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Procedia Engineering 37 (2012) 208 – 213

Procedia Engineering

www.elsevier.com/locate/procedia

The Second SREE Conference on Engineering Modelling and Simulation (CEMS 2012)

An Energy Balance Snowmelt Model for Application at a Continental Alpine Site

Tao Feng[a] Shide Feng[b]

[a]*Beijing Meteorological Service Center ,Beijing,100089,China*

[b]*Institute of Atmospheric Physics,Chinese Academy of Sciences,Beijing,100029,China*

Abstract

The objectives of this study are to measure and evaluate the energy balance of a continental alpine snowpack during spring snowmelt conditions, to evaluate the performance of a point energy and mass balance model of a snow cover in alpine conditions. The investigation is conducted during the 1997 snowmelt season at Niwot Ridge in the Colorado Front Range. Further comparisons of the modeled results to the previously described measured results are made below the energy budget terms. The fluxes are corroborated using a point energy and mass balance model for a snowpack to determining snowpack energy exchanges, with minor differences found between flux magnitudes. This comparison suggests that the representation of internal snowpack energy and mass exchange processes is generally correct.

Keywords:Energy balance; Snowmelt model; Radiative fluxes; Turbulent fluxes

1. Introduction

Snowmelt is an important source of water in much of the world. Modeling snowmelt is important for water resources management and the assessment of spring snowmelt flood risk. The processes involved in snowmelt have been widely described (U.S. Army Corps of Engineers[1]; Anderson [2]; Bras[3]; Marks, D.[4]; Viessman [5]). In snowmelt modeling, the heat flux between the snowpack and the atmosphere is partially governed by the snow surface temperature (Gray and Male[6]; Dozier[7]) which depends on the conductive heat flux into the snow.

*Corresponding author. Tel.:+86-15201055300; fax:+86-010-68400599.
E-mail address: fengtao@mail.iap.ac.cn.

doi:10.1016/j.proeng.2012.04.228

In the period that followed, several groups continue to develop energy balance snowmelt models as research tools. Flerchinger and Saxton[8] have developed and used the SHAW model to simulate the energy and mass balance of the soil and snow cover as a system. This model is too complicated to explicitly distribute over a grid.The SNTHERM model [9] accurately simulates snow cover energy and mass balance, but requires extensive forcing and snow cover structure data.

This paper reports the results of an investigation of snow surface energy exchanges at a continental alpine site in Colorado over a complete snowmelt season. The overall role and importance of the individual components of the energy balance is described. Finally, energy balance results from the model of a snow cover are compared to the experimental results.The comparison can be used to provide confirmation that the representation of physical snowpack processes within the model is appropriate.

2. Data Acquisition

The instrument site is located at 3517 m elevation on Niwot Ridge on the eastern slope of the Front Range of Colorado(40.03°N, 105.35°W). There are four levels of data. Level 0 data are the raw data. Level 1 data are 10-min meteorological data and energy flux calculations. Level 2 data are the 10-min data averaged over hourly and daily time intervals. Level 3 data are segments of the database.

3. Method

3.1. Energy balance

Considered as a volume, the energy balance of a snowpack may be written as [2]

$$\Delta Q_s + \Delta Q_M = Q^* + Q_H + Q_E + Q_G + Q_R \tag{1}$$

where ΔQ_s is the convergence or divergence of sensible heat fluxes within the snowpack volume, ΔQ_M is the latent heat storage change due to melting or freezing, Q^* is the net all-wave radiation flux, Q_H is the sensible heat flux, Q_E is the latent heat flux, Q_G is the ground heat flux, and Q_R is the energy advected by precipitation.

3.2. Radiative fluxes

The net all-wave radiation flux is the balance of the incident and reflected shortwave radiation and the incident and emitted longwave radiation, and is expressed as

$$Q^* = K\downarrow(1-\alpha) + (L\downarrow - L\uparrow) = (K\downarrow - K\uparrow) + (L\downarrow - L\uparrow) = K^* + L^* \tag{2}$$

where $K\downarrow$ is the incident shortwave radiation, α is the shortwave albedo of the snow surface, $K\uparrow$ is the reflected shortwave radiation, $L\downarrow$ is the incident longwave radiation, $L\uparrow$ is the emitted longwave radiation, K^* is the net shortwave radiative flux, and L^* is the net longwave radiative flux.

3.3. Turbulent fluxes

The sensible and latent heat fluxes were estimated using aerodynamic formulas with corrections for stability.The sensible heat flux through the surface boundary layer is expressed as

$$Q_H = \rho(C_\rho)\left(\frac{k(\theta_2-\theta_1)}{\phi_H[\ln(z_2/z_1)]}\right)\left(\frac{k(u_2-u_1)}{\phi_M[\ln(z_2/z_1)]}\right) \tag{3}$$

and the latent heat flux is expressed as

$$Q_E = \rho(L_v)\left(\frac{k(q_2 - q_1)}{\phi_E[\ln(z_2 / z_1)]}\right)\left(\frac{k(u_2 - u_1)}{\phi_M[\ln(z_2 / z_1)]}\right) \tag{4}$$

where ρ is the density of air, C_ρ is the specific heat of air at a constant pressure, L_v is the latent heat of vaporization of water, k is von Karman's constant, ϕ_H is the stability function for heat, ϕ_E is the stability function for water vapor, ϕ_M is the stability function for momentum, z_1 and z_2 are the instrument heights. θ_1 and θ_2 are the potential temperatures, q_1 and q_2 are the specific humidities, and u_1 and u_2 are the horizontal wind speeds.

The specific humidity at each level in the profile is determined by:

$$q = \frac{0.6222(e)}{P - 0.378(e)} \tag{5}$$

Where, P is the atmospheric pressure, e is the vapor pressure, calculated from the equation:

$$e = \frac{e_s(RH)}{100} \tag{6}$$

Where, RH is the relative humidity, and e_s is the saturation vapor pressure calculated from the equation:

$$e_s = 6.11mb \times 10^{aT(T+b)} \tag{7}$$

T is the air temperature (°C) at each level, and a and b are constants.

Table 1 Equations used for calculations of stability function

Stability Function	Richardson criteria Ri <-0.03	-0.03< Ri <0	0< Ri <0.19
ϕ_M	$(1-18Ri)^{-0.25}$	$(1-18Ri)^{-0.25}$	ϕ_M
ϕ_M	$1.3(\phi_M)$	ϕ_M	ϕ_M
ϕ_M	ϕ_H	ϕ_M	ϕ_M

The stability functions are calculated as a function of the Richardson number (Ri) using the equations shown in Table 1.

3.4. Ground heat flux

The flow of heat through the soil is measured using a heat flux plate.

4. Observation results

4.1. Meteological data

The 1997 snowmelt season discussed in this paper begins at maximum accumulation in the spring of 1997 (April, Julian Day (JD) 120) and continued until the snowpack has ablated completely (June 1997, JD 200). The patterns of air temperature, specific humidity, and wind speed during this period are shown in Fig.1.The mean daily air temperature remained above freezing nearly everyday. Specific humidity is no apparent seasonal trend. Wind speed is often quite variable throughout the day.

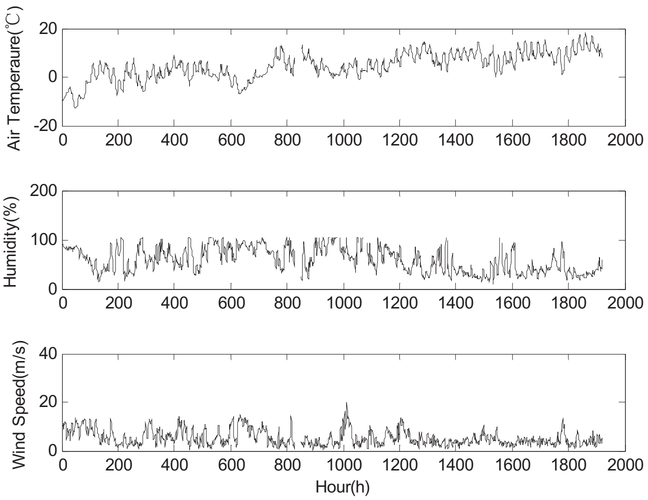

Fig. 1. Seasonal patterns of air temperature, specific humidity, and wind speed recorded at the 2 m level.

4.2. Energy fluxes

The patterns of the snow surface albedo, and net shortwave, net longwave, sensible, and latent heat fluxes are shown in Fig. 2. K^* increased from a daytime maximum of 100 Wm^{-2} to nearly 1000 Wm^{-2}. Q_H is a source of energy to the snow surface. Conversely, Q_E is almost always an energy sink.

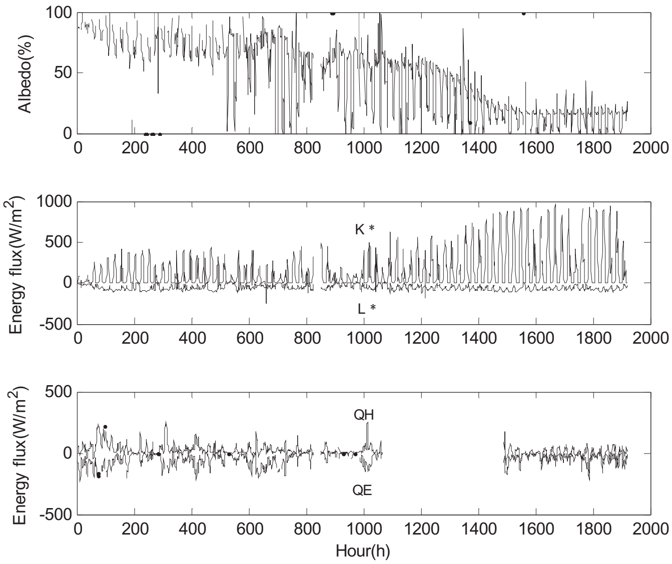

Fig. 2. Seasonal patterns of snow surface albedo, and energy fluxes of K^*, L^*, Q_H, and Q_E.

5. Model results

The comparisons between the observed fluxes and modeled fluxes are shown in Fig.3 and Fig.4. The dashed lines represent predictions and the solid lines represent observations.

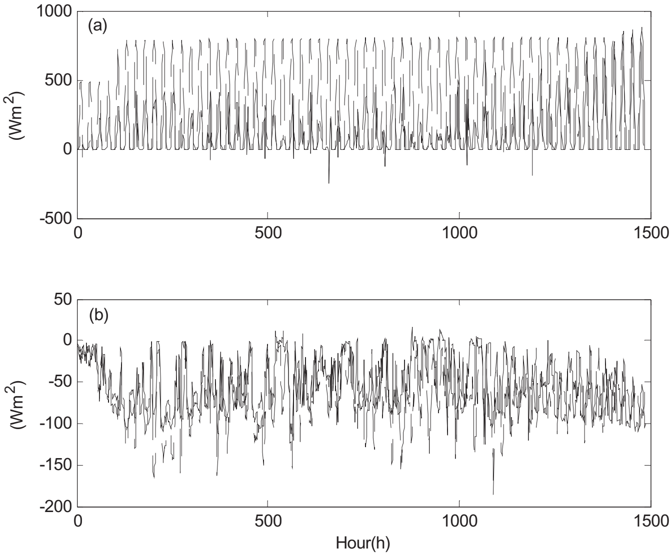

Fig. 3. Comparison between mean hourly observed and modeled fluxes:(a) K^* ; (b) L^* .

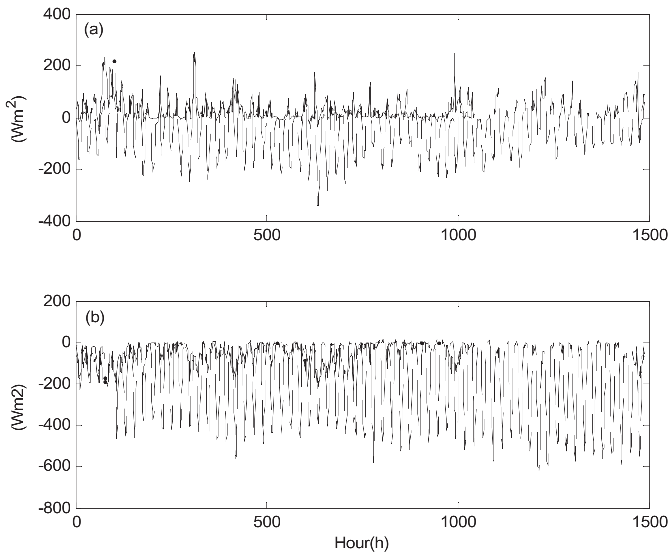

Fig. 4. Comparision between mean hourly observed and modeled fluxes:(a) Q_H ; (b) Q_E .

Comparison between modeled fluxes with the mean hourly observed fluxes show that the model tends to compute larger magnitude radiative fluxes and turbulent fluxes.

6. Conclusions

Snow surface energy exchanges are examined for a complete snowmelt season at a continental alpine site. Further comparisons of the modeled results to the previously described measured results are made below the energy budget terms. While the energy fluxes determined here are not rigorously validated, the fluxes are corroborated using a point energy and mass balance model for a snowpack to determining snowpack energy exchanges, with only minor differences found between flux magnitudes. This comparison suggests that the representation of internal snowpack energy and mass exchange processes is generally correct.

Snow energy exchange measurements will be continued at this site in the future. Future work at the site will include continued evaluation of relationships between point energy exchanges and synoptic weather patterns.

Acknowledgements

This study was supported by the Joint Funds of the National Natural Science Foundation of China (Grant No. 41175057), the National Natural Science Foundation of China (Grant No. 40927002),the National Natural Science Foundation of China (Grant No. 40875036),and the National Natural Science Foundation of China (Grant No. 40675029).

References

[1] U.S. Army Corps of Engineers. Snow Hydrology, Summary report of the Snow Investigations. U.S. Army Corps of Engineers, North Pacific Division, Portland,Oregon. 1956,142 pp.

[2] Anderson EA. A Point Energy and Mass Balance Model of a Snow Cover. NOAATechnical Report NWS 19, U.S. Department of Commerce. 1976,150 pp.

[3] Bras RL. Hydrology, An introduction to hydrologic science. Addison-Wesley:Reading, MA; 1990,643 pp.

[4] Marks D, Dozier J. Climate and energy exchange at the snow surface in the alpine region of the Sierra Nevada. Part III: Snow cover energy balance. Water Resour. Res., 1992, 28, 3043–3054.

[5] Viessman W,Lewis GL and Knapp JW. Introduction to Hydrology. 5th Edition,Prentice Hall; 2002,624 pp.

[6] Gray DM, Male DH. Handbook of Snow, Principles, processes,management & use. Pergamon Press: 1981,776 pp.

[7] Dozier J. Spectral Signature of Alpine Snow Cover from the Landsat Thematic Mapper. Remote Sensing of Environment, 1989,28: 9-22.

[8] Flerchinger FN, Saxton KE. Simultaneous heat and water model of a freezing snow-residue-soil system I. Theory and Development. Transactions of the ASCE ,1989,32: 565-571.

[9] Jordan R. Special Report 91-16, A one-dimensional temperature model for a snow cover: Technical documentation for SNTHERM.89. US Army Corps of Engineers Cold Regions Research and Engineering Laboratory: Hanover, New Hampshire: 1991,49 pp.