A Segmentation Approach for Distributing Snow Processes in the Hubbard Brook Experimental Forest, New Hampshire

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ABSTRACT

Two approaches for segmenting the landscape of the Hubbard Brook Experimental Forest in north central New Hampshire, USA (43º56 N, 71.45ºW) into snowpack energy classes for use with snow–soil models are presented. The purpose of the effort was to develop an efficient segmentation scheme, one that would require fewer model runs. Scheme 1 combined slope-aspect classes and required 540 classes to account for forest cover, solar exposure, and elevation. Scheme 2 combined slope factors and forest solar transmittances, reducing the number of required classes to 52. A discussion is included that describes how an optimal segmentation approach depends on the attributes of the drainage basin, snow model, meteorological data, and computing resources, as well as the application or research purpose.

Keywords: snow processes, distributed energy balance, forested watersheds

INTRODUCTION

A variety of schemes can be devised to divide a basin into response units for snow modeling. The optimal scheme depends on the attributes of the drainage basin, snow model, computing resources, available geographic information and meteorological data, and the application or research purpose. This paper describes development of a segmentation scheme for the Hubbard Brook Experimental Forest (HBEF) that accounts for the basin's most significant spatial attributes and how they impact snowfall and the snowpack energy balance. This paper focuses on development of an efficient segmentation scheme. Applications of this segmentation scheme will be reported separately.

HBEF is located in north central New Hampshire, USA (43º56 N, 71.45ºW) near West Thornton in the southern end of the White Mountain National Forest. The USDA Forest Service provides an overview of the watershed physical and biological attributes and spatial geographic data on their Web site (USDA 2004). Geographic data used here included a 30-m digital elevation model (DEM), forest cover, and a soil association map. HBEF is an oblong basin about 8 km east to west and 5 km north to south. The elevation range extends from 1010 m at points along the basin divide to 180 m at the outlet. The terrain is hilly. The forest categories are hardwoods, mixed predominantly hardwoods, mixed predominantly softwoods, and softwoods. The tree species are predominantly northern deciduous hardwoods including sugar maple (*Acer sacharum*), beech (*Fagus grandifoia*), and yellow birch (*Betula allegheniensis*). White ash (*Fraximus americana*) is found at middle and lower elevations. Red spruce (*Picea rubens*), balsam fir (*Abies balsamea*) and

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white birch (*Betula papyrifera var.* cordifolia) occur at the higher elevations and on rock outcrops. Hemlock (*Tsunga canadensis*) is found along the main Hubbard Brook. The soils are Spodosols developed in glacial till, have a sandy loam texture, and include many rocks from small pebbles to large boulders in size. There is a surface layer of partially decomposed forest organic material ranging from 2 to 20 cm in thickness. The soils are excessively to moderately well drained.

METHODS AND RESULTS

Basin and model attribute analyses

The first step was to consider the requirements for the segmentation scheme based on the basin characteristics, spatial and meteorological data availability, and the intended applications. The attributes considered are summarized in Table 1. The scheme will be useful for a range of applications. One application is using the segmentation scheme to generate combined snowpack and soil model solutions to explore the impact of snowpack development and climate change on soil nitrogen cycling in the Hubbard Brook Forest (Groffman 2001). Other efforts are using the scheme on this and similar drainage basins to look at spatial variation in snowmelt rates and snowpack properties.

The attributes with the greatest spatial variation in the HBEF are solar exposure and forest canopy (Table 1). The majority of this effort was; therefore, aimed at segmenting the HBEF landscape to characterize the influence of these dominant variations on the snowpack energy balance. Limited effort was expended in describing the spatiality of soil attributes because soil differentiation was very limited in the available spatial geographic information. The elevation range (800 m) influence on temperature and precipitation was accounted for by using four elevation bands. Snow redistribution was assumed to be negligible for this forested basin.

The source of available meteorological data and the size of the area were primary factors deciding the segmentation structure. HBEF is a small basin. Regional differences in weather from one end of the basin to the other were assumed to be negligible because of the basin's small size. The snowpack processes can be modeled with data from a single meteorological site that is modified for solar exposure, forest canopy, and elevation related changes (lapse rates for temperature and precipitation). The landscape was segmented by classes of combined attributes (forest, solar exposure, elevation). The energy balance of pixels or polygons belonging to a particular class will be driven by the same meteorology no matter where the pixels or polygons occur spatially within the basin. This is in contrast to schemes more appropriate to larger basins where climate gradients may be described on a pixel-by-pixel or polygon-by-polygon basis. Pixel by pixel modeling at the scale of the DEM (30 m) was not required for any of the intended applications and would be unnecessarily computationally intensive.

Distributed energy balance segmentation

The energy balance of a snowpack is expressed as

$$Q_M + Q_V = Q_K + Q_L + Q_E + Q_H + Q_P + Q_G \quad (1)$$

where Q_M = snowmelt
Q_V = change in stored heat
Q_K = solar radiation
Q_L = terrestrial or longwave radiation
Q_E = latent heat transfer
Q_H = sensible heat transfer
Q_P = heat advected by rainwater
Q_G = conduction of ground heat.

Distribution of the energy balance across the landscape was accomplished by modifying the meteorological data that drive the models for each segmentation class. Forest modifications accounted for reduced Q_K due to reduced solar transmittance through canopy, modified Q_L due to the presence of canopy, and modified Q_E and Q_H due to reduced wind speeds in the canopy. The magnitude of the modification depended on the forest type. Solar radiation (Q_K) was modified for slope and aspect dependence due to topography. Air temperature influences many of the energy terms and was assumed to follow a 0.61°C km^{-1} elevation lapse rate. A precipitation lapse rate with elevation was developed from information provided by Dingman (1993). Canopy interception of precipitation was dependent on forest type.

The segmentation scheme for HBEF simply creates a map that directs the modification of meteorology data from that recorded at a meteorological site located in a non-forested environment. The number of classes is equivalent to the number of model runs. Reducing the number of classes reduces the effort. Two schemes that reduced the number of classes by combining basin attributes were considered.

Table I. Attributes for segmentation of Hubbard Brook

	Importance or appropriateness			
	negligible	low	moderate	high
Basin spatial variation				
Solar exposure				x
Variable forest canopy				x
Soil climate		x		
Elevation range		x		
Snow wind redistribution	x			
Regional extent	x			
Meteorological data				
Single site with no modifications	x			
Single or a few sites, with local modifications				x
Regional or mesoscale	x			
Segmentation structure				
Classes				x
Polygon regions		x		
Pixel by pixel		x		

Scheme 1—Slope-aspect

Solar slope factors calculated using methods described in Dingman (1993) illustrate that solar radiation variation is more sensitive to slope on south-facing (Fig. 1a.) and north-facing (not shown) slopes, when compared to east–west facing slopes (Fig. 1b). The solar factor (solar radiation on a slope relative to that on non-sloping ground) variation due to azimuth is more pronounced near the winter solstice (Dec) than near the equinox and even less pronounced toward (May) the summer solstice. A slope-aspect class diagram that allots more detail to north and south-facing slopes than to east- and west-facing slopes was devised (Fig. 2). Scheme 1 combined these 27 slope-aspect classes, five forest classes, four elevation classes, and one soil class. The number of possible classes was 540 (=27×5×4×1).

Note that if slope and aspect were not combined into slope-aspect classes, there could have been five slope classes and 10 azimuth classes, for a total of 50 possible exposure classes (5×10). Further combining with five forest and four elevation classes would have resulted in 2000 possible classes (5×10×5×4).

Scheme 2—Slope factor canopy transmittance combination

Another approach (Scheme 2) was to combine a slope factor map with canopy transmittance. Solar transmittances for each forest type were assumed (for example, softwoods 0.14, mixed predominantly softwoods 0.25, mixed predominantly hardwoods 0.4, hardwoods 0.5, and non-forested 1.0). Monthly slope factor maps were multiplied by the forest transmittances for the forest types as they occurred in the landscape. The combined slope-factor-transmittances are illustrated geographically in Figure 4. Comparing the range of combined slope-factor-transmittances within and between forest types supported the designation of five hardwood classes, three mixed predominantly hardwoods, two mixed predominantly softwoods, one softwood, and two non-forested classes. Modification of the times series of solar radiation was made on a monthly basis. The number of possible classes by this scheme was 52 (13×4).

DISCUSSION AND CONCLUSIONS

Combining by slope-aspect (Scheme 1) and slope-factor-transmittance (Scheme 2) reduced the number of classes in the segmentation schemes. Many software graphics packages are limited to one byte or 256 classes, so methods that reduce the classes to 256 or fewer are advantageous. Scheme 1 economized to 540 classes, and scheme 2 economized to 52 classes. Scheme 2 required the additional effort of developing monthly slope factor maps. A refinement to weekly or daily maps is possible.

A characteristic of Scheme 2 is that while azimuth information was used in defining the slope-factor-transmittance classes, exact azimuth control has been relinquished. North-facing slopes will have lower factors, south-facing higher ones, and east- and west-facing slopes intermediate ones, but the solar radiation time series will be modified by the respective constant factors throughout the day regardless of the changing sun angle. This method will give reasonable representations of the energy balance across the landscape, but not the true ones. A variation of Scheme 2 was considered that segments the slope factor-transmittance classes into East and West, doubling the number of classes to 104. This variation of Scheme 2 could account for asymmetry in solar radiation before and after local noon by treating East and West parts of the landscape separately. A comparison of snow model results obtained using the two schemes and the suggested E–W variation of Scheme 2 is warranted to see if the different treatments of azimuth result in any significant differences in solutions.

ACKNOWLEDGEMENTS

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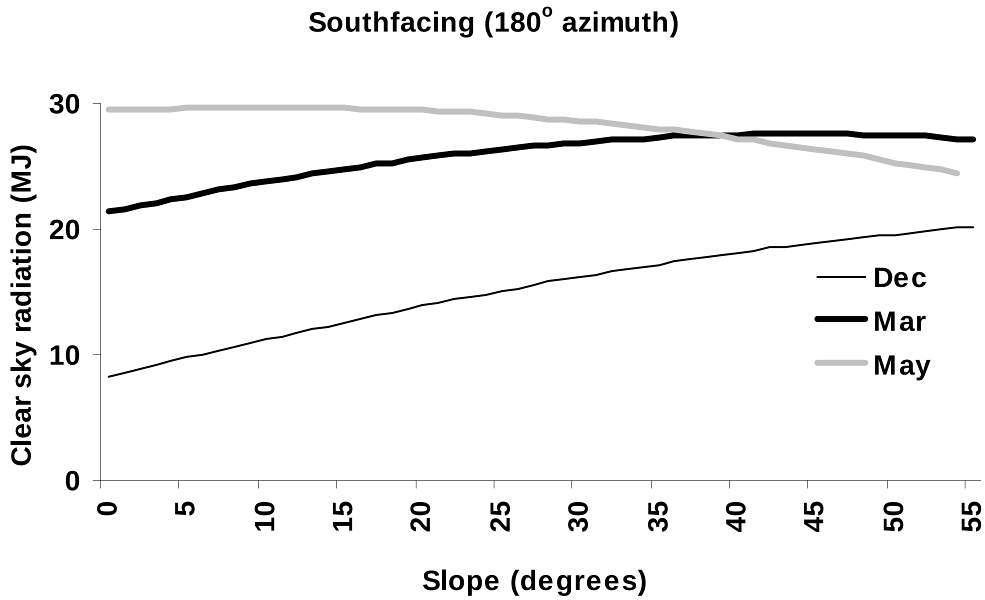
a.



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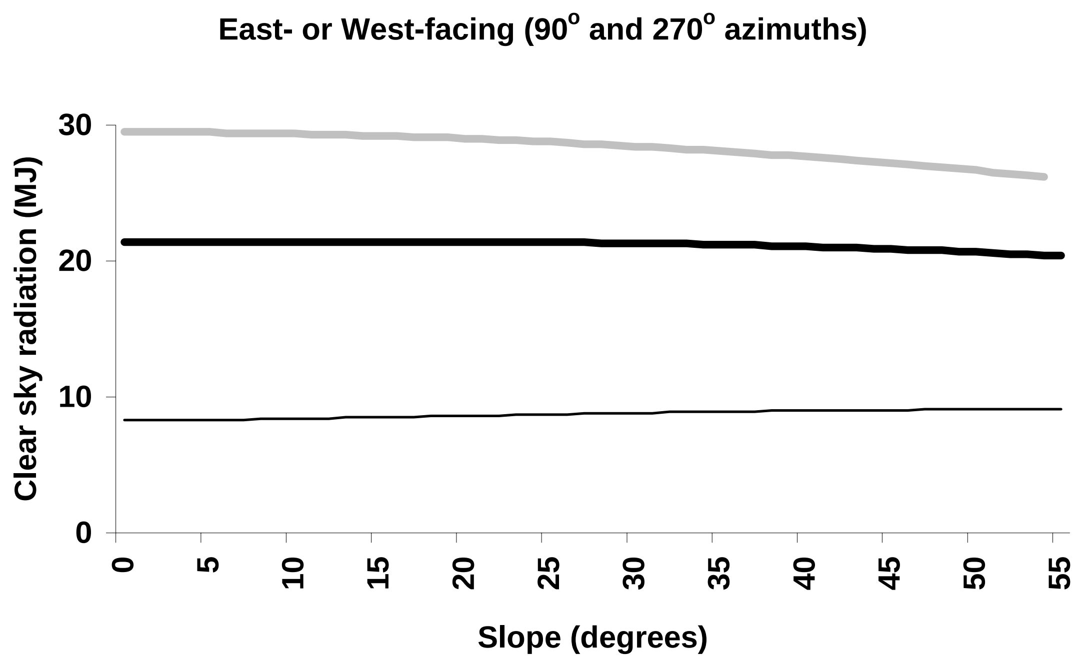
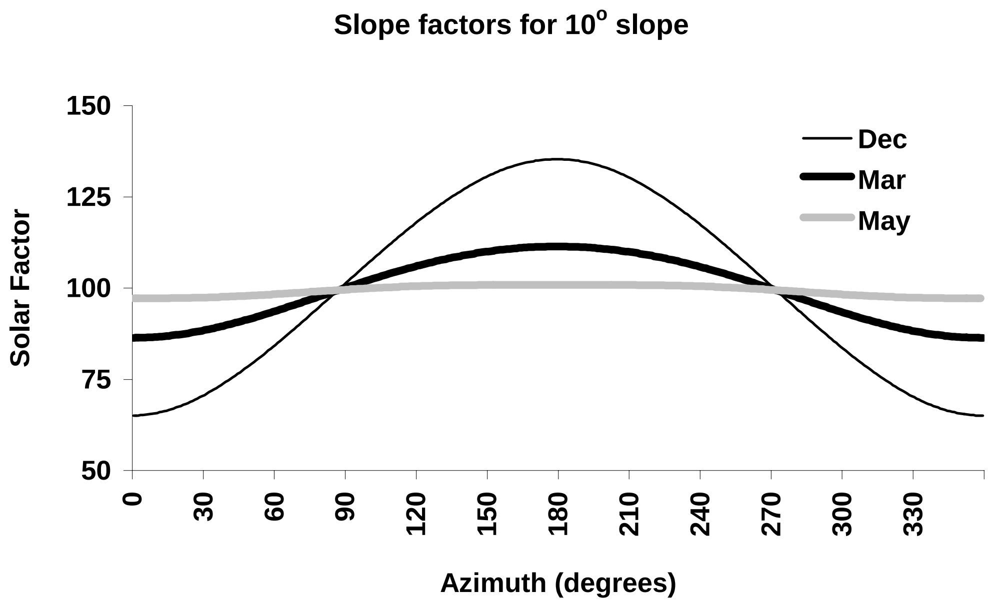


Figure 1. Clear sky radiation dependence on slope for (a) south-facing and (b) east- and west-facing slopes.

a.



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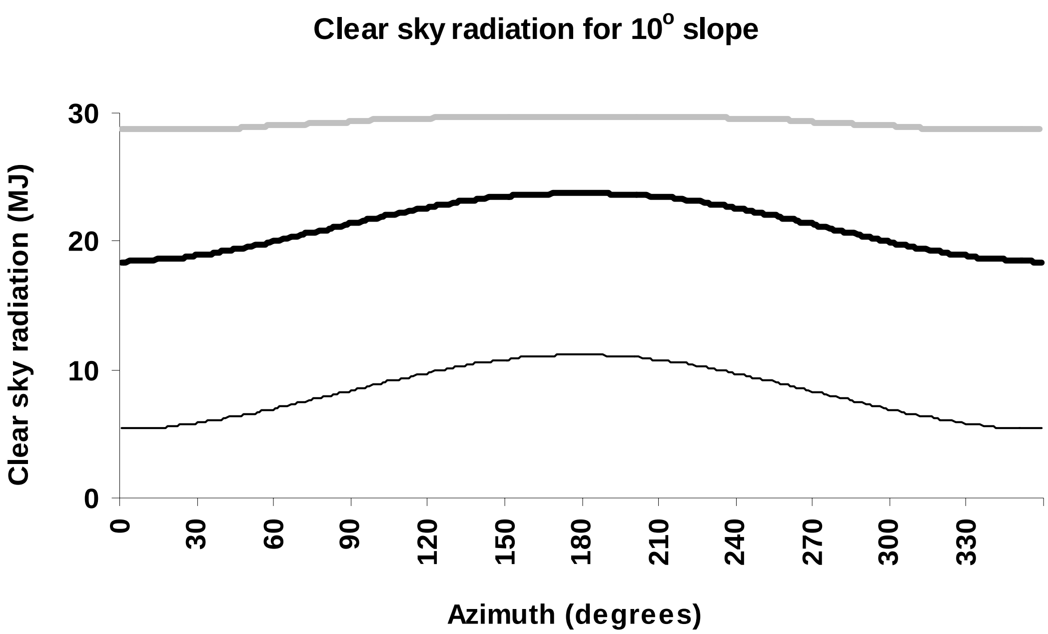

Figure 2. (a) Solar factor and (b) clear sky radiation variation with azimuth (at 10º slopes).

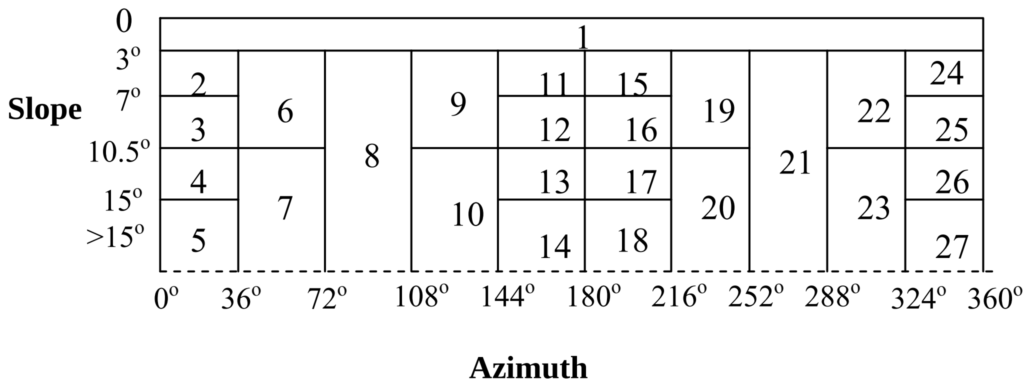

Figure 3. The 27 combined slope-aspect classes of Scheme 1.

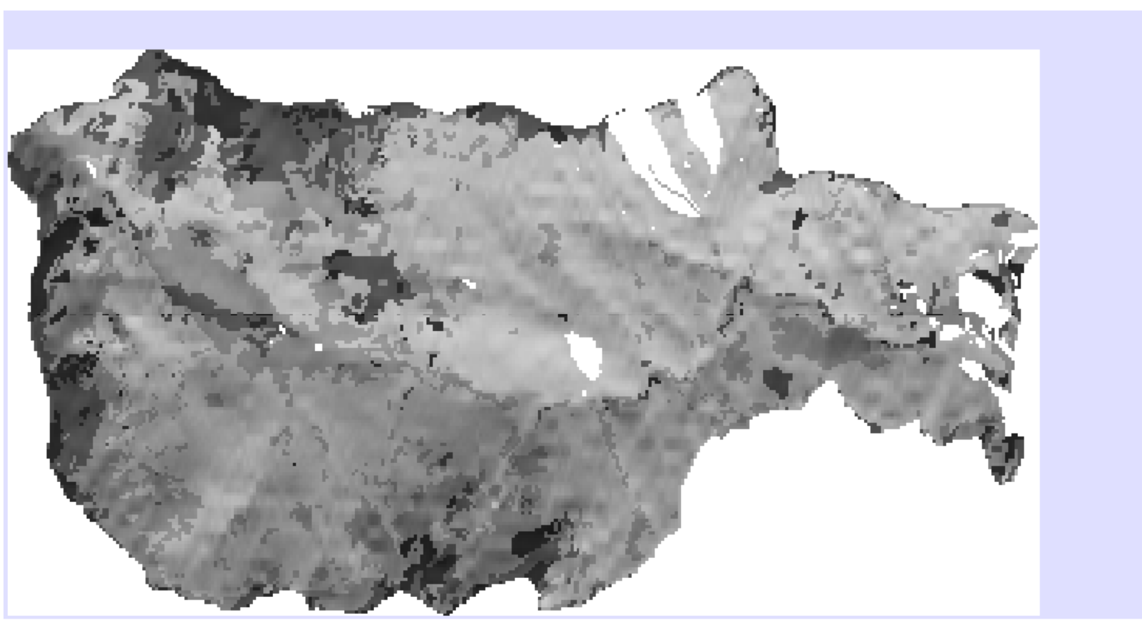

Figure 4. Combined slope factor and transmittance map. The white areas are non-forested, the medium tones correspond primarily to hardwoods (leafless deciduous), and the darkest areas to softwoods (evergreens).