Estimation of net ecosystem productivity with visible, near infrared and thermal infrared bands of MODIS data

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Abstract: Net ecosystem productivity (NEP) in the forest ecosystem is determined by gross primary productivity (GPP) of vegetation and ecosystem respiration (RE). CO2 flux observation sites measure GPP and RE by using eddy covariance technique, and detail seasonal change of CO2 flux has been obtained at discrete observation sites. However, they are point-based observation and cannot cover an extensive area. In order to estimate regional or global CO2 exchange, application of remote sensing is expected. In this research, we investigated NEP scaling up estimation method extrapolating point-based observation of CO2 exchange through remote sensing data. In particular, here, independent estimation method for GPP and RE was examined with red (RED) and near infrared (NIR) data for GPP, and thermal infrared (TIR) data for RE. Images from MODerate resolution Imaging Spectroradiometer (MODIS) onboard Terra was used. And CO2 flux data was measured from Asian flux site at Takayama in Japan. The results showed high correlation between seasonal dynamics of GPP and RE with MODIS VIS・NIR data and with TIR data. This demonstrated the potential of proposed method for scaling up point-based NEP observation by using satellite remote sensing.
Keywords: net ecosystem productivity, gross primal productivity, ecosystem respiration, SAVI2, TIR

1 Introduction

The seasonal variations of gross primary production (GPP) and ecosystem respiration (RE) determine net ecosystem productivity (NEP) of forest ecosystems. In recent years, continuous CO2 flux measurements between forests and the atmosphere at flux tower sites have allowed for a more detailed examination of GPP of forest ecosystems. But the data from flux site is highly local, and it is difficult to extrapolate local flux site data to more extensive area because of the large spatial heterogeneity and temporal dynamics of forest ecosystems across complex landscapes and regions. Regional extrapolation of those CO2 flux measurements is, on the other hand, required to assess CO2 sinc/source for reforested/afforested/reforested areas according to the Kyoto Protocol. One approach to scale-up and extrapolate site specific measurements (GPP, NEP, RE) is to use satellite observation data.

The objective of this study was to develop the satellite based estimation of NEP seasonal dynamics of deciduous broadleaf forests on the ground observed flux data. In particular, here, independent estimation method for GPP and RE was examined with red (RED) and near infrared (NIR) data for GPP, and thermal infrared (TIR) data for RE. We used images from MODerate resolution Imaging Spectroradiometer (MODIS) onboard Terra, and CO2 flux data. As a test site, in this study, Takayama, Japan was selected, and flux site data there was analyzed with time series MODIS data. It was shown that there was a high correlation between the MODIS derived NEP and the ground observed flux data.

2 Method

NEP is defined by the difference between CO2 photosynthetic uptake (GPP) and respiratory emission (RE) in the forest ecosystem as shown in (1),

$$NEP = GPP - RE \tag{1}$$

In this research, NEP was estimated from independent satellite-based estimations of GPP and RE.

GPP is the photosynthesis product of forest CO2 assimilation. A number of Vegetation Indices (VIs) have been developed to explain the biophysical parameters in past researches, including Normalized Difference Vegetation Index (NDVI) as shown in (2):

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}} \tag{2}$$

where ρ_{red} and ρ_{nir} are band value of RED and NIR. Soil Adjusted Vegetation Index 2 (SAVI2, [1]) is also widely used vegetation index which was reported as least affected by background reflectance:

$$SAVI2 = \frac{\rho_{nir}}{\rho_{red} + b/\gamma} \tag{3}$$

where γ and b are the slope and intercept of soil line respectively. In this research these two vegetation indices were used to estimate GPP. Satellite-based GPP estimation was calculated by using liner regression function of Vegetation Index (VI) as shown in (4):

$$GPP = aVI + b \tag{4}$$

where a and b are parameters. SAVI2 was used as VI parameter, and the biophysical performance for GPP was validated through the comparison with that of NDVI.

RE is the total respiration of whole ecosystem. It is known that atmospheric temperature (T) is the dominant factor determining the RE [2]:

$$RE = AQ^{(T-10)/10} \tag{5}$$

where Q is the temperature coefficient, and A is parameters. TIR band captures land surface temperature, which has high correlation with atmospheric temperature. Hence, satellite-observed TIR was used to estimate RE:

$$RE = AQ^{(\rho_{tir}-10)/10} \tag{6}$$

where ρ_{tir} is band value of TIR, Q is the temperature coefficient, and A is parameters.

3 The Study Site and Data Description

The eddy flux tower site (36°08'N and 137°25'E, 1420 m elevation) is located within Takayama, Japan. Vegetation at the site is primarily a 30-40 year old deciduous broadleaf forest, and dominant species are birch and oak forest. Annual mean temperature is about 7.7 °C and annual precipitation is about 1900 mm. Daily measured NEP flux data and derived GPP and ecosystem respiration (RE) from 2003-2004 were used. For the MODIS based analysis, we averaged daily CO2 flux data to get 10-days mean CO2 flux data.

The MODIS sensor onboard the NASA Terra satellite was launched in December 1999. The MODIS sensor acquires daily images of the globe at a spatial resolution of 250-1000 m. Reflectance values of the 10-day composite data set [3] from red and near infrared bands were used to calculate VIs (NDVI, SAVI2). For a time series of VIs, we used a gap filling method of the best index slope extraction algorithm [4] to fill VIs values of those cloudy pixels.

4 Results

The ground observed NEP, GPP and RE (NEP_{obs}, GPP_{obs} and RE_{obs}) time series during 2003–2004 at Takayama site had a distinct seasonal cycle (Fig.1.). GPP values were near zero in winter season (December, January, February), because the deciduous dominated canopy is die. GPP began to increase in late April and reached its peak in late June to early July. GPP declined gradually after its peak.

The comparison between VIs and GPP_{obs} showed that the seasonal dynamics of SAVI2 better agreed those of GPP_{obs} in terms of phase and magnitude (Fig.2.). When using all the observations in 2003-2004, SAVI2 had strong liner relation ship with GPP_{obs} (Fig.5.).

Fig.3. shows the comparison of seasonal dynamics between estimated RE and RE_{obs}. There were little tendencies to overestimate spring RE and to underestimate autumn RE. The TIR based estimation indicated the high correlation with RE_{obs} (Fig.6.).

The comparison of seasonal dynamics between the proposed method and NEP_{obs} showed good agreement (Fig.4.). When using all the observations in 2003-2004, proposed method indicated strong liner relationship with NEP_{obs} (Fig.7.).

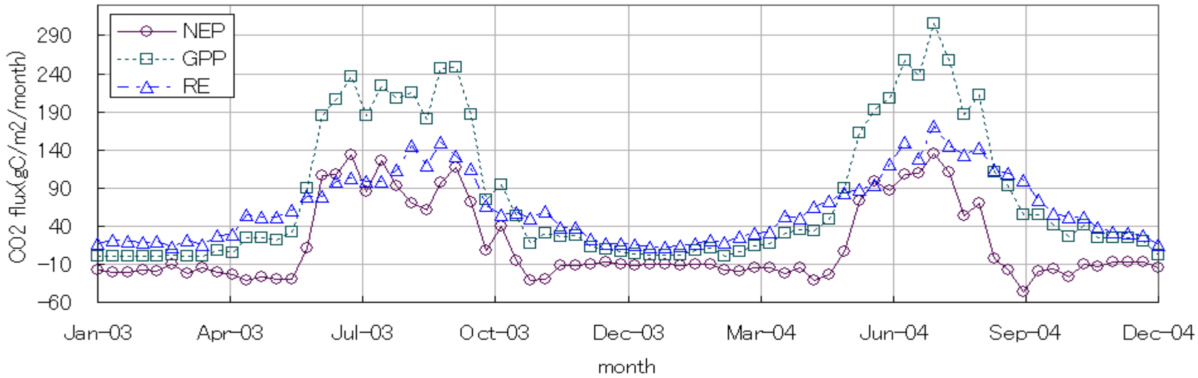

Figure1. The seasonal dynamics of net ecosystem productivity (NEP), gross primary production (GPP) and ecosystem respiration (RE) in 2003-2004 at Takayama site.

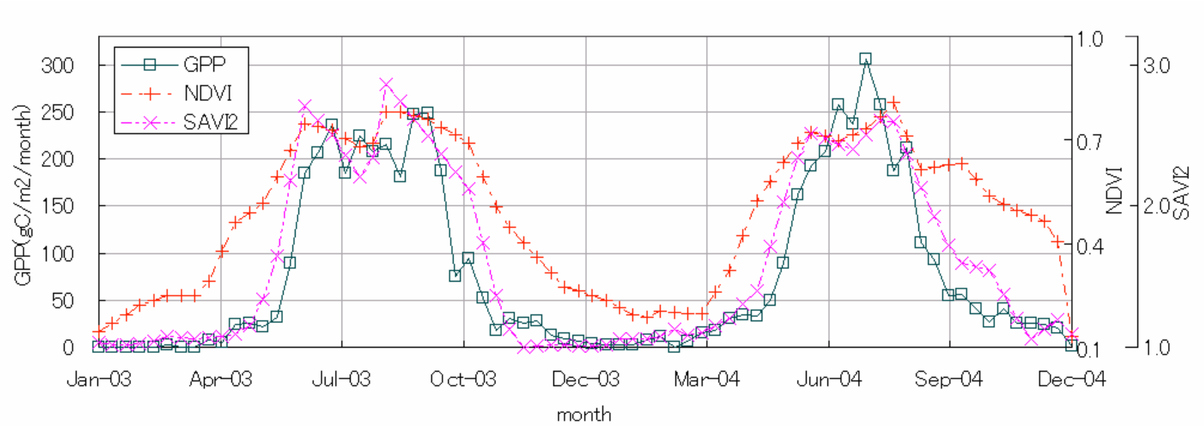

Figure2. The seasonal dynamics of gross primary production (GPP), Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Indices 2 (SAVI2) in 2003-2004 at Takayama site.

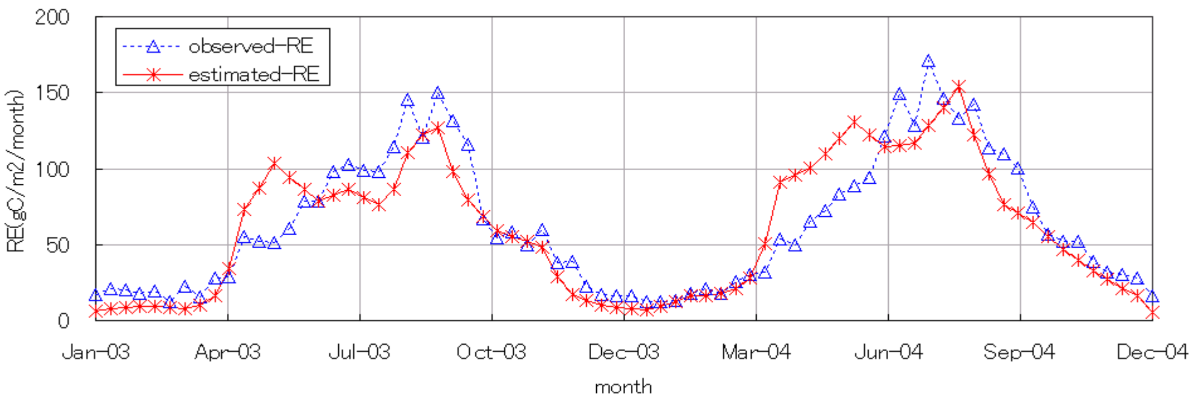

Figure3. The seasonal dynamics of observed ecosystem respiration (RE) and estimated RE in 2003-2004 at Takayama site.

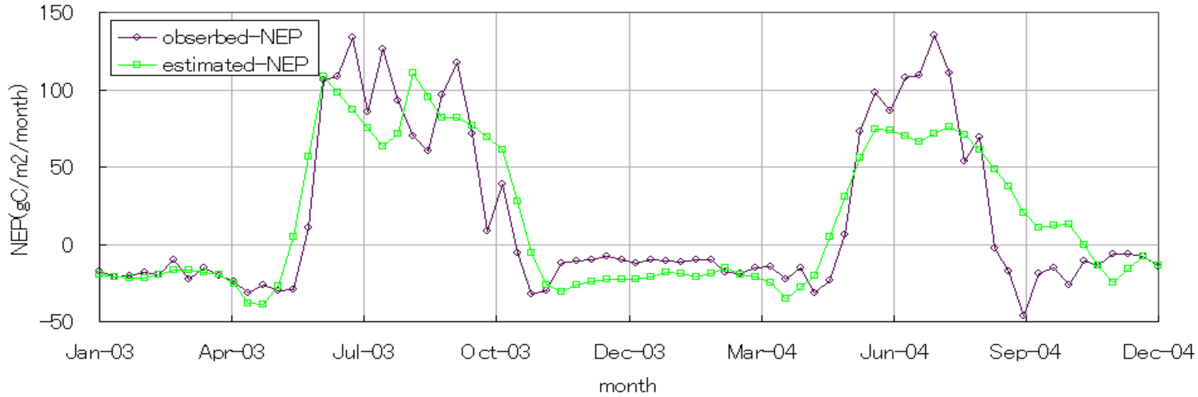

Figure4. The seasonal dynamics of observed net ecosystem productivity (NEP) and estimated NEP in 2003-2004 at Takayama site.

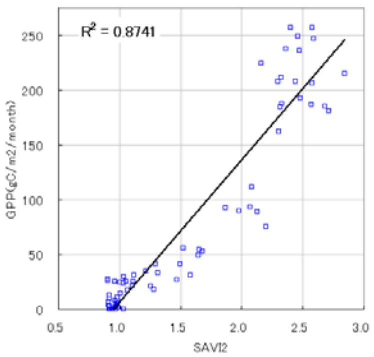

Figure5. Simple linear regression analyses between observed gross primary productivity (GPP) and SAVI2 during 1/2003 -12/2004 at Takayama site.

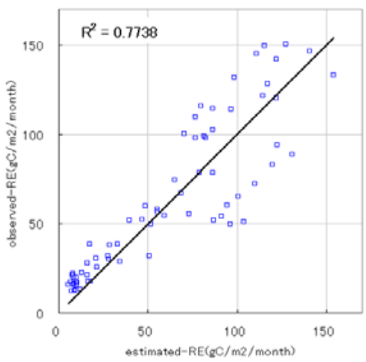

Figure6. Simple linear regression analyses between observed ecosystem respiration (RE) and estimated RE during 1/2003 -12/2004 at Takayama site.

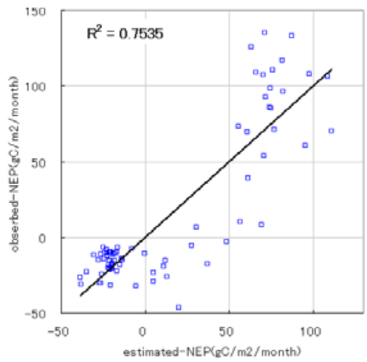

Figure7. Simple linear regression analyses between observed net ecosystem productivity (NEP) and estimated NEP during 1/2003-12/2004 at Takayama site.

5 Discussion and Summary

Satellite based estimations of each biophysical parameter have shown high agreement with observed data. However, estimated NEP indicated lower agreement than those of GPP and RE. It was because that the integration of overestimated GPP and underestimated RE amplified the disagreement with observation data especially in autumn season. And there were large differences in 2004 autumn. The large discrepancy can be attributed to the typhoon which destroyed the part of forest in Takayama site.

In summary, this study has shown the high biophysical performance of SAVI2 and TIR in relation to GPP and RE of a deciduous broadleaf forest respectively, and has also demonstrated the potential of satellite based NEP estimation to quantify the seasonal dynamics and interannual variation of NEP.

6 References

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