Mapping NPP for a Coniferous Forest in Southern Sweden using data from Terra/MODIS

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Abstract – Net primary production (NPP) is modeled for a coniferous forest in southern Sweden for 2001. The model is based on the light-use efficiency concept where NPP is calculated as a product of absorbed photosynthetically active radiation (APAR) and a light-use efficiency factor (ε). APAR is estimated from the fraction of APAR (FAPAR) multiplied with the daily total amount of incoming PAR. FAPAR is obtained by linear transformation of 250 m NDVI from Terra/MODIS. Prior to the transformation, the NDVI has been seasonally adjusted by fitting local asymmetric Gauss functions to the time series. ε is modeled daily as a function of temperature, latitude and time. The model is evaluated against an NPP time series obtained from flux measurements of net ecosystem exchange (NEE) and measurements of respiration carried out simultaneously at the site (r^2 = 0.78 for modeled and measured NPP). FAPAR is evaluated against measurements 2004.

Keywords: FAPAR, NPP, LUE, MODIS, Norway spruce, Sweden

1. INTRODUCTION

The boreal forest plays an important role in the climate system by acting as either a carbon sink or carbon source. Net primary production (NPP), defined as the yield of dry matter production of a plant community (Larcher, 2003), is accordingly an important component of the carbon cycle.

An appealing way to estimate NPP is to model it as a product of absorbed photosynthetically active radiation (APAR) and a light-use efficiency factor (ε). Since the fractional APAR (FAPAR) can be obtained from satellite data, large area estimations of NPP with a rather high temporal resolution are possible with the implementation of satellite-driven LUE-models (Monteith, 1977; Ruimy *et al.*, 1994; Seaquist, 2001).

In this study, such a model is constructed with ε modeled at daily resolution as function temperature, latitude, and day of the year (DOY). The model is run for 2001 at a site where measurements of net ecosystem exchange (NEE) and heterotrophic respiration were carried out simultaneously. Since NPP is the sum of these two parameters a thorough evaluation of the model is possible.

2. MEASUREMENTS

2.1 Site Description

Asa Experimental Forest is located in Småland, southern Sweden (57.17° N, 14.80° E) and is part of the NECC flux site network. Two plots were identified both consisting of Norway spruce (*Picea abies* (L.) Karst.) on formerly arable land: one homogenous stand with a tree height of slightly less than 20 m (named Plot 1), and one rather heterogeneous with taller trees located right next to the Asa flux tower (named Plot 2). The plots are located approx. 260 m away from each other. Mean annual temperature is about 5.6° C and mean annual precipitation is 662 mm (von Arnold *et al.*, IN PRESS).

2.2 NPP

NPP is obtained from flux measurements of NEE by adding the heterotrophic respiration. Measurements of dark forest floor CO_2 release were carried out during 2001 at Asa. Heterotrophic activities were set to 50% of the release (von Arnold, IN PRESS). Since measurements were collected during 35 days distributed over the year, a daily resolution was achieved by applying a cubic spline interpolation to the time series. Flux measurements of NEE were measured simultaneously at the same site. Figure 1 shows measured NEE and heteotrophic respiration.

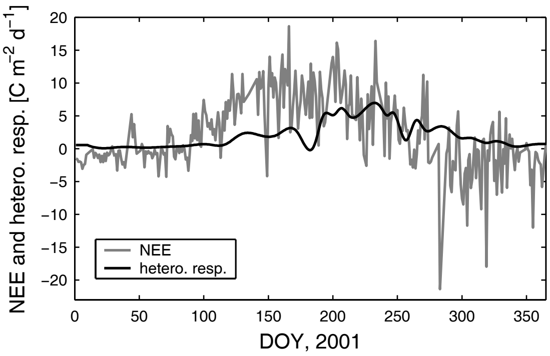

Figure 1. NEE, heterotrophic respiration and resulting NPP for 2001.

2.3 FAPAR

By measuring incident PAR below and above the canopy it is possible to calculate the fraction of intercepted PAR (FIPAR, symbolized f_i, equation 1). In order to obtain the fractional absorption (symbolized f_a, equation 2), the PAR reflected from ground and canopy also has to be measured (Gower *et al.*, 1999):

$$f_i = 1 - \frac{E_b}{E}, \qquad (1)$$

$$f_a = \frac{(E - E_r) - (E_b - E_{r,b})}{E}, \qquad (2)$$

where E and E_r are incident and reflected PAR above canopy, respectively; and E_b and $E_{r,b}$ the corresponding parameters below canopy.

At Plot 1, FAPAR was measured during the summer of 2004 using sensors mounted on a 20 m telescope mast. Two PAR sensors were mounted on the top of the mast – one looking up and one looking down – just above the canopy. Below canopy, two sensors were mounted at a height of approximately 2 m in the same manner, and eight sensors were randomly placed on the ground. All sensors were connected to the same logger and measurements were averaged every five minutes.

During the same time at Plot 2, twelve PAR sensors connected to a logger (same configuration as the one described above) were randomly placed on the ground. Incident PAR was taken from the mast in Plot 1 in order to derive FIPAR. To obtain FAPAR, canopy reflectivity measured by the sensors on the mast was subtracted from the FIPAR values.

Measurement period (2001) for Plot 1 was DOY 180-231 (28 Jun-18 Aug) with a break DOY 199-209 (17 July-27 Jul) due to power failure and for Plot 2 DOY 180-217 (28 Jun-4 Aug) also with a break DOY 199-209.

For both plots daily means were calculated.

2.4 Meteorological variables

At the Asa flux tower incident PAR was measured at a a height of 35 m during 2001. Temperature was measured during the same period.

3. MODEL

NPP (symbolized P_n) is calculated according to equation 3.

$$P_n = E_a \varepsilon , \tag{3}$$

where E_a is the absorbed PAR, which in turn is calculated as the product of the fractional absorption, derived from linear transformation of NDVI and the total amount of incoming PAR:

$$E_a = (a + bNDVI)E . \tag{4}$$

ε is modeled at daily resolution as a function of temperature, latitude and day number (DOY). The LUE-model is described in detail in Lagergren *et al.* (2005).

In order to estimate APAR, the fractional absorption first has to be obtained. In our model this is done by linear transformation of seasonal adjusted NDVI. The adjustment is performed by fitting local asymmetric Gauss functions to the NDVI time series using the computer program TIMESAT (Jönsson and Eklundh, 2002; Jönsson and Eklundh, 2004). The algorithm uses quality controls for the NDVI values in order to assign a weight for each value used for the adjustment (see figure 1). In this study the quality controls were taken from the "VI Usefulness Index" included in the NDVI Quality Science Data Set (/MODIS VI User Guide).

The FAPAR used in this study is part of a larger FAPAR dataset for Scandinavia 2000-2005. Here, the linear transformation of NDVI is performed by calculating the 98th and 5th percentile for six land cover classes for the whole of Scandinavia for each year (percentiles for 2001 were used in this study). Land cover is obtained from the GLOBAL LAND COVER 2000 Project (Bartholomé *et al.*, 2002). By assuming that the 98th percentile represents a FAPAR of 95% and the 5th percentile a FAPAR of 0% (Sellers *et al.*, 1994), linear relationships between NDVI and FAPAR are obtained for each year and land cover class.

Since the FAPAR is derived from the MODIS VI product (MOD13Q1) the resolution characteristics of the FAPAR data set will be inherited from MOD13Q1, i.e. a spatial resolution of 250 m and a temporal resolution of 16 days (Huete *et al.*, 2002). For an NDVI or FAPAR time series this means that a value at position i is representing the period $i + 15$ days. Since incident PAR is measured daily, a daily resolution for the APAR time series is thereby obtained as APAR is the product of the fractional absorption and the incident PAR. Accordingly, NPP is modeled at daily resolution.

4. RESULTS

4.1 FAPAR

Figures 2 and 3 show the seasonally adjusted NDVI plotted with NDVI from Terra/MODIS for the pixels in which Plot 1 and Plot 2 are located, respectively. The two pixels are located next to each other (pixels R1357, C3852 and R1357, C3851 in MODIS tile H18V03).

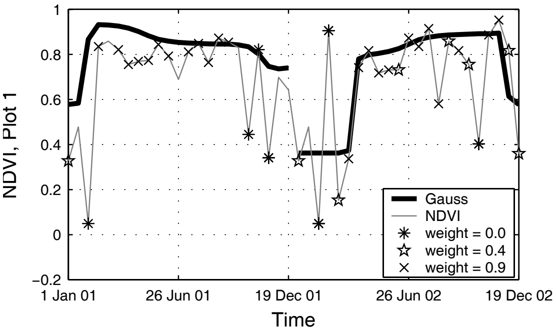

Figure 2. Adjusted and raw NDVI for Plot 1.

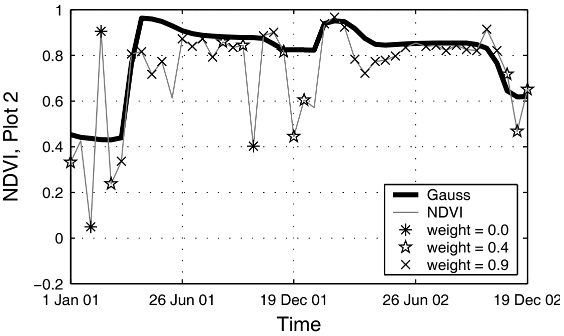

Figure 3. Adjusted and raw NDVI for Plot 2.

As can be seen in the figures, most of the noise is screened out. During 2001 the two time series displays some unrealistic values in February and during the end of the growing season which are all efficiently screened out. However, the adjustment seems to be producing too high values in between the growing seasons: at Plot 1 the NDVI drops to about 0.6 while at Plot 2 it fails to capture the NDVI decrease. This behaviour can also be seen at the end of 2002 in Plot 1.

Figure 4 and 5 show the FAPAR time series derived from NDVI transformation plotted together with measured FAPAR and FAPAR derived from Terra/MODIS. The latter has spatial resolution 1 km and the time series are extracted from the pixels "containing" the measurement site. When comparing the measured with the calculated time series it is obvious that the linear transformation is a successful and robust method for estmation of FAPAR. However, the method underestimates FAPAR of about 2 and 3 percentage points at Plot 1 and 2, respectively.

For Plot 1 both FAPAR and FIPAR was measured and the difference (the reflectivity) was in average 2.1 percentage points. This figure was subtracted from the FIPAR measurements at Plot 2 in order to obatin FAPAR.

The FPAR product from Terra/MODIS (MOD15A2) maps FAPAR successfully during the measurement period at Plot 2 but contains some unrealistic values just prior and after the period.

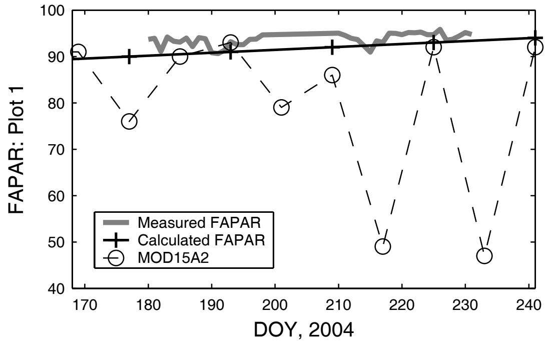

Figure 4. Calculated and measured FAPAR, and FAPAR from Terra/MODIS at Plot 1.

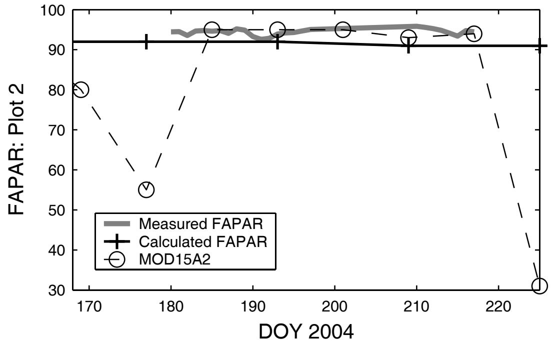

Figure 5. Calculated and measured FAPAR, and FAPAR from Terra/MODIS at Plot 2.

At Plot 1 the product is able to map FAPAR at approximately 5-6 times during period for which the data is plotted. The other values underestimates FAPAR by approximately 5-15% or are unrealistic (as at DOY 217 and 233).

4.2 NPP

Figure 6 shows the modeled NPP plotted with measured NPP (10 day running average) for 2001. The coefficient of determination for the whole year was calculated to 0.78 (r^2 = 0.64 for the non-averaged time series).

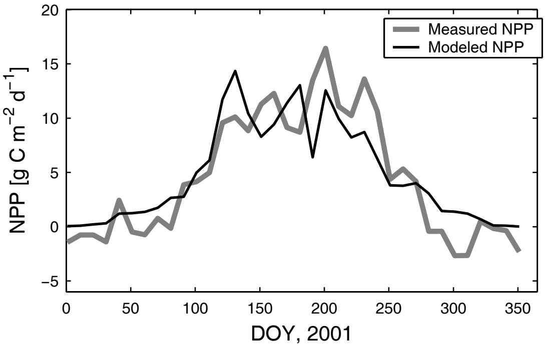

Figure 6. Modeled and measured NPP.

5. DISCUSSION AND CONCLUSION

The method for seasonal adjustment of NDVI efficiently screens out cloud interference and unrealistic values. However, it tends to fail to capture the NDVI decrease in between growing seasons. This phenomenon is currently under investigation.

The FAPAR product from Terra/MODIS (MOD15A2) is useful if it is possible to screen out unrealistic values, for example, by consulting the belonging quality data sets. This has not been investigated. Employing a method like the one used for the NDVI data in this study could probably also be used for screening out unrealistic values (preferably together with the quality data sets). However, since the plots where the measurements took place are smaller than the satellite pixels of 1 km for the MOD15A2 (or even for the 250 m NDVI data) a scaling error is introduced biasing the comparison of in-situ measurements and satellite sensor-derived FAPAR. A study is being planned during the time or writing aiming at investigating this bias.

As can be seen in Figure 6 the model is able to map NPP rather successfully, and the result is consistent with model performance observed for a mixed Scots pine/Norway spruce forest in central Sweden where coefficient of determination for 2000 and 2001 was calculated to 0.84 and 0.80, respectively (Olofsson *et al.*, SUBMITTED). Then, the model failed to map the production increase during spring, especially for 2001, but performed well after April and throughout the year. In this study a slight overestimation of NPP is present during both spring and fall, and during summer the noisy behaviour of both measured and modeled NPP reveals a certain discrepancy. These disagreements can probably be attributed to the fact that ε is not a function of water availability. Even though it has been reported that temperature is the most dominating growth limiting factor for cold climates (Bergh *et al.*, 1998), a production increase for a Norway Spruce stand in Asa was observed by Bergh *et al.* (1999) as an effect of long-time irrigation.

In order to further determine the performance of the model it will be run for a couple of more sites in Sweden. The model will also be run for longer periods, preferably from 2000 to 2005. Since estimates of heterotrophic respiration for deriving NPP from NEE are rare, a stochastic differentiated seasonal model with a suitable external signal (such as air and soil temperature) will be set up allowing prediction of the respiration time series.

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6.4 Acknowledgements

Thanks to Leif Klemedtsson, Per Weslien and Karin von Arnold for providing flux and meteorological data from Asa Research Station.