Sensitivity of modelled 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 evapotranspiration (ET) is currently unknown. This study examines the sensitivity of ET (Penman-Monteith variant) to variability in canopy structural and ground surface characteristics at eight sites and three land-cover types (mature upland mixedwood, regenerating upland mixedwood, and peatland) during the growing season in 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 evapotranspiration (ET) within this complex mosaic of upland aspen dominated mixedwood forests, peatlands, and ponds. ET is the dominant hydrologic flux in this environment (Marshall *et al.*, 1999), and any changes in ET 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 ET to variability in canopy structural and ground surface characteristics at eight sites, daily from 1 June to 31 August 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°4′N, 115°28′W) (Fig. 1). Average air temperatures range between –14.6 to 15.6°C, and average annual PET (517 mm) exceeds *P* (481 mm) by 36 mm (Bothe & Abraham, 1993; Environment Canada, 2005). 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).

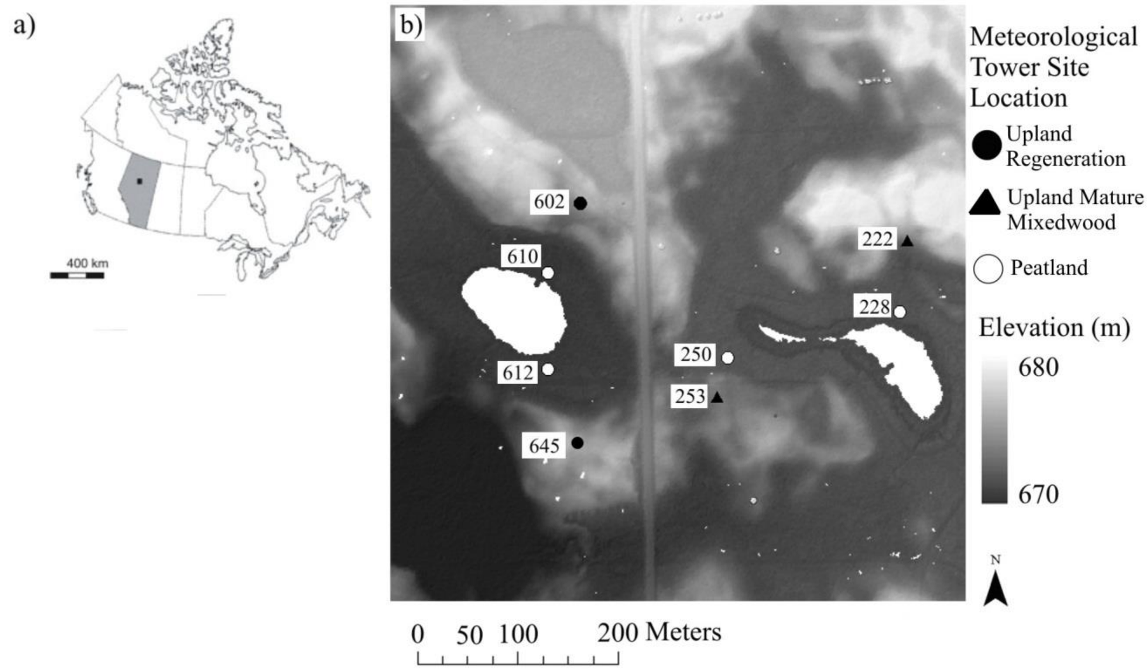

Fig. 1 (a) Location of the URSA study area in Alberta, Canada; (b) DEM showing placement of energy balance meteorological towers within upland regeneration, upland mature mixedwood, and peatland, land-cover types (towers referred to by number). White regions in the DEM represent missing data where laser pulses were absorbed or reflected away in open water areas.

Data collection

To examine the influence of canopy structure on ET, 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}, °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}, °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, USA) 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.*, 2007). 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) (Fig. 1).

LiDAR data were collected at the URSA for Alberta Sustainable Resource Development on 20 September 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°. A 50% overlap of scan lines was adopted in order to reduce laser “shadowing” by canopies and to ensure sampling of both sides of the 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 ET model and for site classification within the larger basin. These included: a digital elevation model (DEM, m), a 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 × 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 ET estimates

To examine the representativeness of energy balance towers and ET within the wider basin, a Boolean classification of canopy structural and topographic characteristics found within the homogeneous area representing the site (100 m radius, upland mixedwood, 20 m radius upland regeneration, 5 m radius peatland) of each of the energy balance meteorological towers (Table 1) was performed over a larger subset of the basin (Fig. 2).

The greatest canopy heights occur in mature upland mixedwood forests (U222 and U253), whereas the 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 via towers within the larger study area is best represented by peatlands, followed by upland regeneration. The least represented land-cover type is upland mature mixedwood (Fig. 2(a)).

Table 1 Ecosystem characteristics (mean, (standard deviation)) of energy balance tower sites. P = peatland and U = upland mixedwood.

Site name	Canopy height (m)	Canopy fractional cover (% × 100)	Elevation (m)	Area of upland: low-land (ratio)	% total subset area described
P228	3.33 (0.98)	0.60 (0.08)	672.46 (0.06)	0:1	52% peatlands
P250	4.19 (1.98)	0.46(0.10)	672.77 (0.08)	37:63	
P610	4.86 (1.66)	0.53 (0.15)	671.1 (0.09)	0:1	
P612	1.4 (0.46)	0.36 (0.07)	671.39 (0.06)	0:1	
U222	13.82 (0.59)	0.49 (0.06)	674.4 (0.69)	89:11	34% upland
U253	13.37 (0.94)	0.68 (0.04)	674.20 (0.12)	1:0	mixedwood
U602 (regen.)	0.68 (0.30)	0.18 (0.07)	675.89 (0.54)	21:4	2% upland
U645 (regen.)	0.3 (0.15)	0.17 (0.18)	673.46 (0.47)	61:39	regeneration

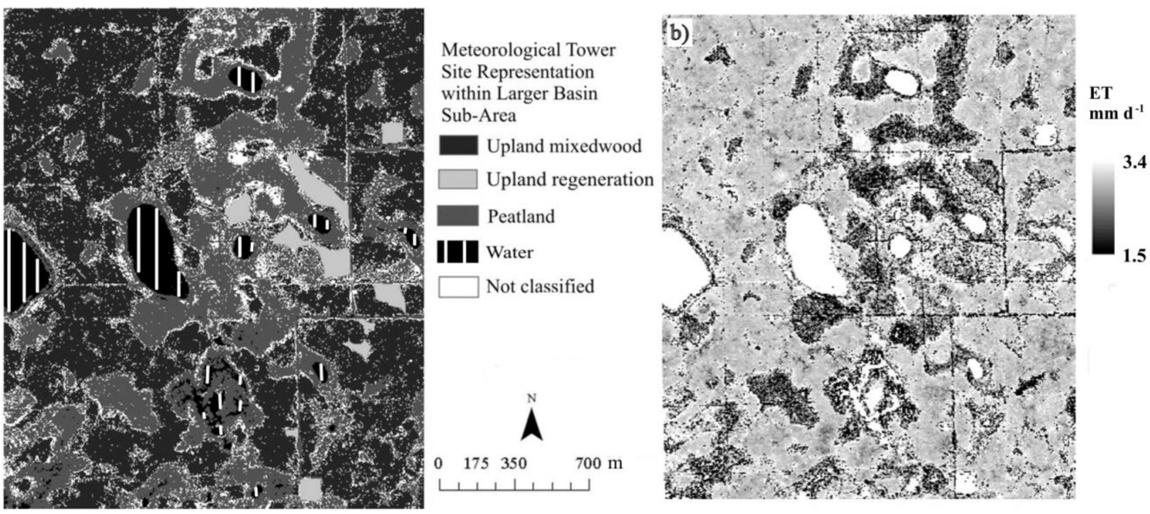

Fig. 2 (a) Boolean classification of areas represented by meteorological towers; (b) Average ET (mm d^{-1}) estimated for site types based on canopy structure and topographic characteristics.

ET differences between sites

Average growing season (JJA) differences in ET between sites ranged from between 2.1 mm d^{-1} (U602) to 3.7 mm d^{-1} (U253), with greatest estimated ET occurring at upland aspen and peatland sites (average = 3.3 mm d^{-1}, standard deviation (stdev.) = 1.8 mm d^{-1}), and lowest ET occurring within upland regeneration (average = 2.5 mm d^{-1}, stdev. = 1.7 mm d^{-1}) (Fig. 2(b)).

Sensitivity of ET to variable vegetation structure

ET 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 land-cover 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 increased canopy height (r^2 = 0.46), LAI_e (r^2 = 0.56) and elevation (r^2 = 0.22). Based on modelled differences in ET between upland mature mixed wood and immature regeneration stands, land-cover changes due to harvesting could lead to decreases in ET of >10%.

CONCLUSIONS

Inclusion of canopy and topographic structure within evapotranspiration models provide insight into how ET may vary within a variety of land-cover 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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