PHYSICAL CONTROLS OF SNOWMELT IN THE HJ ANDREWS EXPERIMENTAL FOREST

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ABSTRACT

The relative importance of snow energy balance (EB) components in rain-on-snow environments is poorly understood. We investigated the snow EB over eight snow seasons (1996-2003) at three meteorological sites in the H.J. Andrews Experimental Forest. We used a physically based snowmelt model (SNOBAL) to quantify EB components at annual, bi-weekly and event timescales. The study period included 20 measurable ROS events. Net radiation flux dominated the EB over the annual timescale. Even during ROS events, net radiation dominated snow EB—turbulent exchanges of sensible and latent heat dominated melt only during periods of high winds. During the largest ROS event in 1996, latent and sensible heat fluxes amounted to 32 % of total flux. In general, ground heat fluxes were high when there was a shallow transient snowpack. Energy balance components during several ROS events varied among three sites, however, net radiation was the dominant driver of melt at each of the sites, even during ROS events.

INTRODUCTION

Snow energy balance (EB) studies in the Pacific Northwest (PNW) have focused largely on rain-on-snow (ROS) events (Berris and Harr, 1987; Marks, 1999). Snowmelt during major ROS events has been shown to be driven by the turbulent energy exchanges of sensible and latent heat. While individual events have been measured and modeled, few studies in the PNW have examined melt components over multiple temporal scales (from multi-year and annual, to biweekly and hourly) to examine how the relative importance of the EB components changes over time. Here, we use a physically based model as a tool to address the following questions over multiple time scales:

1. What are the relative contributions to melt of energy balance components?
2. How do the components of the snow energy balance change over different periods of amortization?
3. How frequently do turbulent exchanges of sensible and latent heat dominate melt in the study area?

METHODS

We investigated the snow energy balance in the H.J. Andrews Experimental Forest (HJA), in the Western Oregon Cascades (Figure 1), revisiting the study area of the U.S.A.C.E. (1956) and Berris and Harr (1987). A physically based snow energy balance model, SNOBAL (Marks, 1998), was used to derive the energy exchanges over an eight-year period. We ran SNOBAL with data from three meteorological stations (Figure 1, Table 1) in the HJA to calculate the EB. Clean snow albedo was modeled according to Wiscombe and Warren (1980). Albedo was then further reduced to account for litter and debris deposition on the snow surface using a simple logarithmic function similar to Garen (2005) and Hardy et al. (2002).

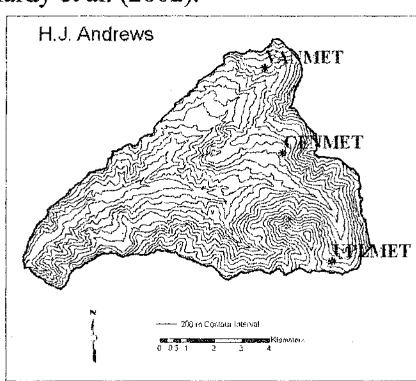

Figure 1. H.J. Andrews Experimental Forest in the Western Oregon Cascades and meteorological stations

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The model was run for eight consecutive water years (1996 to 2003) (Figure 2). Energy balance components were then computed for daily, biweekly, and annual periods. Additional model runs for WY 1996 were completed to further evaluate the albedo reduction model. Linear and square-root albedo reduction models were applied from peak snowpack to melt out. ROS events that occurred at all three sites were evaluated for average EB components during these events.

Table 1. Forcing Parameters for SNOBAL

Forcing Parameter	Net Shortwave	Downwelling Longwave	Air temperatrue	Vapor pressure	Windspeed	Soil temperature
Sensor	Kipp & Zonnen (.28 to 3.0 µm)		Campbell Scientific HMP35C (4.5 m)	Campbell Scientific HMP35C (4.5 m)	RM Young (10 m)	Campbell Scientific 107 (20 cm)
Model Parameter	Albedo	Brusaert Method corrected for clouds and vegetation		Derived from relative humidity		

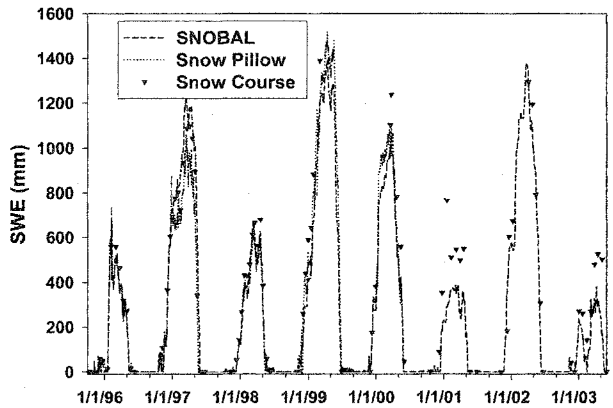
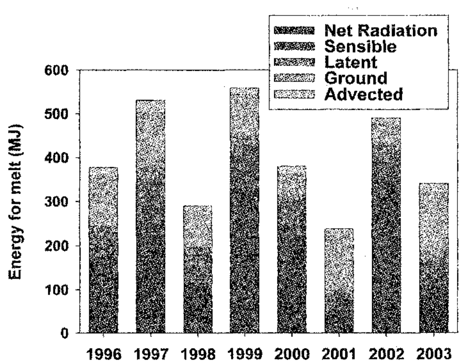


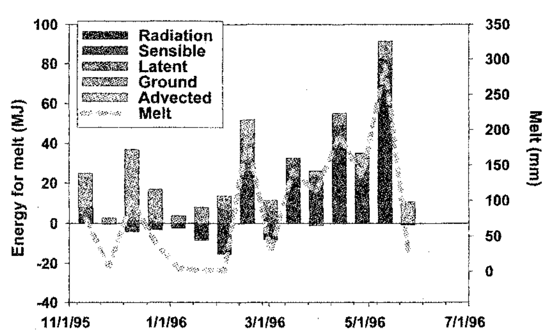
Figure 2. UPLMET, modeled and measured SWE for WY 1996 to 2003

RESULTS AND DISCUSSION

Energy Balance

Energy inputs were summed for each water year (Figure 3). Ground heat flux and radiation comprised a large portion of the input energy. These fluxes were then broken down for WY 1996, to investigate the EB of a major ROS event. The biweekly cumulative fluxes (Figure 4) showed that ground heat flux composed a large portion of the EB when there was a shallow snowpack. Radiation then dominated the spring melt out.





Figures 3 and 4. Annual and biweekly snow energy balance components at UPLMET.

Energy balance components for the ROS event of 1996 (Figure 5) were similar to the results of Marks (1998). Turbulent fluxes were high due to increased wind speeds during the event. The radiation balance during this event also contributed to melt, enhanced by a low albedo, low cloud cover, and a high atmospheric thermal radiation flux. The importance of radiation and ground heat flux at the annual scale challenges the current conception of turbulent-exchange-dominance of snowmelt in the PNW.

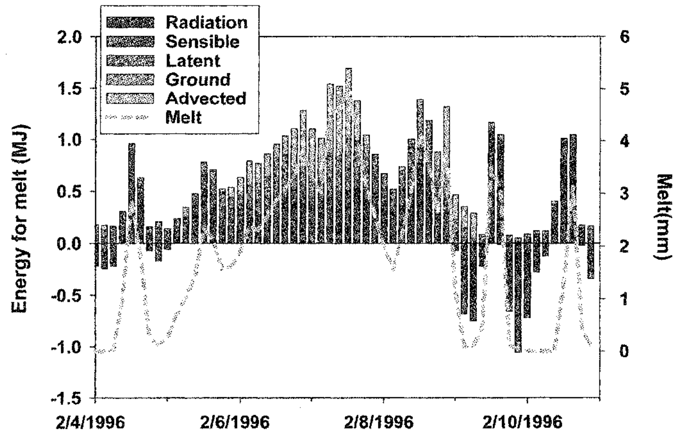
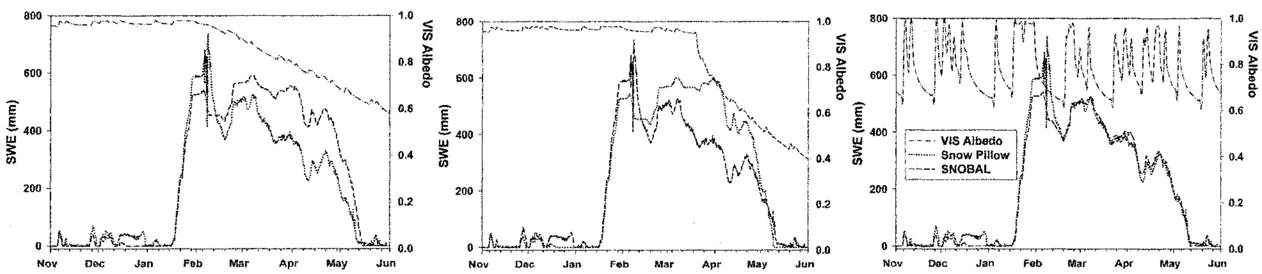


Figure 5. Energy balance components for February 1996 ROS event at UPLMET.

Net Solar Radiation Modeling

Modeled snow water equivalence (SWE) values using either the square root (Figure 6) or linear (Figure 7) albedo decay functions did not fit well with measured SWE for WY 1996. The dynamic logarithmic model (Figure 8, Equation 1) followed the patterns of accumulation and melt. This suggests a variable albedo, allowing for periods of higher radiation inputs to the EB. The annual energy budgets were similar for each of the three models, suggesting that a dynamic albedo does not over-estimate net solar radiation over a longer time period.



Figures 6, 7, and 8. WY 1996 for the linear, square root, and dynamic albedo functions.

Ground Heat Flux

Measured soil temperatures throughout the snow season were above 0°C. Fluctuations in temperature reflected melt water pulses through the soil profile. High-energy inputs were observed during periods when there was a shallow snowpack (Figure 9). Early season snow fell on warm soils, which quickly melted the overlying snow. These calculations may be exaggerated due to the model's assumption of a bare mineral soil surface.

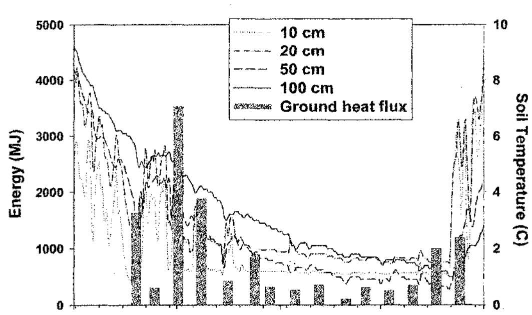


Figure 9. Soil temperatures at depth and ground heat flux for WY 1996

ROS events

The three monitored HJA sites were compared for ROS events in the upper HJA watershed. Twenty events were observed at all three stations (Figure 10). The event precipitation amounts ranged from 20 to 280 mm at UPLMET. Melt amounts for all of these events varied depending on site characteristics. The highest melt rates were observed at the lowest elevation station. These events were then broken down to average energy fluxes during ROS events for each site (Figure 11). Radiation was the dominant EB component during all ROS events, although high turbulent exchanges were modeled at VANMET. This site is south-facing and is susceptible to strong frontal winds.

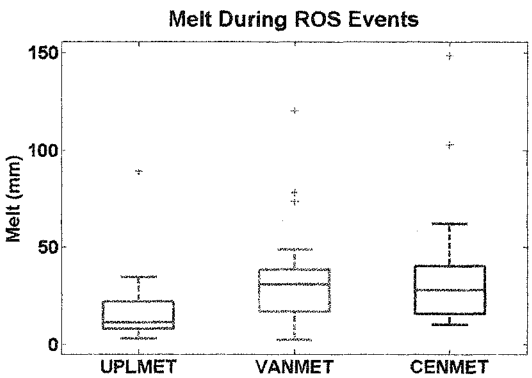


Figure 10. Total estimated melt for 20 ROS events at three HJA meteorological stations.

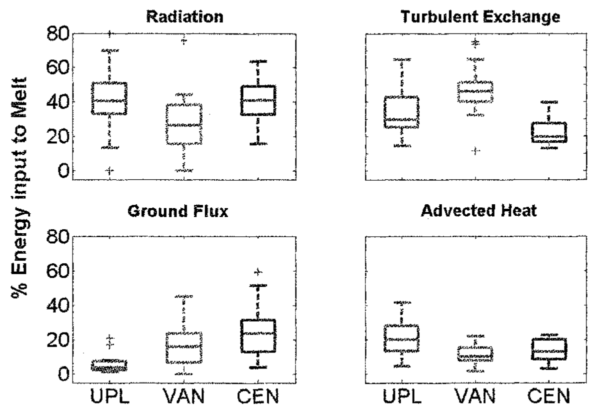


Figure 11. Average EB contribution to melt for 20 ROS events at three HJA meteorological stations..

CONCLUSIONS

The snow energy balance at the HJA over annual time periods is dominated by radiation. However, EB components varied over different time periods. Our modeling results show that ground heat flux contributions are high early in the season when shallow transient snowpacks and relatively high ground temperatures exist. Turbulent exchanges are positive throughout most of the season due to warm temperatures and high humidity. Radiation is the driving component of the energy balance during spring melt. Turbulent exchanges of sensible and latent heat appear to dominate melt only during periods of high winds. The relative importance of EB components varied within the HJA for the same event. Eighteen percent of the ROS events measured at UPLMET were dominated by turbulent exchange. An evaluation of albedo as a model parameter suggests that the low-cold-content snowpacks of the HJA have a variable albedo throughout the winter due to cyclical melt and accumulation periods.

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