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Sensitivity of modelled actual evapotranspiration to canopy characteristics within the Western Boreal Plain, Alberta

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Abstract In recent years, the Western Boreal Plain (WBP) of northern Alberta has undergone intense anthropogenic disturbance via oil and gas extraction, and silvicultural activities. The extent to which changes in land cover types/characteristics affect estimates of actual evapotranspiration (AET) is currently unknown. This study examines the sensitivity of AET (Penman-Monteith variant) to variability in canopy structural and ground surface characteristics at eight sites and three land cover types on a single cloud-free day in July, 2008.

Key words boreal, evapotranspiration, remote sensing, LiDAR, vegetation structure

INTRODUCTION

The climatology of the Western Boreal Plain (WBP) of northern Alberta is characterized by prolonged periods of drought with infrequent wet years (Petrone *et al.* 2007). During most years, potential evapotranspiration (PET) exceeds precipitation (P) (Devito *et al.* 2005). Therefore, future changes in climate, especially P will likely alter actual evapotranspiration (AET) within this complex mosaic of upland aspen dominated mixedwood forests, peatlands, and ponds. AET is the dominant hydrologic flux in this environment (Marshall *et al.* 1999), and any changes in AET will affect CO_2 exchanges and the local water balance. This is especially important in areas where land cover types have been disturbed by anthropogenic (e.g. oil and gas exploration and extraction, or forest harvesting) activities.

This study examines the sensitivity of AET to variability in canopy structural and ground surface characteristics at eight sites on a single cloud-free day in July (July 10, 2008). Continuous, energy balance meteorological data from each site, used as inputs into the ET model, were installed within four peatland ecosystems, two regenerating upland mixedwood forests and two mature upland mixedwood forests. Vegetation and topographic metrics used to spatially model ET were derived from airborne Light Detection and Ranging (LiDAR). The objectives are: 1) classify tower site representation within a subset of the larger basin; 2) quantify differences in ET between sites; and 3) determine the sensitivity of ET to variable vegetation structure. This study provides a rationale for using vegetation structural information within ET models.

METHODOLOGY

Study Area

The site is located within the Utikuma Regional Study Area (URSA), approximately 370 km north of Edmonton, Alberta, Canada ($56^{o}4'$N, $115^{o}28'$W) (Figure 1). Average air temperatures range from between -14.6 to 15.6^{o}C, and average annual PET (517 mm) exceeds P (481mm) by 36 mm (Bothe and Abraham, 1993; Environment Canada, 2003). This creates a water deficit during most years, with 50% to 60% of precipitation occurring between June to August, resulting in rapid growth of vegetation and maximum ET (Brown *et al.*, 2010).

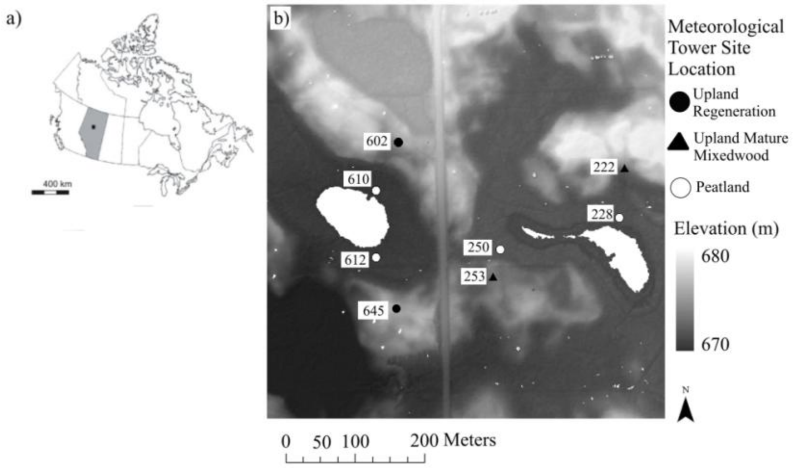

Figure 1. a) Location of the URSA study area in Alberta, Canada; b) Placement of energy balance meteorological towers within upland regeneration, upland mature mixedwood, and peatland, landcover types (towers referred to by number). Background map is a subset DEM of a larger area (not shown).

Data Collection

To examine the influence of canopy structure on AET, energy balance meteorological towers were installed at the start of the growing season 2008 (DOY 91) and ran continuously until DOY 288. Air temperature (T_{air}, ^{o}C), relative humidity (RH, %) (HOBO Onset Pro Temp/RH, Hoskin Scientific, Vancouver, Canada), above and below canopy net radiation (Q*, Wm^{-2}) (NRLite, Kipp and Zonen, The Netherlands), soil temperature profiles (T_{soil}, ^{o}C) at 0.10, 0.25, 0.5, and 1 m depths (Omega copper-constantin, Campbell Scientific Inc, Logan, Utah, USA), average soil moisture (θ, m^3 m^{-3}) (CS616, Campbell Scientific Inc, Utah, USA), and wind speed and direction (m s^{-1}, degrees) (model 05013-10 Wind Monitor, R.M. Young, Michigan, U.S.A) were continuously measured at each site. Ground heat flux was determined using the calorimetric method based on the T_{soil} profile and heat capacity at each layer (Petrone *et al.* 2006). Half hourly or hourly average measurements were made at heights of 3.2 m (peatland), 2.5 m (regenerating upland), and 18 m (above canopy, mature upland mixedwood) (Figure 1).

LiDAR data were collected at the URSA for Alberta Sustainable Resource Development on September 20, 2008 using an Optech Inc. (Toronto, Ontario) ALTM 3100EA operated at a flying height of 1400 m above ground level, a pulse repetition frequency (PRF) of 50 kHz, and a scan angle of ±25^{o}. 50% overlap of scan lines was adopted in order to reduce laser 'shadowing' by canopies and to ensure sampling of both sides of trees. LiDAR data were classified and processed in TerraScan (Terrasolid, Finland) and output into ground and non-ground classes, after removal of outliers. Numerous products were created and used within the AET model and for site classification within the larger basin. These included: digital elevation model (DEM, m), digital surface model of the mean maximum height (DSM, m), a canopy height model of the mean maximum height (CHM, m), uplands and lowlands determined from the DEM residuals of a low-pass average filter with resolution approximating the narrowest part of uplands (100 m x 100 m), zero plane displacement (*d*, m), fractional canopy cover (%), effective leaf area index (LAI_e, m^2 m^{-2}), aerodynamic resistance (r_a, s m^{-1}), bulk surface resistance (r_s, s m^{-1}) roughness length governing momentum ($z0_m$, m), and roughness length governing heat and vapour ($z0_h$, m).

Evapotranspiration Model

The ET model used in this study is a Penman-Monteith variant developed for agricultural crops by the Food and Agricultural Organisation of the United States (known as the "FAO Penman-

Monteith") (Allen *et al.* 1998). This model is physically-based and incorporates meteorological, bio-physical, and vegetation structure variables commonly either measured or modelled.

RESULTS AND DISCUSSION

Tower Site Representation of AET Estimates

To examine representativeness of energy balance towers and AET within the wider basin, a Boolean classification of canopy structural and topographic characteristics found within a 5 m radius of each of the energy balance meteorological towers (Table 1) was performed over a larger subset of the basin (Figure 2).

Table 1: Ecosystem characteristics (mean, (standard deviation)) found within 5 m of energy balance towers. P = peatland and U = upland mixedwood.

Site Name	Canopy Height (m)	Canopy fractional cover (% × 100)	Elevation (m)	Maximum surface height (DSM) (m)	Area of upland: low-land (ratio)	Percent of total subset area described (%)*
P228	3.33 (0.98)	0.60 (0.08)	672.46 (0.06)	675.76 (0.65)	0:1	7
P250	4.19 (1.98)	0.46(0.10)	672.77 (0.08)	677.1 (1.81)	37:63	14
P610	4.86 (1.66)	0.53 (0.15)	671.1 (0.09)	675.96 (1.67)	0:1	13
P612	1.4 (0.46)	0.36 (0.07)	671.39 (0.06)	673.42 (0.74)	0:1	3
U222	13.82 (0.59)	0.49 (0.06)	674.4 (0.69)	689.20 (1.59)	89:11	2
U253	13.37 (0.94)	0.68 (0.04)	674.20 (0.12)	687.01 (1.50)	1:0	4
U602 (regen.)	0.68 (0.30)	0.18 (0.07)	675.89 (0.54)	676.62 (0.60)	21:4	0.6
U645 (regen.)	0.3 (0.15)	0.17 (0.18)	673.46 (0.47)	674.53 (0.75)	61:39	9

*Percent of total area per landcover type often describes similar vegetation structural and topographic characteristics. Therefore, some overlapping characteristics exist between site types.

Greatest canopy heights occur in mature upland mixedwood forest (U222 and U253), whereas shortest vegetation occurs in peatlands and within regenerating upland sites (U602, U645, P612). Upland mature mixedwood sites typically have the greatest fractional canopy cover, whereas recently harvested (regenerating uplands) have the least (Table 1). Peatland ecosystems are primarily located within low lying parts of the study area, and have the lowest elevations when compared with upland tower sites. The structural and topographic variability accounted for by towers within the larger study area is best represented by peatlands, followed by upland regeneration. The least represented landcover type is upland mature mixedwood (Figure 2a). Limited representation of mature mixedwood forests using the Boolean classification method may have been biased by the small search radius of canopy and topographical characteristics used. For example, a 5 m search radius may have been too small to include a statistically significant number of mature trees.

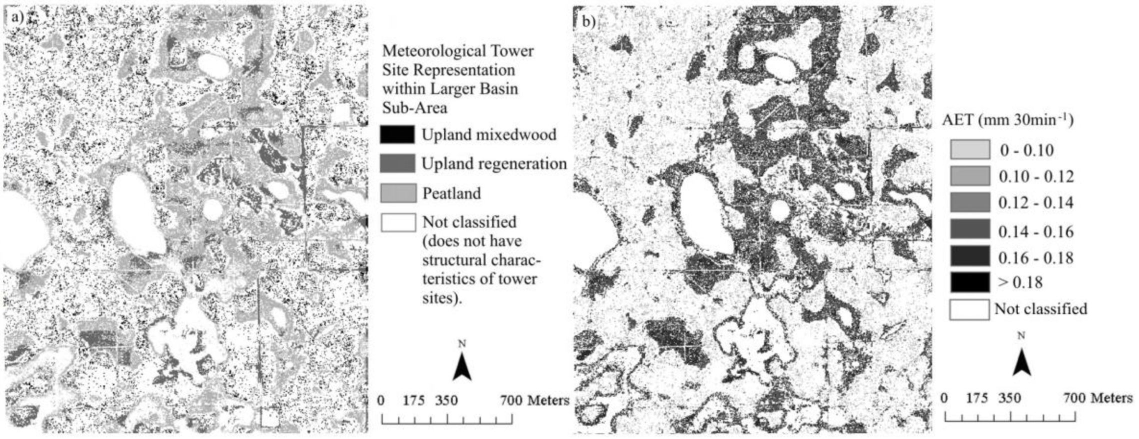

Figure 2a) Boolean classification of areas represented by meteorological towers; b) AET (mm $30min^{-1}$) estimated for site types based on canopy structure and topographic characteristics within a 5 m radius of towers.

ET Differences Between Sites

Average differences in AET between sites ranged from between 4.55 mm day^{-1} (U222) to 8.56 mm day^{-1} (U645), with greatest estimated ET occurring at peatland sites (average = 7.61 mm day^{-1}, standard deviation = 0.91 mm day^{-1}), and lowest ET occurring within mature upland sites with high LAI$_e$ (average = 4.58 mm day^{-1}, standard deviation = 0.04 mm 30 day^{-1}) (Figure 2b). Greatest average difference in ET between sites on this day (July 10, 2008) is 39%.

Sensitivity of ET to Variable Vegetation Structure

AET modelled for individual energy balance sites varied as a result of canopy structure and the amount of Q* incident on foliage and the ground surface. Brown *et al.* (2010) found that vegetation type and structure had a significant influence on peatland ET, and Stagnitti *et al.* (1989) suggest that Q* had the greatest influence on annual evaporative demand within arid ecosystems. Therefore, canopy structure will have a strong influence on evaporative demand, especially with anthropogenic changes to landcover types (Petrone *et al.* 2007). In this study, LAI$_e$ was significantly related to below canopy Q* ($r^2 = 0.90$, $p < 0.001$). ET increased with decreases in vegetation biomass, canopy height (r^2=0.52) and LAI$_e$ (r^2=0.22), although relationships were weak due to averaging within 5m radius of towers (often representative of a wide range of canopy structural and topographic characteristics). Improvements should consider all ranges of canopy characteristics within close proximity (e.g. 5 m radius) of energy balance towers. Landcover changes or disturbance (e.g. forest harvesting) could lead to increases in ET by 4% when comparing regenerating upland forests to mature upland mixedwood. Similar findings were also discussed in Petrone *et al.* (2007), whereby removal of a nearby forest was expected to increase pond ET at URSA.

CONCLUSIONS

Inclusion of canopy and topographic structure within evapotranspiration models provide insight into how ET may vary within a variety of landcover types. This is especially important when examining possible water balance scenarios following natural and/or anthropogenic disturbance. Use of remote sensing data, especially high resolution airborne LiDAR allows for classification and assessment of site representation within the larger watershed.

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