NERC GEOPHYSICAL EQUIPMENT FACILITY LOAN 877 SCIENTIFIC REPORT

Modelling gap microclimates in broadleaved deciduous forests using remotely sensed data: the contribution of GPS to geometric correction and product validation.

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Abstract

When treefalls occur or tree crowns are damaged due to windthrow, tree death, disease or anthropogenic disturbance, the gaps that are created in the forest canopy initiate dramatic changes in abiotic conditions, particularly microclimate. It is generally acknowledged that the magnitude of the changes in microclimate is related to the size, shape and 3-D geometry of the gap and characteristics of the remaining surrounding canopy. However, there is currently a paucity of models that are able to describe these relationships, particularly in temperate forests. Furthermore, we currently have very limited ability to characterise the consequences of the variations in the spatial distribution of gaps on the microclimatic conditions across entire forest stands. The present project aims to address these issues by using a unique combination of field observations, numerical modelling and remote sensing techniques. *In situ* observations at the field site are helping to provide the empirical evidence with which to construct a dynamic spatio-temporal model of gap microclimates, while experiments over the growing season will develop robust and extendible remote sensing techniques for characterising relevant gap and canopy properties. The use of the NERC GEF GPS equipment, deployed during an extensive ground campaign coinciding with the NERC ARSF overflights, has enabled a comprehensive validation of our outputs.

Background

Precise and reliable information extraction from remotely sensed data requires accurate geometric correction of the data. The geometric correction process utilizes ground control points (GCPs) for the removal of image distortions, and the correction accuracy depends on the accuracy of GCPs used. GPS is a valuable tool for the determination of precise GCP coordinates. As technology progresses, remotely sensed data such as LiDAR and hyperspectral data continually becomes finer in terms of spatial resolution. Previous studies have shown that differential GPS can be used effectively to derive GCPs for the geometric correction of fine resolution airborne scanner data (Witter *et al.*, 2001). The accuracy of digital elevation models (DEMs) and land cover maps derived from remotely sensed data can vary greatly depending on the accuracy of GCP coordinates used. GPS could be an accurate and effective solution for the determination of GCP coordinates.

The GPS System 500 loan from NERC GEF was deployed in a number of canopy gaps created naturally in Eaves Wood (2˚ 49'W, 54˚ 10'N), located on a Carboniferous limestone hill north of Silverdale, Lancashire (Figure 1). This area is situated within the Arnside and Silverdale area and is designated as an Area of Outstanding Natural Beauty (A.O.N.B.) and Site of Special Scientific Interest (SSSI) notified under section 28 of the Wildlife and Countryside Act, 1981 in England and Wales. It is a mixed semi-natural deciduous forest which covers an area of 51.5 ha and is managed by the National Trust.

The specific objectives of this project were to use GPS data to:

i) determine GCP coordinates for the geometric correction of NERC ARSF airborne remotely-sensed data;
ii) to validate a digital terrain model of the field site derived from OS data;
iii) collect ground-based data on tree species distributions and canopy height with which to validate species and canopy maps derived from hyperspectral and LiDAR imagery.

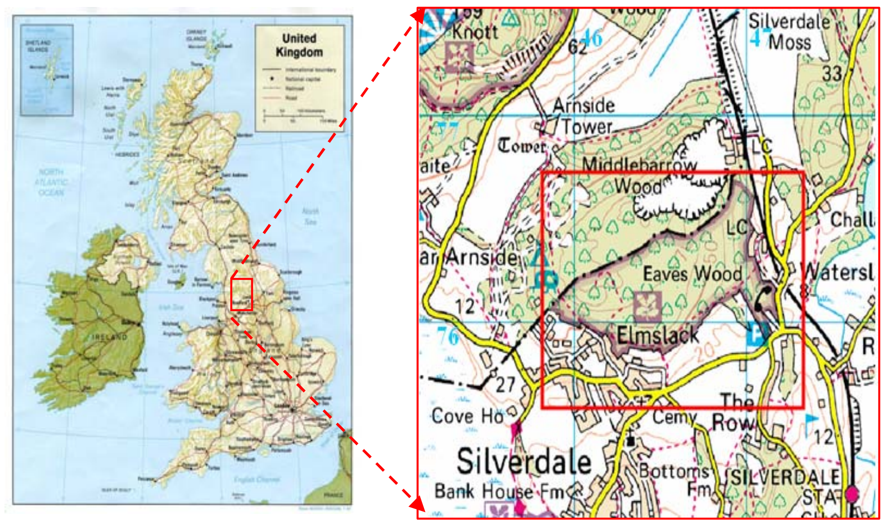

Figure 1: Map of study area at Eaves Wood, Silverdale, U.K.

SURVEY PROCEDURE, DATA QUALITY AND DATA PROCESSING

Ground Control

The first task of this project is to establish suitable ground control points in the study area. NERC Geophysical Equipment Pool loan (877) of Leica GPS equipment was secured for this purpose. Four (4) GPS control points were established surrounding the vicinity of the study site, Eaves Wood. At each station, measurements were performed in static mode using a set of Leica dual frequency receivers (model SR530 of Leica Geosystems). The observation duration was at least 45 minutes with a recording interval of 15 sec. The coordinates of the station were processed with other permanent UK Ordnance Survey (OS) GPS based stations located at Ambleside (station id: AMBL). All GPS ground control observations were post-processed using in house NERC GEF software, Leica Geo Office. A minimally constrained adjustment was performed with AMBL base station held fixed in the survey network to correct the locations of other ground control points established at the study site.

Validating DTM Derived From OS Data

A selection of observation points which are completely free from obstructions (e.g. bare areas, road surfaces etc.) were used to validate the DTM derived from OS data. Measurements were performed in kinematic mode (Stop and Go technique). Leica dual frequency GPS receivers were placed on a pole and a five seconds (5 sec) recording interval was selected. The point spacing was selected at around 10 to 15 meters at identified clear areas and the observation time at every point was 3 minutes. A reference receiver was be placed near the test field, therefore the maximum baseline length for every point of each kinematic chain did not exceed 1 km. In all observing sessions the GDOP value was between 3 to 6 and the SNR values for almost all satellites at their maximum. Reduction and analysis of GPS measurements were carried out using the Leica Geo Office software. The validated DTM was be used as part of spatial inputs in the modelling work.

Generation Of Validation Data For Tree Species Classification and Canopy Height model

A survey of tree species and canopy height was undertaken using the Real Time Kinematic (RTK) GPS technique. With this positioning method an accuracy of a few centimeters was usually obtained. Leica dual frequency GPS receivers were placed on a pole and a five seconds (5 sec) recording interval was selected. The points were selected at identified tree species areas and 5 minutes observation time were taken at every point for the GPS, while canopy heights were being measured. A reference receiver was placed near the test field or at the center of canopy gaps. In all observing sessions the GDOP value varied between 3 to 6 and the SNR values for almost all satellites at their maximum. Reduction and analysis of GPS measurements were carried out using the Leica Geo Office software. The coordinates were use to derive data sets to validate maps of tree species generated from AISA Eagle and Hawk hyperspectral imagery and maps for canopy height generated from the DTM and LiDAR first return data. The tree species and canopy height maps were then used as spatial inputs for the modelling work.

MODELLING

The FORGAP-BD model was written in the dynamic script modelling language PcRaster and it comprises two sub-modules, radiation and soil water balance. The radiation sub-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 soil water balance sub-module calculates the soil moisture content at 5cm depth both within gaps and beneath the forest canopy. The model was driven by a set of spatial inputs derived from the airborne remotely sensed data: canopy extinction coefficient (derived from tree species maps), leaf area index (using spectral indices), canopy height (from DTM and LiDAR first return), gap distribution (extracted from canopy height map). The DTM and meteorological data from a nearby weather station were the other inputs.

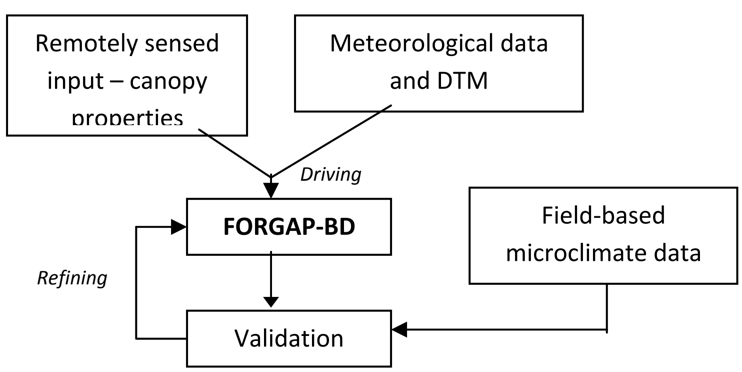

Figure 2. Methodological flowchart the integration of remotely sensed and meteorological data into FORGAP-BD and validation of the model.

INTERPRETATION TO DATE AND PRELIMINARY FINDINGS

GPS Ground Control Points

A total of four(4) GCPs were established using GPS System 500 and post processed using Leica Geo Office software. All the GCPs were then used as local survey control points in the geometrical correction of the NERC ARSF imagery, measure tree locations and also to validate the DTM generated using OS data. The list of coordinates of ground control points in WGS84 are shown in Table 1.

Table 1. Descriptions of OS base station and ground control points in WGS84 established at the vicinity of Eaves Wood using minimally constrained network adjustment.

Station Name	X_{WGS84} (m)	Y_{WGS84} (m)	Z_{WGS84} (m)	Description
AMBL	3713093.8659	-192301.8652	5165094.9892	OS GPS Base Station
GCP1	3736030.8642	-183530.3017	5148894.0724	Ground control point
GCP2	3736853.0868	-183504.7686	5148310.1291	Ground control point
GCP3	3735004.6326	-183543.5444	5149641.5126	Ground control point
GCP4	3735817.6088	-184881.1186	5149054.6898	Ground control point

Validation of OS Digital Terrain Model and LiDAR-derived Canopy Height Model

An accuracy assessment using 90 ground-based GPS control points revealed a root mean squared error (RMSE) of 0.48 m for the OS DTM. The CHM was calibrated using ground-based estimates of tree height, to account for the underestimation of tree height in LiDAR data caused by propagation of laser pulses into the canopy (Gaveau and Hill, 2003). The final CHM had an RMSE of 1.54 m. Canopy gaps were delineated by applying a threshold to the canopy height model.

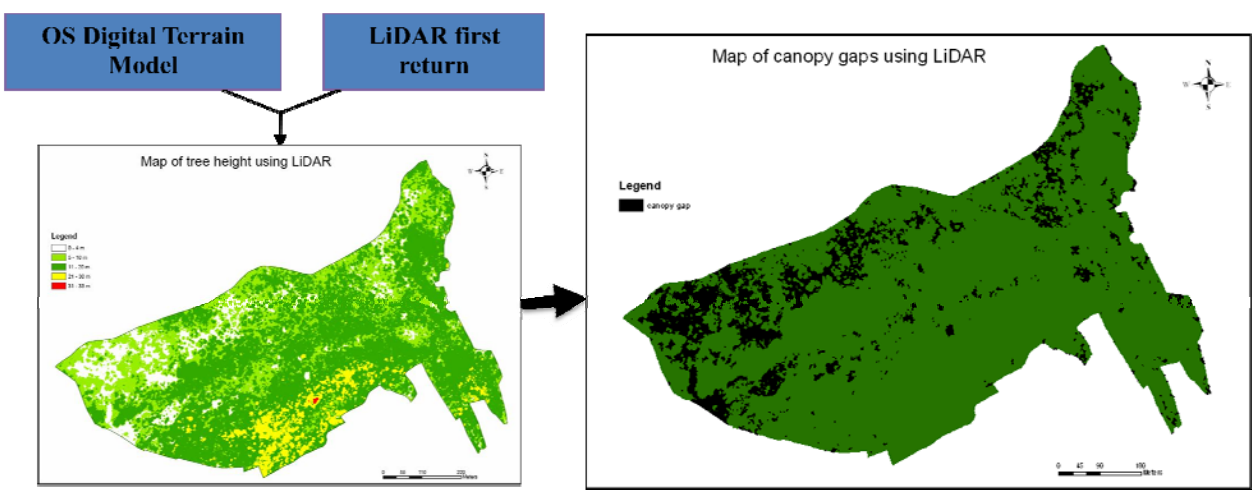

Figure 3 : Derivation of tree canopy height model and gap map.

Classification of tree species using hyperspectral imagery

Part of the tree species data collected using GPS (Figure 4) were used as training data in the supervised classification of hyperspectral imagery using a maximum likelihood decision rule in Erdas Imagine 9.1. This generated a map of dominant tree species (oak, beech) and other sub-dominant species (birch, yew, hazel, pine). The remainder of the GPS field data was used to validate this map which produced an assessed overall accuracy of 75% (Kappa = 0.67) (Figure 5).

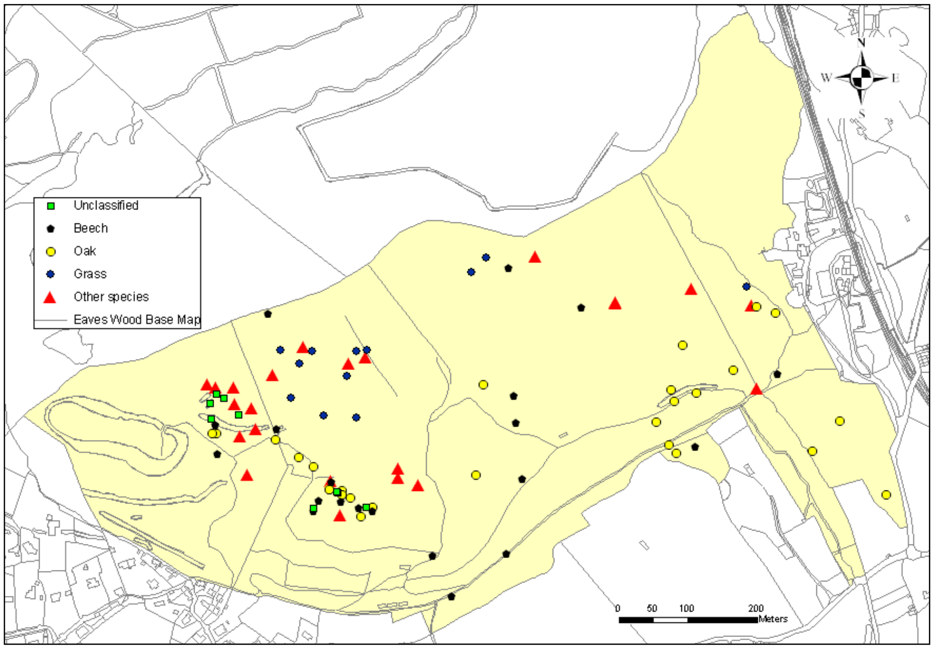

Figure 4. Sampling points derived using GPS for tree species classification

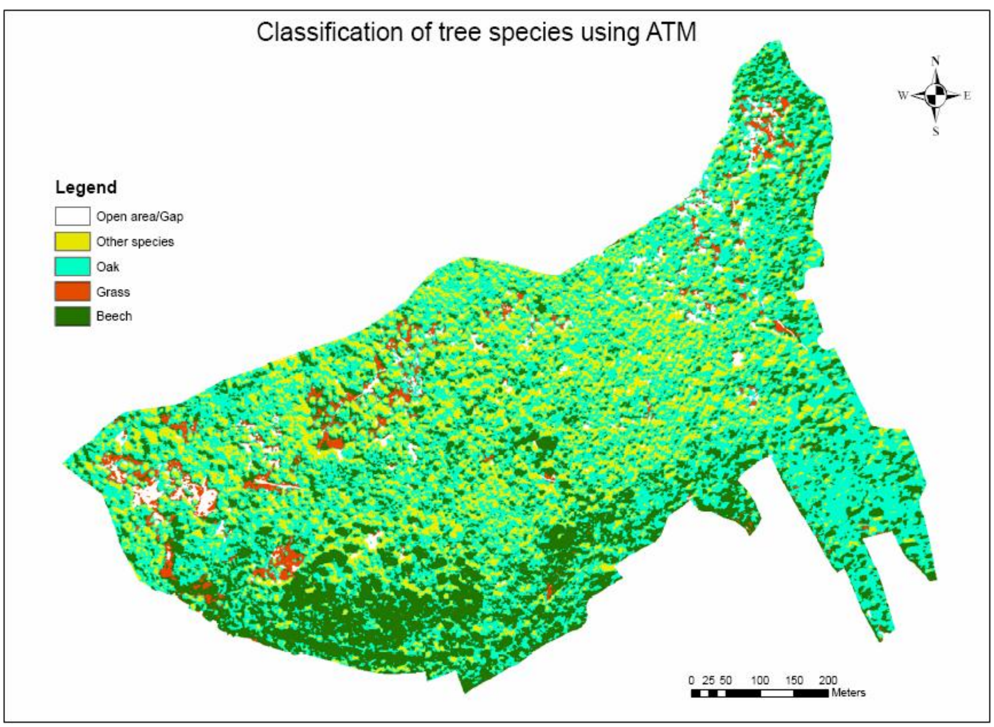

Figure 5. Map of tree species based on classified hyperspectral data

CONCLUSION AND RECOMMENDATIONS

The accuracy canopy and gap properties extracted from NERC ARSF remotely-sensed data is critical for studying gap microclimates using a combined remote sensing and numerical modelling approach. The use of GPS techniques has provided a basis of training extraction techniques and validating the spatial outputs from remote sensing before they are used in the microclimate model. The overall accuracy of the final DTM and maps of tree species and height were acceptable for modelling the microclimate in gaps and beneath surrounding canopy. Publications have been written and are in preparation pertaining to the work at the field site where NERC GEF equipment were deployed (see below) and other publications, based on the approach developed at this site, are being generated.

References

Witter, J.D. and Lyone, J.G. 2001. Differential GPS geometric rectification of fine resolution aircraft scanner data. *Journal of Surveying Engineering* 127(2), pp. 52-58.

Project outputs

PhD:

Z. Latif (2010) *Modelling microclimates in broadleaved deciduous forests using remotely-sensed data.* Unpublished PhD thesis, Lancaster University.

Conference papers:

Abd Latif, Z. & Blackburn, G. A. (2010) Extracting gap and canopy properties using LiDAR and multispectral data for forest microclimate modelling. *6th International Colloquium on Signal Processing & Its Applications. Malacca, Malaysia, 21-23 May 2010.*

Abd Latif, Z. & Blackburn, G. A. (2009) Driving a forest microclimate model using gap and canopy properties derived from LiDAR and multispectral data. *RSPSoc2009, "New Dimensions in Earth Observation", University of Leicester, 8-11th September 2009.*

Abd Latif, Z. & Blackburn, G. A. (2009) Extraction of gap and canopy properties derived from LiDAR and multispectral imagery for forest microclimate modeling. *33rd International Symposium on Remote Sensing of Environment. Stressa, Italy, 4-8 May 2009.*

Journal paper:

Abd Latif, Z. & BLACKBURN, G. A. (in prep) A spatially-explicit microclimate model for broadleaved deciduous forest driven by remotely-sensed inputs. *Ecological Modelling.*