Monitoring of Gross Primary Productivity (GPP) and Crop Yield via MODIS in Soyang River Basin, South Korea

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Abstract: Several models for estimated vegetation productivity have been developed by combining remote sensing data with carbon cycle processes. NASA Earth Observing System (EOS) currently produces a regular global estimate of vegetation primary productivity (both GPP and NPP) and annual net primary productivity (NPP) of the entire terrestrial earth surface at 1 km spatial resolution. Remote sensing imagery allows us to examine the terrestrial biophysical processes across broad regions, but there are many challenges in accurately capturing the terrestrial processes using the remote sensing techniques due to many interrupting factors, including potential cloud contamination, choice of alternative algorithms, and the model parameterization. MODIS GPP and NPP algorithms use meteorological data provided by the NASA Data Assimilation Office (DAO). Hence, the sub-pixel heterogeneity or complex terrain effects on meteorological conditions are hardly reflected due to coarse spatial resolutions of the DAO data (a resolution of 1° × 1.25° in latitude and longitude). In this study, we utilized a higher spatial resolution dataset from a regional-scale meteorological prediction model (i.e., WRF) to provide more detailed meteorological variables in addition to the DAO data for cloudy days. Furthermore, remote sensing input variables for GPP and NPP estimation (i.e., FPAR and LAI) were improved to reduce cloud contamination effects on the variables. New MODIS GPP and NPP datasets were retrieved with WRF meteorology and cloud-filled MODIS data for the Soyang River Basin for a period covering the last 10 years. The derivatives included daily minimum air temperature, daytime mean VPD (Vapor Pressure Deficit), and daily solar radiation. Our preliminary results indicate that the use of MODIS and WRF data can provide a useful tool for estimating GPP, NPP, and subsequently,crop yield.

Keywords: *MODIS, WRF, vegetation primary productivity, crop yield*

1. Introduction

Estimation of the CO_2 exchange between biosphere and atmosphere and vegetation productivity at regional, continental, and global scales can be accomplished by combining remote sensing data with information on carbon cycle processes. NASA Earth Observing System (EOS) currently produces a regular global estimate of gross primary productivity (GPP) and annual net primary productivity (NPP) of the entire terrestrial earth surface at 1 km spatial resolution. Annual NPP, a fixed amount of total carbon assimilated into plant biomass, can be used to estimate biomass growth. However, MODIS has several limitations in estimating the productivity. First, MODIS GPP and NPP algorithms use meteorological data provided by the NASA Data Assimilation Office (DAO) with coarse spatial resolution of 1° × 1.25° in latitude and longitude. Hence, MODIS GPP and NPP hardly reflect fine-scale heterogeneity in regional meteorology. Secondly, biome parameters used in MODIS GPP and NPP algorithms do not distinguish different crop types, such as corn, soybean, and rice. Third, MODIS FPAR (Fraction of incident Photosynthetically Active Radiation) and LAI (Leaf Area Index) products that are input variables of MODIS GPP and NPP algorithms have low reliability under cloudy conditions. In this study, we improved the official MODIS productivity variables by incorporating 3-km WRF (Weather Research and Forecasting) meteorology and cloud-filled FPAR and LAI products. The improved NPP was then applied to estimate GPP and NPP in the Soyang River basin.

2. Study Site and Materials

The study site is the Soyang River Basin in South Korea. This area includes diverse land cover types including deciduous broadleaf forest (DBF) (48.2% in areal percentage), mixed forest (42.3%), crop land (5.5%). MODIS land cover product (MODIS12Q1) was utilized in this study to provide a land cover map at 500m resolution (Fig 1).

The LUE (light use efficiency) model used in MODIS GPP algorithm is an application of radiation conversion efficiency concept to calculate daily GPP by using MODIS15A2 FPAR, incident daily PAR, daily minimum air temperature, and daytime mean VPD. Maintenance respiration and growth respiration are estimated from allometric relationships using MODIS LAI and daily mean air temperature which are then subtracted from GPP to calculate annual NPP. In this study, a MODIS land surface product (MODIS15) was used to retrieve 8 day LAI (Leaf Area Index) and FPAR (Fraction of incident Photosynthetically Active Radiation) at 1km resolution. Both FPAR and LAI data were subject to cloud contamination, and then filled by temporal interpolation using both previous and following week cloud-free products. QC (Quality Control) flag was utilized to recognize presence of cloud. WRF data provides hourly meteorological data at 3 km spatial resolution including minimum temperature, mean temperature, shortwave radiation and mean VPD. We derived daily meteorological inputs from the hourly WRF data for MODIS GPP and NPP algorithms. To evaluate the input meteorological variables, National Weather Service (NWS) meteorology for the last 10 years were utilized in this study.

Figure 1. Land cover map of study site – see page 145

3. Methods

The MODIS17 GPP algorithm is based on the LUE model proposed by Monteith (1972). Monteith's logic suggested that a conservative relationship exists between absorbed photosynthetically active radiation (APAR) and net primary productivity (NPP). MODIS GPP is calculated from the plant absorbed PAR by multiplying by PAR conversion efficiency. The PAR conversion efficiency, ε, is constrained by environmental factors including air temperature and VPD. APAR is estimated from IPAR (PAR incident on the vegetative surface) by multiplying by FPAR derived from MODIS15 product. IPAR is then estimated from incident shortwave radiation. Such a simple approach, especially for primary productivity using satellite images, has been widely used in remote sensing applications.

The MODIS primary productivity algorithm takes a simple approach and considers only the effects of temperature and VPD. The algorithm requires daily inputs of IPAR, daily minimum temperature, and daytime mean VPD. These meteorological data are provided by the NASA DAO. Additionally, MOD17 inputs include FPAR and LAI derived from MODIS15 product. The MODIS Biome Parameter Look Up Table (BPLUT) provides parameters for each biome type. In this study, we estimated daily GPP and annual NPP using meteorological data retrieved from WRF hourly data and cloud-filled MODIS LAI and FPAR.

4. Results

To validate the estimated input variables, we compared the WRF-derived minimum temperature (T_{min}) and daytime mean VPD ($VPD_{daytime}$) with observed ones at the NWS sites. T_{min} showed good agreement with ground-based observations (Fig 2). The coefficient of determination (r^2) ranged from 0.93 to 0.94 (Figure 3). The estimated GPP ranged from 1000 g C m^{-2} y^{-1} to 1600 g C m^{-2} y^{-1} for mixed forest and deciduous broadleaf forest (DBF) ecosystems, respectively. The estimated GPP was generally higher in mountainous areas. The NPP spatial variability ranged from less than 30 g C m^{-2} y^{-1} to 900 g C m^{-2} y^{-1} for grassland and DBF ecosystem types, respectively (Fig 4). The NPP map showed a tendency toward low NPP along the Soyang River valley areas.

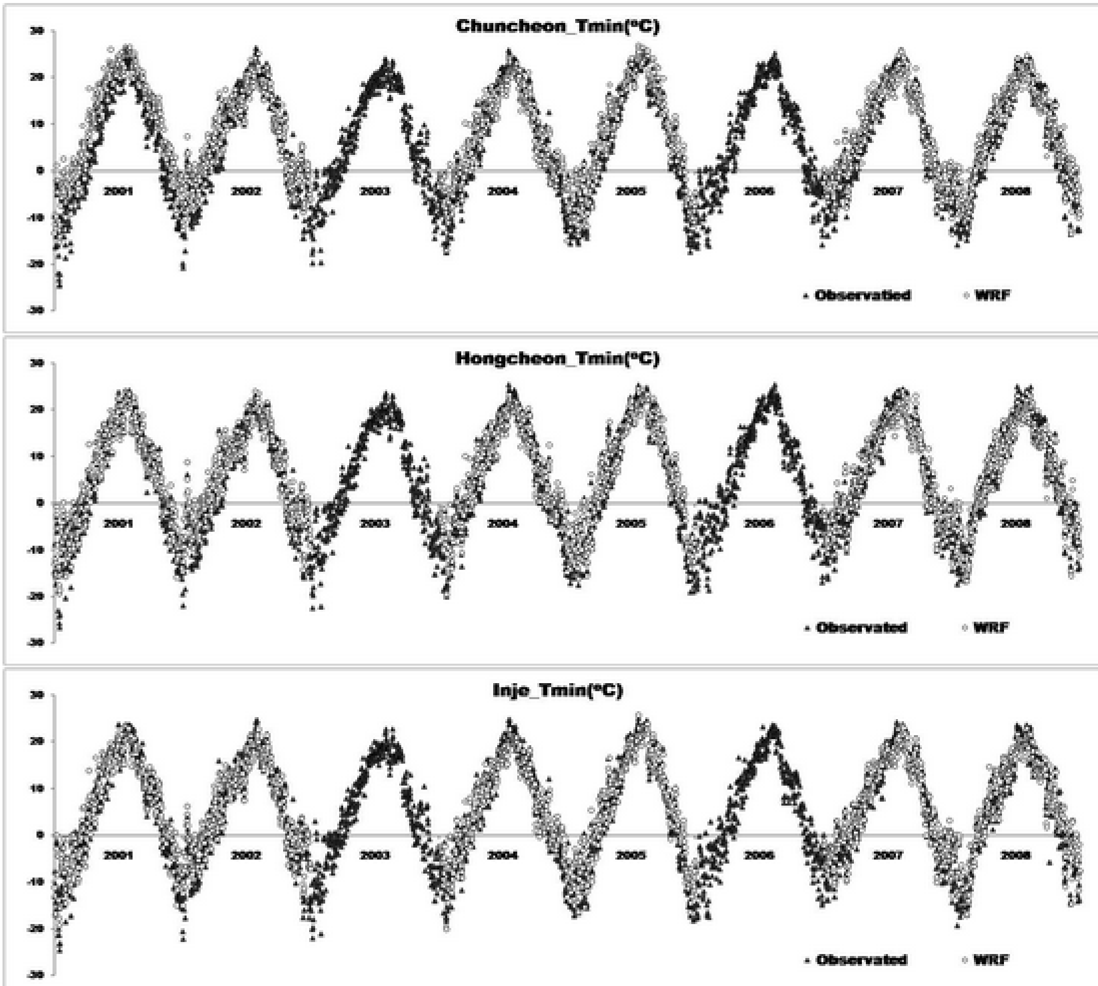

Figure 2. Time series comparing the WRF-derived daily minimum temperature and measured daily minimum temperature during study research period.

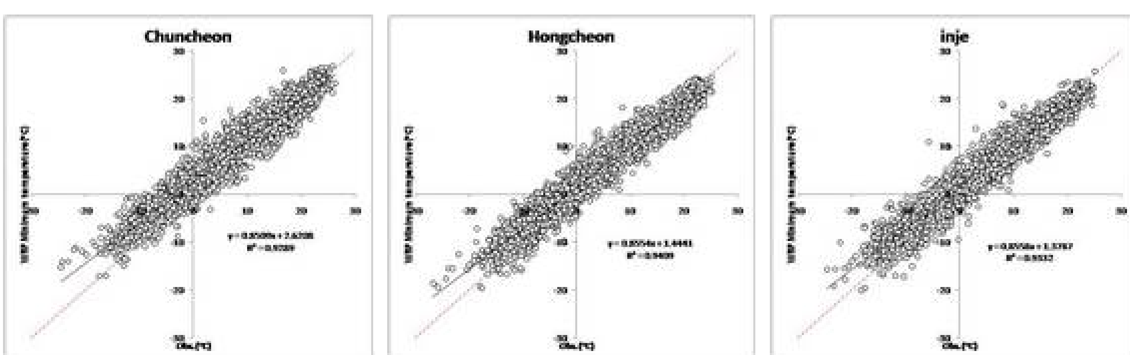

Figure 3. Scatter plots comparing the WRF-derived daily minimum temperature and measured daily minimum temperature

Figure 4. Estimated GPP and NPP in 2001for Soyang Lake Watershed - see page 4 of this abstract

5. Discussion and Conclusions

In this study, we attempted to calculate GPP and NPP using WRF meteorological data and MODIS land surface products. The algorithm is based on the LUE model suggested by Monteith (1977). By using WRF meteorological data instead of DAO data, the calculated GPP provides a much better spatial representation for gradients within the Soyang River Basin. Daily minimum temperature derived from WRF showed good agreement with weather station data. Our results indicate that the use of derived MODIS land surface products together with WRF applications can provide a useful tool for estimating GPP. Our results can be applied to examine regional scale patterns of vegetation productivity. The results can be also linked with other model predictions (e.g. PIXGRO, SWAT) for scaling of processes up to basin scale.

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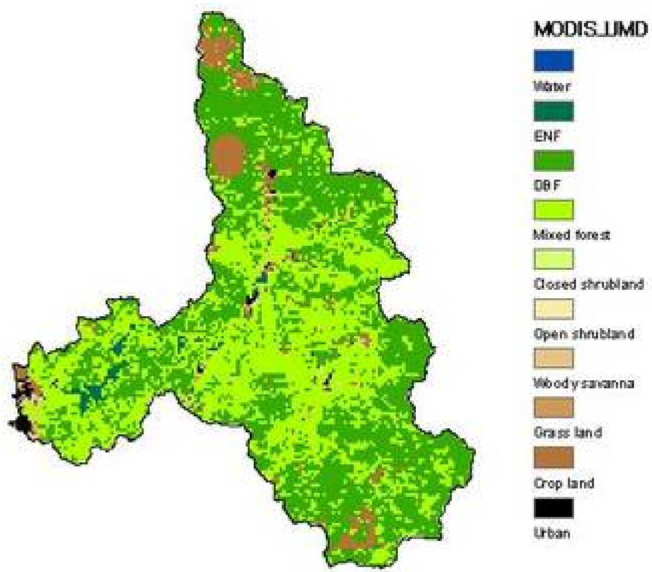

Figure 2. Land cover map of study site

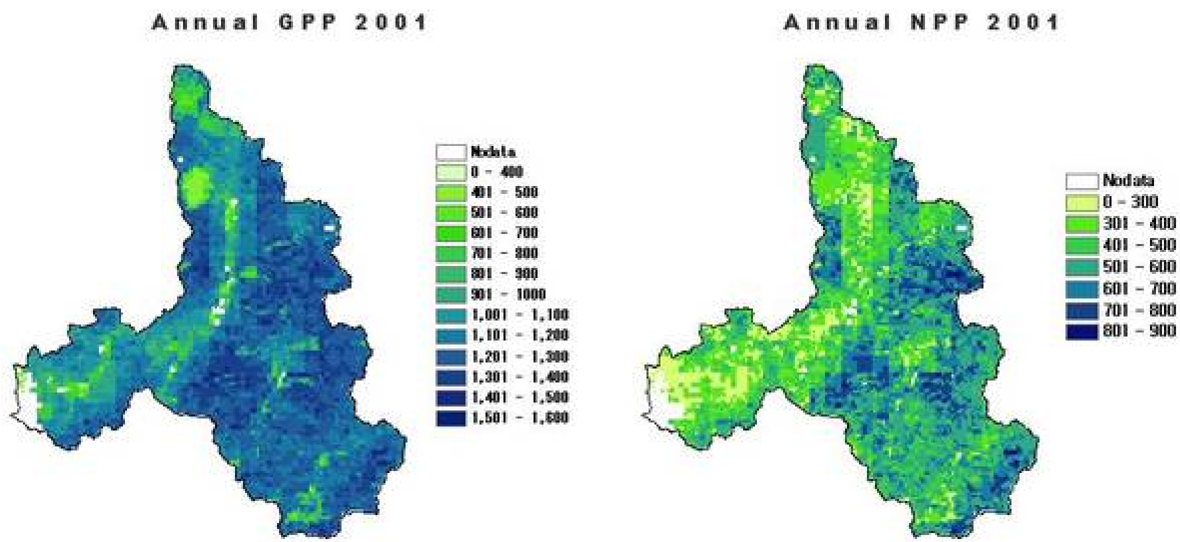

Figure 4. Estimated GPP and NPP in 2001for Soyang Lake Watershed (g C m^{-2} year^{-1})