorophyll; APARchl: absorbed PAR by chlorophyll.

### 4.2 Eddy covariance CO2 measurement

Eddy covariance systems are used to measure the exchange of CO2, H2O, CH4, and energy between the earth’s surface and the atmosphere, empowering researchers to advance scientific understanding of climate and ecosystem dynamics. Large datasets of greenhouse gas and energy surface-atmosphere fluxes measured with the eddy-covariance technique (e.g., FLUXNET2015, AmeriFlux) are widely used to benchmark models and remote-sensing products. In this study, hourly or half-hourly temporal resolution variable “GPP\_DT\_VUT\_REF” was used to aggregate 8day temporal resolution GPP.

# **5. Results**

In this study, 8day temporal resolution GPP calculated by eddy tower data (GPPec) and 8day temporal resolution GPP estimated by VPM (GPPvpm) were generated. MOD17A2 GPP product generated from google also used to make model comparison. Linear regression was used to compare the GPPvpm and GPPmod17A2H with the GPPec.

### 5.1 The Harvard Forest site

The seasonal dynamics of GPPvpm and GPPMOD17A2H correspond well with GPPec over the 20 years (from 2000 to 2020) in the Harvard forest site (Fig.2). GPPvpm started to increase in early-April and reached the peak in late-July every year. GPPvpm decreased gradually after late-September. The simple linear correction analysis between GPPvpm and GPPec showed that GPPvpm was strongly correlated with GPPec during this period (slope=0.8, R2=0.91, Fig.3a). The simple linear correction analysis between GPPMOD17A2H and GPPec showed that GPPMOD17A2H was strongly correlated with GPPec during this period (slope=0.62, R2=0.87, Fig.3b). Our VPM model has better performance to predicted GPP in this site than MOD17A2H product.

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Fig.2 Seasonal dynamics and interannual variations of GPP at the Harvard Forest site during 2000-2021. GPPec: Estimated GPP from the eddy tower data; GPPvpm: predicted GPP by the VPM model; GPPMOD17A2H: global GPP data product predicted from MODIS data.

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Fig.3 The comparison between predicted and estimated GPP (GPPvpm, GPPMOD17A2H amd GPPec) at the Harvard Forest site. a) GPPvpm compare with GPPec, GPPvpm = 0.8\*GPPec -0.07, R2=0.91, N=949; b) GPPMOD17A2H compare with GPPec, GPPMOD17A2H = 0.62\*GPPec+0.99, R2=0.87, N=959.

### 5.2 The Tonzi Savanna site

The seasonal dynamics of GPPvpm and GPPMOD17A2H tracked well with GPPec during the 15 years from 2001 to 2014 in the Tonzi savanna site (Fig.4). GPPvpm started to increase in mid-February and reached the peak in early-May every year. GPPvpm decreased gradually after mid-October. The seasonal dynamics of GPPvpm in every year showed the same trend. The simple linear correlation analysis showed that GPPvpm correlated well with GPPec in the 15 years period (slope=0.81, R2=0.84, Fig.5a). The simple linear correction analysis between GPPMOD17A2H and GPPec showed that GPPMOD17A2H was strongly correlated with GPPec during this period (slope=0.8, R2=0.8, Fig.5b). Our VPM model has better performance to predicted GPP in the Tonzi savanna site than MOD17A2H product.

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Fig.4 Seasonal dynamics and interannual variations of GPP at the Tonzi savanna site during 2001-2014. GPPec: Estimated GPP from the eddy tower data; GPPvpm: predicted GPP by the VPM model; GPPMOD17A2H: global GPP data product predicted from MODIS data.

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Fig.5 The comparison between predicted and estimated GPP (GPPvpm, GPPMOD17A2H amd GPPec) at the Tonzi savanna site. a) GPPvpm compare with GPPec, GPPvpm = 0.81\*GPPec +0.54, R2=0.84, N=643; b) GPPMOD17A2H compare with GPPec, GPPMOD17A2H = 0.8\*GPPec+1.39, R2=0.8, N=643.

# **6. Future work**

As the limitation amount of eddy tower sites and there are many missing data in the eddy tower datasets. In the future, we may use global climate reanalysis data as the input parameters to run our VPM model and provide a global GPP product predicted by VPM model. Eddy tower sites data is used to validate VPM model.

**Project team and individual contribution:**

Cheng Meng and Li Pan completed the code, report, and presentation equally.