Representation of Forest Cover in a Physically Based Snowmelt Model, Phase II

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EXTENDED ABSTRACT

The architectural properties of a forest are known to significantly modify meteorological forcing of snowcover (Hardy and Albert 1995; Metcalf and Buttle 1995; Davis et al. 1997; Hardy et al. 1997; Hardy et al. 1998; Pomeroy et al. 1998a, b; Metcalf and Buttle 1998; Koivusalo and Heikinheimo 1999). Current numerical snow models utilize a wide range of vegetation representations for application to particular biomes. Most do not explicitly represent the combined effects of the canopy on processes of mass (Lundberg and Halldin 1994, Lundberg et al. 1998, Hedström and Pomeroy 1998) and energy transfer beneath the canopy. The results herein summarize the major findings of Hellström (2000).

Phase I (Hellström 1999) of this project utilized hourly meteorological measurements from deciduous, coniferous, and open test sites at the University of Michigan Biological Station (UMBS, 45°34′ N, 84°40′ W, 238 m), Pellston, Michigan, to develop process-based modules of sub-canopy longwave irradiance, solar irradiance, wind speed, and precipitation. All modules were designed to operate using average tree height, vegetation area index and canopy openness parameters that are easily measured from ground-based (LI-COR 1992) and/or interpreted from remote sensing imagery (Metcalf and Buttle 1998). Statistical and qualitative comparisons of measured and modeled above- and below-canopy forcing variables suggested realistic estimated sub-canopy forcing by the four modules (Table 1).

Table 1. Ratio of below-to-above canopy seasonal mean of forcing variables. Index of agreement (d_{below}) (Willmott 1981) between predicted and observed below-canopy predictions and observations. Perfect agreement is theoretically d_{below} = 1. Below canopy measurements were not measured for designations N/A.

Forcing Variable		Deciduous		Coniferous	
Forest		below/above	d_{below}	below/above	d_{below}
Solar Irradiance		0.38	0.97	0.13	0.94
Longwave Irradiance		1.06	N/A	1.13	N/A
Wind Speed		0.16	0.84	0.08	0.80
Precipitation	snowfall	0.82	N/A	0.73	N/A
	rainfall	0.72	N/A	0.63	N/A

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In addition, the results of Phase I suggest:

- The transmittance for solar radiation is about 3 times greater for the deciduous canopy, and mean values are within 10 % of those measured.
- Sub-canopy wind speed remained below 2.5 m s^{-1} for the deciduous and below 1.5 m s^{-1} for the coniferous canopy; variability was high, but mean values are within 10% of those measured.
- The longwave radiation module plausibly estimated magnitudes beneath the canopy, with about twice as much enhancement of irradiance below the coniferous forest.
- Although the interception model was not verified, qualitative analysis of simulated sub-canopy snowfall suggest plausibility with visual observations of water drip and snow slip from the canopy.

During Phase II, the four modules and a more realistic atmospheric stability scheme (based on Monin-Obukhov theory) were included independently and in combination to produce modified versions of the Utah Energy Balance (UEB) snow model (Tarboton and Luce, 1996). A statistical comparison (Willmott, 1981) between observed and predicted snow depth suggested that the combination of all four modules and replacement of the stability scheme improved snow depth simulations beneath the coniferous site and at an open location. The substantial reductions in wind speed observed and modeled beneath each canopy did not appear to substantially influence snow depth, particularly with low air temperatures. The effects of wind speed were more significant with warm air advection during the latter part of the final melt period. Precipitation interception is important during the early half of the snowcover season, when lake-effect snowfall contributes to the majority of snowpack accumulation.

A SWE depth (W_s) sensitivity analysis was applied to 8 versions of the UEB model (Table 2). Note that UEBSTAB provides the base of comparison for UEBK, UEBL, UEBU and UEBP. The major findings of a qualitative analysis (by graphical interpretation) of simulated W_s for inclusion of the four independent modules are summarized below:

UEBK vs. UEBSTAB:	Reduction of solar radiation decreased snowpack ablation throughout the season
UEBL vs. UEBSTAB:	Increased longwave radiation increased snowpack ablation throughout the season
UEBU vs. UEBSTAB:	The effects of wind speed were more significant with warm air advection during the latter part of the final melt period.
UEBP vs. UEBSTAB:	Precipitation interception was important during the early half of the snowcover season, when lake-effect snowfall contributed to the majority of snowpack accumulation.

The UEB, UEBFC, UEBSTAB, and UEBMOD models were verified by measurements of W_s at each of the sites throughout the snowcover season: 112 observations at the deciduous site and 78 at the coniferous site (Hellström, 2000). The cases below compare observations to model simulations of snow depth:

UEB:	For the open site, W_s is greatly underestimated and the timing of final melt was premature.
UEBFC:	Comparison of UEBFC with UEBMOD shows that W_s is better estimated by the UEBFC model for the deciduous canopy, but better estimated by UEBMOD for the coniferous canopy.
UEBSTAB:	For the open site, W_s is underestimated during the early half of the season and overestimated during the latter half; the timing of final melt was within one day of that observed.
UEBMOD:	For both canopies W_s is underestimated during early half of season, and better estimated during latter half. The timing of final melt is within one day of that observed at both sites.

Table 2. Different sub-model combinations for the original and modified versions of the UEB snow model. * no forest canopy and original UEB model parameterizations for stability, radiaton processes, wind, and no precipitation interception.

Models	Parameters	UEB	UEBFC	UEBSTAB	UEBK	UEBL	UEBU	UEBP	UEBMOD
Original	*	X	X						
	Parameterization using FC		X						
Modified	M-O stability scheme			X	X	X	X	X	X
	Solar below canopy				X				X
	Longwave below canopy					X			X
	Wind below canopy						X		X
	Precipitation interception							X	X

The results generally suggest improvement of snow depth simulation beneath the forest canopies at UMBS, with one noteworthy exception. The original UEBFC model performed better than the fully modified version, but only for the deciduous site. Considering the poor performance of the same model for an open site (UEB), it is plausible that the FC parameter used by the original model is overcompensating for deficiencies found in the open case, which may not be realistic for other types of forest, such as the coniferous site in this project. Hence, simulations of W_s by the UEB model were highly inconsistent and site specific.

In conclusion, this project has shown that snow depth is sensitive to forest cover modification of solar radiation, longwave radiation, wind speed, and precipitation, particularly in a coniferous forest. Opposing transfers of energy and mass by these four processes are important and tend to moderate meteorological forcing beneath a forest canopy. The fully modified model version

UEBMOD produced acceptable estimations of snow depth for open, deciduous and coniferous forests in Northern Michigan.

There are several significant ways to further contribute to the results presented by this project. Explicit representation of substrate processes such as soil infiltration and changing density of the snowpack should improve early season simulations of W_s and the sensitivity to abrupt melt events. The diffusion theory applied to all models in this project is not quite valid within the canopy space: some consideration of large eddy and advection effects should be introduced into UEBMOD. A synopsis on canopy airflow (Raupach, 1988) provides the motivation for replacing or adjusting K-theory (diffusion theory) for evaluation of turbulent heat fluxes within the canopy. Shaw *et al.* (1988), Raupach (1989a,b), and Leclerc *et al.* (1990) support this argument. Zeng and Takahashi (2000) provide a first order closure scheme that supposedly includes the effects of large eddies on wind flow above and within leafed and defoliaged deciduous canopies. The UEBMOD model needs further testing in different forest biomes under different climate conditions. Finally, the UEBMOD model results should be compared with those of other snow models under the same or very similar environmental conditions.

Incorporated as a distributed snow model, the UEBMOD model could potentially improve modeling of snow depth and meltwater yield in areas with heterogeneous forest cover. Ultimately this model could be used for snow and forest management practices for optimizing hydrological processes on a regional scale.

ACKNOWLEDGEMENTS

A substantial portion of this research was supported by The Graduate Student Alumni Research Award and University Small Grant from The Ohio State University. I wish to thank Dr. John Arnfield for his intellectual support and encouragement. Dr. Peter Curtis, at The Ohio State University, provided access to meteorological data from the AmeriFlux tower at the University of Michigan Biological Station (UMBS). I am grateful to the winter-over staff for permitting deployment of micrometeorological measurement systems on UMBS property, and for providing lodging and access to lab facilities. The AmeriFlux project is supported in part by the U.S. Dept. of Energy (National Institute for Global Environmental Change) and the University of Michigan Biological Station. I thank Dr. Robert Davis, at the Cold Regions Research and Engineering Lab, for loaning the fish-eye camera and LAI-2000 canopy analyzer (LI-COR, 1992). I also wish to thank Dr. Mary Anne Carrol, Department of Atmospheric, Oceanic, and Space Sciences, University of Michigan, for providing access to weather data from the PROPHET tower at UMBS.

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