Estimating gross primary productivity (GPP) of forests across southern England at high spatial and temporal resolution using the FLIGHT model

UNIVERSITY OF Southampton

P. Pankaew[a]*, J. Dash[a], E.J. Milton[a], T.P. Dawson[b]

[a]Geography and Environment, University of Southampton, Southampton, SO17 1BJ, UK

[b]School of Environment, University of Dundee, Dundee, DD1 4HN, UK

*Email: P.Pankaew@soton.ac.uk

1. Introduction

The gross primary productivity (GPP) of vegetation quantifies the rate at which vegetation converts energy into biomass. Therefore, it is a crucial input in understanding the global carbon cycle. However, for a given vegetation type, GPP varies both diurnally and annually due to changes in phenology, environmental conditions and photosynthetically active radiation (PAR). Although many studies have focused on the annual variation of GPP, relatively little has reported on diurnal variation and particularly on the effect of direct and diffuse PAR on GPP. Here we present initial results on diurnal variation of GPP by using a modified version of the Forest LIGHT interaction (FLIGHT) model (North, 1996) to predict GPP (Alton *et al.*, 2005).

2. Study areas

We used data from two sites in southern England having FLUXNET stations (Fig. 1). Each site has an ultrasonic wind sensor and a gas analyser for GPP measurement using the eddy covariance method.

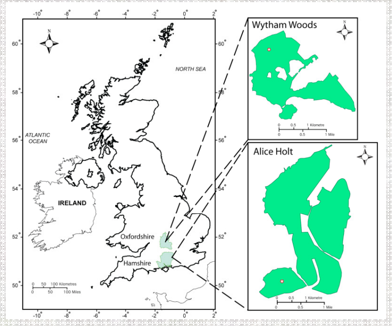

Fig. 1 Study sites at Alice Holt forest, Hampshire and Wytham Woods forest in Oxfordshire, in southern England, UK

Alice Holt forest, in Hampshire (0° 51´18˝W, 51° 10´ 45˝N) is a mixed forest with the main canopy species being Corsican pine (*Quercus robur*, *Q. petraea*) and Oak (*Pinus nigra* var. *maritima*). It is classified as semi-natural ancient woodland and covers an area of approximately 8.5 km².

Wytham Woods, in Oxfordshire (1° 20' 18" W , 51° 46' 37"N) is mixed woodland including ancient woodland, grassland and plantation. The main canopy species in Wytham Woods are pedunculate oak (*Quercus robur*), ash (*Fraxinus excelsior*), sycamore (*Acer pseudoplatanus*), beech (*Fagus sylvatica*), conifers and some plantations in an area covering approximately 2 km², surrounded by grasslands and agriculture fields.

3. Method and results

FLUXNET measurement uses the eddy covariance method and the measured wind 3D component and gas concentration data from an ultrasonic anemometer and an infrared gas analyser at the flux stations. To study the diurnal and annual variation of GPP, hourly average GPP was obtained for 2005-2010. Three years data for Alice Holt and four years data for Wytham Woods were available.

FLIGHT uses the Monte Carlo method to model the path of photons through the canopy. GPP is one of the FLIGHT outputs from an additional photosynthesis module (Alton et al. 2005). Inputs to FLIGHT comprise more than 40 variables. For this study photosynthetically active radiation (PAR, 400-700 nm), diffuse fraction (fDIF), sun azimuth (ψ), sun zenith (θ_z), leaf area index (LAI) and aerosol optical depth (AOD) were obtained from a combination of sources including site characteristics, meteorological data and MODIS data.

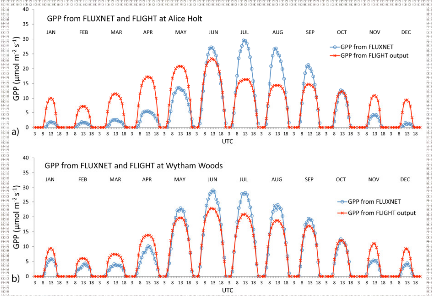

Fig. 2 variation of the hourly GPP from FLIGHT and measured GPP using FLUXNET at a) Alice Holt and b) Wytham Woods

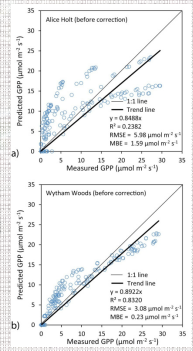

Fig. 3 comparison between hourly average per month of the predicted GPP using FLIGHT before correction and measured GPP using FLUXNET at a) Alice Holt and b) Wytham Woods

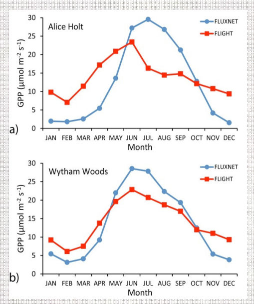

Fig. 4 variation of the midday GPP predicted using FLIGHT before correction and the midday GPP measured using FLUXNET at a) Alice Holt and b) Wytham Woods

Method and results (continued)

We compared the difference between the variations of the hourly GPP from eddy covariance with those predicted using FLIGHT at both sites (Fig. 2 and 3).

Both data sets showed a similar diurnal pattern, but there was a mismatch between the amplitude of the GPP. FLIGHT predicted GPP was higher in winter and lower during summer months than measured FLUXNET values.

Therefore, a correction factor was derived using the midday (12.00 UTC) GPP values between the measured and modelled GPP for each month.

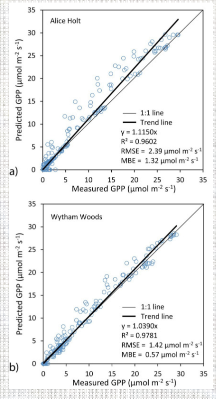

Fig. 5 comparison of the hourly average GPP between the predicted GPP using FLIGHT after correction and measured GPP using FLUXNET at a) Alice Holt and b) Wytham Woods

The correction factor was applied to modelled GPP at every hour of the day in those months and was compared with the hourly data measured through eddy covariance (Fig. 5 and 6). The correction factor improved the model prediction and resulted in higher coefficient of determination (R^2), lower root means square error (RMSE) and means bias error (MBE) (Fig. 3 and 5).

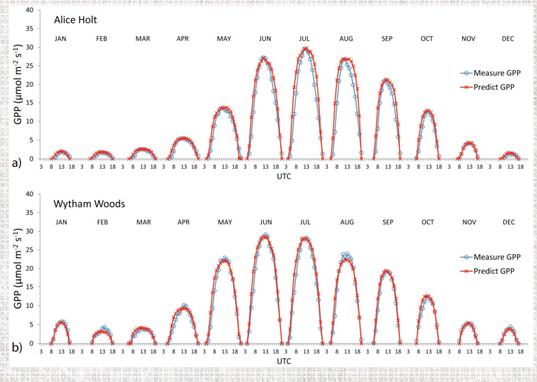

Fig. 6 comparison of the variation of the hourly GPP after correction between the predicted GPP using FLIGHT and measured GPP using FLUXNET at a) Alice Holt and b) Wytham Woods

4. Discussion

The GPP in forest and woodland can be estimated using the eddy covariance method involving wind speed and direction by FLUXNET or can be simulated without wind data in FLIGHT. Initial results suggest good agreement for the diurnal pattern but mismatch in amplitude of GPP by the two methods. Many factors can contribute to this mismatch, but a major source of uncertainty is the accuracy of model parameters and input data. For example, we used a generalised plant physical and physiological parameter for this investigation. Detailed site specific data would also improve the model performance.

The MODIS LAI used as an input to the model has been shown to over-estimate true LAI during early spring and late autumn at similar sites (for example, Ogutu et al., 2011) which could be responsible for the model over-prediction during this time of the year. However, in this study, we demonstrated that we can use a simple method to correct the mismatch between them. The advantage of the FLIGHT model is that once it is calibrated, we can use it to further investigate the effect of direct and diffuse PAR on GPP.

5. Conclusion

The advantage of the FLIGHT model approach to estimating GPP is that the user can input the data from multiple sources, from field measurements or remotely sensed data such as from MODIS products, for example.

With further refinement of the model parameters and some site-specific input data we suggest that it will be possible for FLIGHT to be routinely used for monitoring and mapping GPP over large areas, even on an hourly basis.

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