Forest microclimate modelling using gap and canopy properties derived from LiDAR and hyperspectral imagery

Z. Abd Latif, G.A. Blackburn

Division of Geography, Lancaster Environment Centre,
Lancaster University, Lancaster LA1 4YQ, United Kingdom.
z.abdlatif@lancs.ac.uk, alan.blackburn@lancs.ac.uk

Abstract

The creation of gaps in forest canopies can dramatically change the microclimate and soil water balance which strongly influences the process of regeneration and biodiversity within forest ecosystems. Hence, understanding the microclimatic conditions in canopy gaps is a prerequisite in developing and improving techniques for forest management and conservation practices. However, information is scarce on how the size and shape of gaps and their spatial distribution affects the microclimate and soil water balance across forest stands. In the present study we investigated the potential for retrieving forest gap and canopy attributes from LiDAR and hyperspectral sensors in order to provide new opportunities for modelling forest microclimates. A spatially explicit microclimate model (FORGAP-3D) was developed which could be driven using inputs from remote sensing. The model was implemented for a study site in the New Forest, UK in order to quantify the spatio-temporal dynamics of microclimates over an entire forest stand. Further work will focus on improving the methods for deriving gap and canopy properties from LiDAR and hyperspectral data and evaluating the impact of these techniques on the accuracy of microclimate model outputs.

Key words: Hyperspectral, LiDAR, Meteorology, Spatial, Three-dimensional

1. Introduction

Forests are crucial to the well being of humanity; they provide foundations for life on Earth through ecological functions, by regulating the climate and water resources, and by serving as habitats for plants and animals. In temperate forests wind throw often creates canopy gaps which can dramatically change the microclimate and soil water balance (Spice *et al.*, 1990, Yamamoto, 1995). Hence, understanding the microclimate conditions in canopy gaps is a prerequisite in developing and improving techniques for forest management and conservation practices. Figure 1 demonstrates the nature of these changes, in general terms. However, information is scarce on how precisely gap size and shape affects the microclimates within canopy gaps and beneath surrounding tree canopies and how the spatial distribution of gaps influences microclimates across entire forest stands.

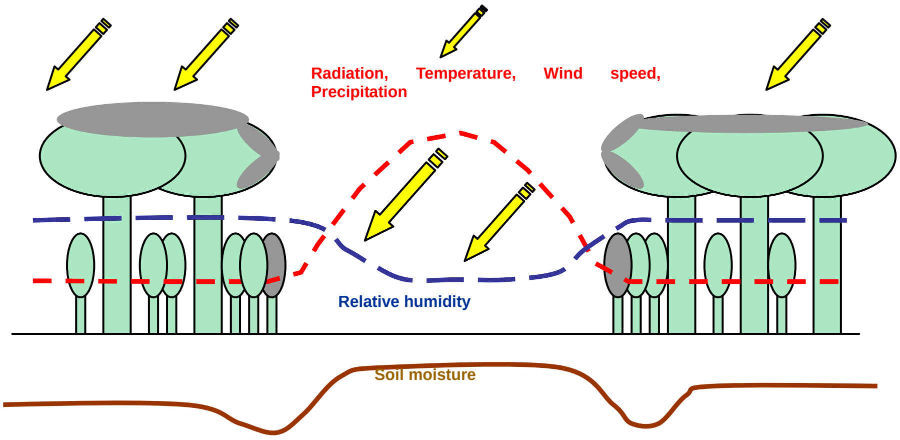

Figure 1. Gradients of microclimate conditions and soil moisture in forest canopy gaps. The grey areas on the vegetation represent the parts of the crowns that can receive direct solar radiation.

Remote sensing is increasingly seen as an important tool for providing information for the achievement of sustainable and efficient forest management. The past decade has seen growing interest in the use of remote sensing technologies in forest studies. Devices such as Light Detection and Ranging (LiDAR) and hyperspectral sensors together with new analytical techniques allow increasingly detailed information to be extracted from such imagery. LiDAR technology is becoming capable of providing 3-dimensional information at high spatial resolutions and vertical accuracies (Lee and Lucas, 2007). Hyperspectral data provides much finer spectral resolution than conventional multispectral data. Forest attributes such as crown heights and individual canopy gap delineations can be directly retrieved from LiDAR data (Koukoulas and Blackburn, 2005) while tree species classifications may be derived from hyperspectral imagery (Lucieer *et al*., 2005). LiDAR is a relatively new technology that offers an alternative to *in situ* field surveys and photogrammetric techniques for the collection of elevation data. LiDAR provides accurate, timely data, is capable of operating in difficult terrain and is increasingly affordable (Flood and Gutelius, 1997).With high spatial resolution remotely sensed imagery, the spatial properties and composition of tree canopies and gaps can be obtained over large areas. With the capabilities of direct retrieval of forest attributes offered by remote sensing, this provides new opportunities to model forest gap microclimates. Modelling the spatial patterns of microclimates in a gap and its surroundings using traditional methods would require a large volume of ground-based measurements and many model runs in order to cover a large spatial extent. By developing an inherently spatial microclimate model and driving this with inputs from remote sensing we have the potential to quantify forest gap microclimates over entire forest stands. This study aims to examine the feasibility of such an approach using a case study of a broadleaved deciduous forest in the UK.

2. Data collection

2.1 Study site

The LiDAR and hyperspectral imagery used for this research were collected at Frame Wood, New Forest (1˚30'W, 50˚50'N), southern England, an area recognized as being of international importance to nature conservation. There are 4049 ha. of unenclosed primary woodland where the dominant tree species are *Quercus (pendula and pubescens*) and *Fagus sylvatica*. Betula (pendula and pubescens) can be found mainly in canopy gaps and in association with Quercus spp.. The specific study site, Frame Wood presents a wide range in all of the gap and canopy variables of interest, being described by Flower (1977) as primary woodland dominated by *Quercus robur*. Previously, this area has been the focus of a number of ecological remote sensing studies (e.g. Koukoulas and Blackburn, 2004, 2005).

Figure 2: Location of the New Forest, U.K.

2.2 Airborne data

The LiDAR data used in this research were acquired by the UK Environment Agency (EA) using an Optech Airborne Laser Terrain Mapping (ALTM) 1020. The altitude of the aircraft was 730 m (2400 ft) above the ground level and a swath width of approximately 600 m was surveyed along each flight line. The laser scans across the aircraft flight line at 5000 light pulses per second (at 1047 nm wavelength), sweeping left and right in a zig-zag movement over the ground. Individual measurements were made at approximately 1 return per square metre. The travel times of the laser pulses, from the aircraft to the ground and vice versa, were measured with a precise timer. This instrument recorded the time of the first returned pulse. The time intervals are then converted into range measurements using the velocity of light. In this way, the surface height is calculated to accuracy of within 15 cm. The LiDAR data provided contained single return.

Imagery of the study site was also acquired using an Itres Compact Airborne Spectrographic Imager (CASI) onboard the Natural Environment Research Council (NERC) Airborne Research and Survey Facility. The aircraft altitude was 670 m (2200 ft) which generated imagery with a spatial resolution of 1 m. The CASI instrument acquired imagery in 12 narrow wavebands across the visible and near-infrared.

3. Methodology

3.1 Derivation of a Canopy Height Model and gap delineation

Gap identification from LiDAR imagery was performed using Erdas Imagine (v.9.1) and ArcGIS (v.9.2) software (Environmental Systems Research Institute, Inc.). Canopy heights were derived from LiDAR data; however an estimate of the ground elevation is needed. Because the LiDAR sensor recorded only the first return, a digital terrain model (DTM) was constructed from elevation data provided by the U.K. Ordnance Survey (OS). A canopy height model (CHM) was calculated as the difference between elevation values in the LiDAR data and ground elevation at corresponding locations. Figure 3 shows the CHM model where tree heights are classified into five classes for display purposes. Based on the field visits of previous work by Koukoulas and Blackburn (2005), it was determined that the height below which areas would be identified as gaps should be between 3 and 5 m. Thus, the height of 4 m was therefore selected as the threshold for distinguishing canopy from gap areas. From the CHM all grid cells with a height less than or equal to 4 m were assigned as gap areas.

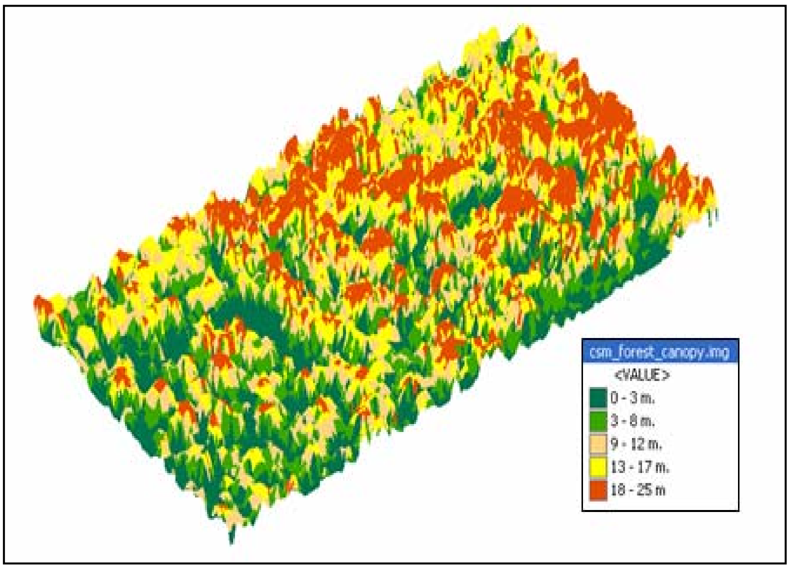

Figure 3. Canopy Height Model (CHM) extracted from LiDAR data.

3.2 Derivation of LAI

Leaf area index (LAI) is a major parameter in understanding forest microclimate and a key input to forest microclimate models in order to quantify the interception of light by the canopy. The following relationship, derived from a previous work at the study site (Blackburn, 2002) between a simple ratio (SR) of CASI bands 12/3 and LAI ($R^2 = 0.71$) was used:

$$LAI = 0.6348\,(SR) - 1.3985 \qquad (3)$$

where Simple Ratio (SR) = $NIR_{CASI} / Green_{CASI}$ = 865 nm/553 nm

3.3. Forest gap microclimate modelling

A spatially explicit model of forest gap microclimates and soil water balance was developed based on previous reviewed literatures and field measurements of microclimates and soil water balance (Van Dam, 2001). FORGAP-3D is written in the dynamic script modelling language PcRaster (PcRaster, 1995) and comprises two sub-modules, radiation and soil water balance. The radiation module calculates the potential radiation on the vegetation, the potential radiation on the saplings in the gap and area surrounding the gap and the potential radiation on the soil. The second sub module calculates the soil moisture content at 5cm depth both within gaps and beneath the forest canopy. FORGAP-3D was developed to be driven by a set of spatial inputs derived from remote sensing (canopy height, gap map and LAI) together with a DEM and meteorological data from a nearby weather station (Figure 4). In order to refine the model, future work will concentrate on validation using ground-based micrometeorological measurements.

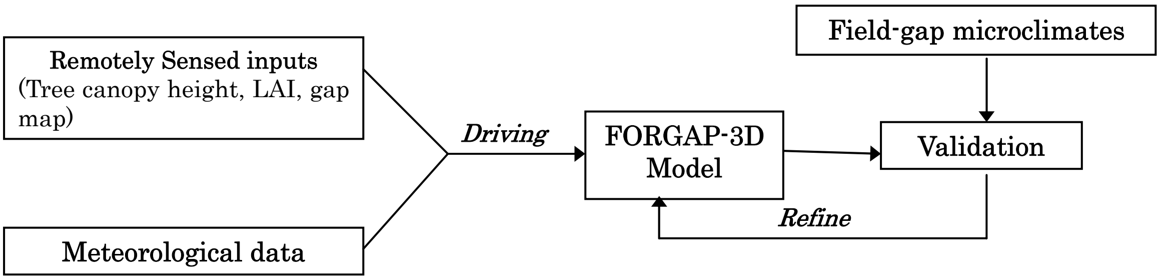

Figure 4. Methodological framework of the integration of remotely sensed and meteorological data into the FORGAP-3D model.

4. Results and Discussion

Gap areas extracted from the LiDAR data in Frame wood are shown in Figure 5 while the map of LAI derived from CASI is shown in Figure 6.

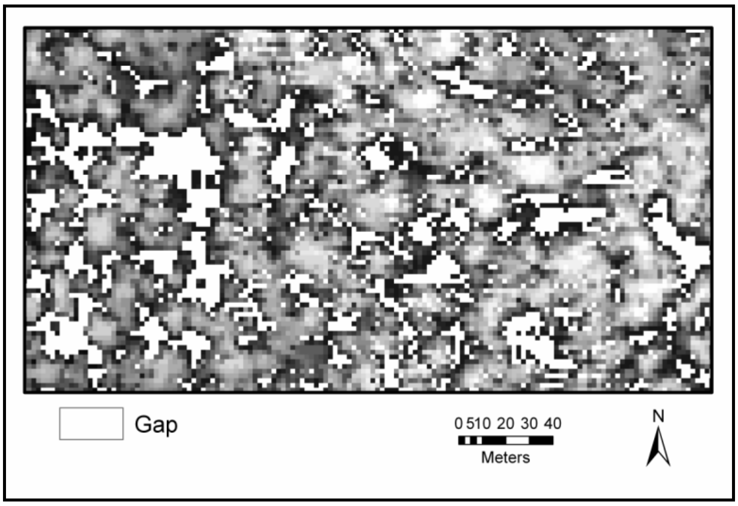

Figure 5. Canopy gaps in Frame Wood as estimated from the CHM. Gaps are shown as white areas outlined in black.

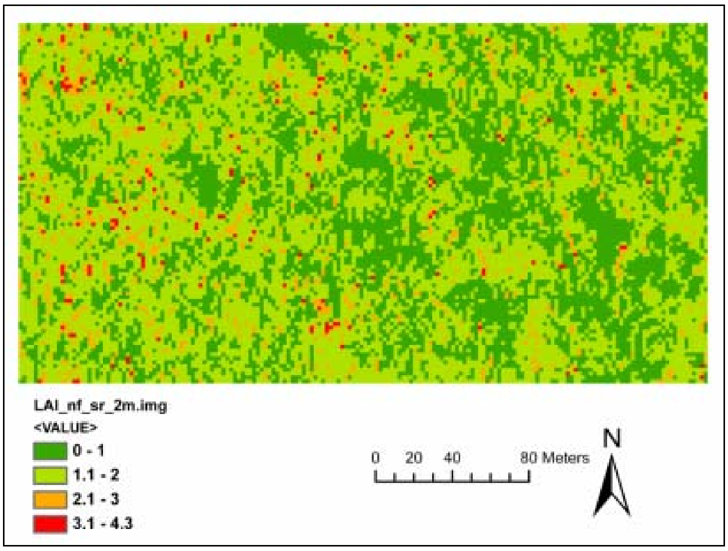

Figure 6. LAI map of study area derived from CASI.

The spatial data above were used to drive the FORGAP-3D model in order to generate both spatial and temporal simulations of forest microclimates. In order to demonstrate the output from the FORGAP-3D model, Figure 7 shows diurnal time series of microclimate conditions (total radiation, air temperature, relative humidity and wind speed) for a specific location at the centre of a gap as well as a location beneath the adjacent forest canopy. At solar noon total solar radiation in the gap was higher than that beneath the adjacent forest canopy by 192 W.m^{-2}. Likewise air temperature and wind speed was higher at the gap centre than beneath the forest. However, relative humidity values were lower than in the forest at noon. Figure 8 shows examples of the spatial output from FORGAP-3D for a specific time point (solar noon), which illustrates the detailed spatial information concerning microclimate that the model is able to generate.

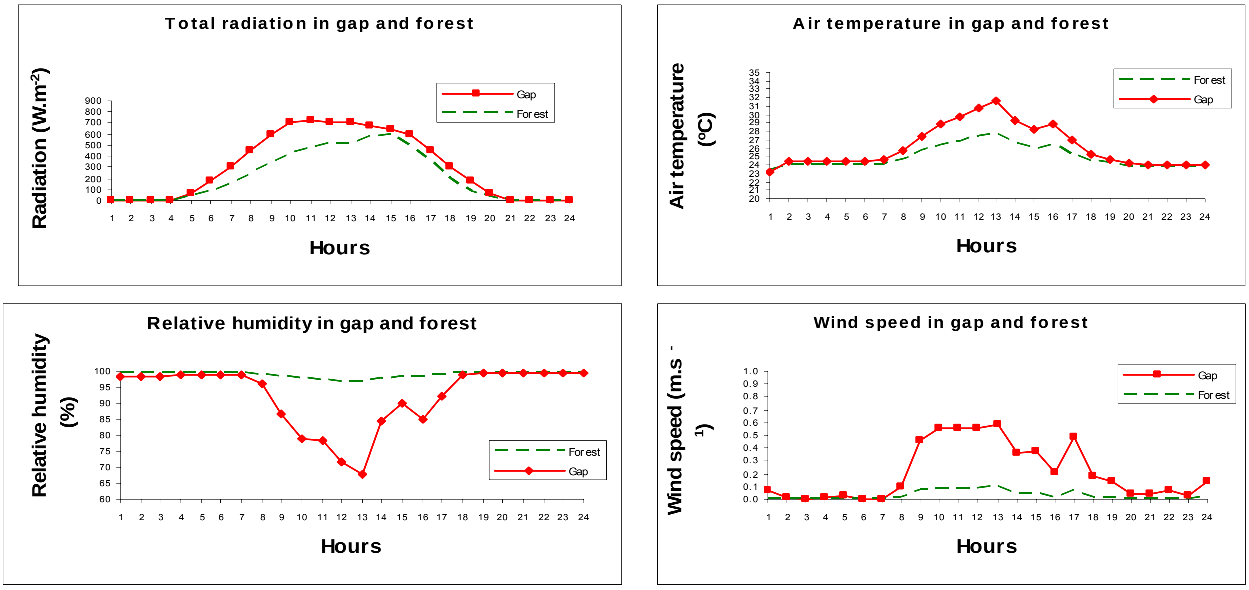

Figure 7. FORGAP-3D diurnal pattern outputs of total solar radiation, air temperature, wind speed and relative humidity at a gap centre and beneath the adjacent forest canopy.

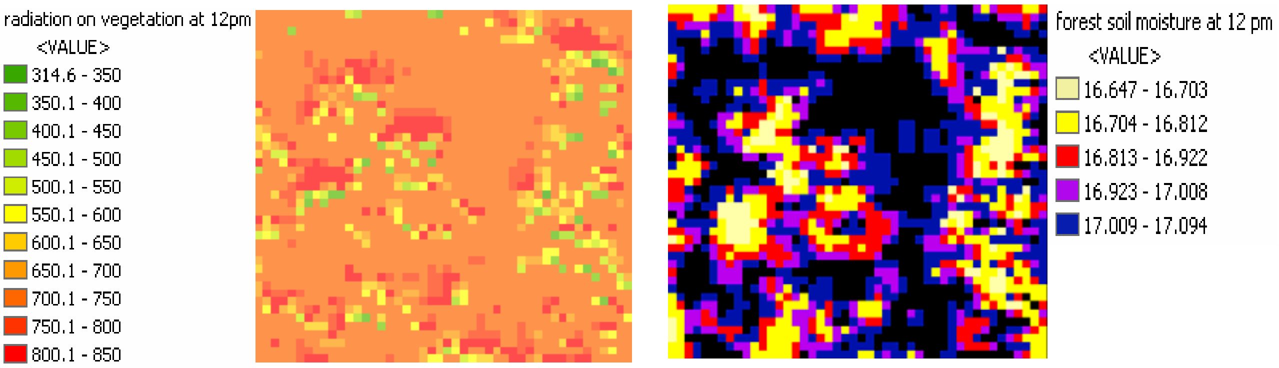

Figure 8. Examples of the spatial output from FORGAP-3D for a sample area within Frame Wood at a specific point in time (solar noon). Area covered by each image is 50 x 50m.

5. Conclusion

This preliminary study has demonstrated that remote sensing is a promising tool for forest microclimate modelling, in particular when combining LiDAR and hyperspectral data sources. The use of remote sensing technology greatly reduces the time and fieldwork effort required and can provide a comprehensive set of spatial information that is difficult to obtain using traditional methods. Forest gap microclimate modelling can be a valuable tool for understanding the spatio-temporal characteristics of microclimates within gaps and across the entire forest landscape. Remote sensing provides an increasing variety of spatial data layers that are potentially useable as model input. This study has demonstrated that it is possible to drive a simulation model using gap and canopy data derived from remote sensing in order to generate spatial and temporal estimates of microclimate. Further work will focus on improving the methods for delineating gaps and extracting canopy properties from LiDAR and hyperspectral data, driving the model using a seasonal time series of gap and canopy variables and evaluating the impact of these techniques on the accuracy of microclimate model outputs.

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