A snowpack evolution model based on the mass and heat balance method

H. Sugaya

(Fruit Tree Research Station, Ibaraki 305, Japan)

Abstract

A numerical model, based on the heat balance method, was developed to simulate snowpack evolution at a given location, as a function of meteorological conditions : air-temperature, wind speed, precipitation and incident short-wave radiation.

The model takes into account three major processes, (1) the increase in the amount of snowpack by precipitation, (2) melting of the surface snow layer as a result of energy balance and (3) drainage of water from the snowpack. The model was tested with data collected at TAKADA and NAGAOKA, JAPAN. The results show the ability of the model to simulate the day-to-day changes of the snow mass with reasonable accuracy. Emphasis was placed on the characteristics unique to this and other warmer climatic regions.

Key words : Snowpack, Snow-load, Accumulation, Heat balance, Drainage

1. Introduction

Deep and long-lasting snow-cover occurs in the Hokuriku Region, which extends on the west coast of the central Main Island of Japan. Due to its geographical location, the depth and duration of snowcover in this region are highly variable both temporally and spacially. In the heavy snow season, acceleration of snow melting, by blackening the snow surface or furrowing the snow surface, is carried out on cultivated land. Because of the long snowcover, snow mold will occur in the biennial crop. Before the acceleration of snow melting, it is necessary to estimate the effects of these methods. The objective of this study was to provide quantitative information on the physical processes influencing the accumulation and melting of snowcover.

2. Amount of snow

There are two ways to describe the amount of snow. One is snow depth (cm), another is snow-load (kg/m^2). Snow depth is easy to image. However, even with snow of the same depth, snow mass is not equal. Since snow density changes large (for example, the first of accumulation period ≈ 0.15 ; the end of melting period ≈ 0.5). In this model, therefore, the snow mass of snowpack was simulated as a snow-load (kg/m^2), that is equal to the water equivalent (mm). With this, we can directly use precipitation data.

3. Model

The model takes into account three major processes, (1) the increase in the amount of snowpack by precipitation, (2) melting of the surface snow layer as a result of energy balance and (3) drainage of water from the snowpack.

1) Accumulation of snowpack

The amount of snowpack generally increases when solid precipitation (snow, pellet, sleet) occurs. In contrast, increased drainage and runoff from the snowpack

can be expected when liquid precipitation occurs. However, precipitation data observed by JMA (Japan Meteorological Agency) gauges, was measured mixed with solid and liquid type. Therefore, it is necessary to distinguish between the form of precipitation events. In a simple way, it is considered that liquid type precipitation falls above one temperature and solid type falls below one temperature. This temperature is the critical air temperature (T_c). From the left panel of Fig.1, T_c is defined as 2.0 °C. In this model, the form of precipitation was distinguished by using this temperature (T_c).

A new method is presented using the critical wet-bulb temperature (T_{cw}). This method is more correctly, because number of errors are diminished about to half and the difference of critical temperature between sites becomes more small. From the right panel of Fig.1, T_{cw} is defined as 1.0 °C. In this method, wet-bulb temperature is calculated from air-temperature and humidity. Therefore, it is necessary to obtain humidity data. However humidity data is not observed in AMeDAS.

2] Melting snowpack

The basic equation for snowpack is given by the following heat balance formula.

$$Q_M = Q_R + Q_H + Q_E + Q_G + Q_r$$

Here, Q_M is the energy flux available for snowmelt, Q_R is the net radiation flux at the snow surface layer, Q_H is the sensible heat flux from the air at the snow-air interface, Q_E is the latent heat flux at the snow-air interface, Q_G is the heat flux from the ground, and Q_r is the heat from rain, all in $\text{MJ/m}^2\text{d}^{-1}$.

Q_R is calculated by following formula.

$$Q_R = (1 - A) * I + Q_L$$

Here, I , A and Q_L are the incident short-wave radiation, albedo and net long-wave radiation, respectively. Yamazaki et al. (1991) have recently reported that A is varied with surface snow conditions, such as water content, density, grain size, and accumulation of dust. However in this model, A is set up from 0.75 to 0.5 at each calculation period. Q_L is calculated from the incident long-wave radiation and that emitted from the snow surface. Emitted long-wave radiation is in proportion to the forth power of absolute temperature at the surface. However, the surface temperature and the incident long-wave radiation are derived from many meteorological factors and are more complicate. Then, $Q_L \approx 0$. Since incident and emitted radiation have opposite components, and since Q_L is positive in daytime and negative at night.

Q_H is indicated as follows.

$$Q_H = k * U * (T_a - T_s)$$

Here, U , T_a and T_s are wind speed (m/sec), and air temperature (°C) at height of 1m and snow surface temperature (°C). $T_s \approx 0$. k is the heat flux coefficient ($\text{MJ/m}^3 \text{ } ^\circ\text{C}^{-1}$) at the snow surface. Kojima(1979) obtained values of k (≈ 0.36) over a snow surface at a reference height of 1m.

Q_E is the latent heat flux which is calculated from two meteorological data, namely vapor pressure (mb) and wind speed. However under normal climatic conditions in winter season, this flux is much smaller than Q_M , and then $Q_E \approx 0$.

Q_G and Q_r are negligible components in seasonal heat balances of snowpack

when compared to Q_R , Q_H , and Q_E and then considered to zero. Thus Q_M becomes as follows.

$$Q_M = (1 - A) \cdot I + 0.36 \cdot U \cdot T_a$$

3] Drainage of water from snowpack

In this model, snowpack was regarded as a kind of water tank with one plug for discharge at the bottom. This plug has one valve operated by temperature like a thermostat. The temperature was set up empirically during each period of winter time.

4. Calculation

Winter was divided into three periods. The first period was 80 days from December 1. The second was from the 80th day to the 100th day. The third was after the 100th day to snowmelt. Albedo was set up 0.75, 0.6, and 0.5 in each period. Temperature during drainage was set up as follows. In the first period, if it lasted for two days in which daily mean temperature exceeded 1.0 °C, the drainage occurred. In the second period, if daily mean temperature exceeded 1.0 °C, drainage occurred. In the third period, drainage occurred everyday.

5. Simulation results

Calculations were carried out for 6 years at TAKADA and for 2 years at NAGAOKA. Both sites were observed daily for the snow-load and basic meteorological factors. Daily meteorological data was used in calculation, and calculated snow-load was compared with observed ones. Fig.2 shows the calculated value (solid line) and the daily observed value (circle) in TAKADA. The right panel shows the 1985-86 winter, this is the heavy snow season. The left panel shows the 1982-83 winter, which was less snow season. The agreement between calculated and observed value is fairly good in both seasons. Table 1 shows difference of calculated and observed values on maximum snow-load and snow melting days in each winter season. With maximum snow-load, the model could estimate good agreement with 10% error except for the 1979-80 season in TAKADA. While on the snow melting day, there was a agreement within 5 days.

6. Conclusion

A numerical model, based on the heat balance method, was developed to simulate the snowpack evolution at a given location. Many models which have been presented estimate the snowmelt in the main, and limited in snow melt period. This model considered an increase of snowpack by precipitation, it can simulate the snowpack from accumulation period to melting period. It also can estimate the effect of the acceleration of snow melting, because this model is based on the heat balance method. For example, in case of the blackening method, we can alter the albedo.

References

- Kojima, K., 1979: Mechanism of snowmelt and heat balance. Meteorological Research Note, 136, 1-37 (in Japanese).
- Yamazaki, T., Sakuraoka, T., Nakamura, T., and Kondo, J., 1991: A study of snow metamorphism: Model description. J. of the Japanese Society of Snow and Ice, 53, 115-123.

Fig.1 The proportion of precipitation form on air temperature(left) and wet-bulb temperature(right). The wet-bulb temperature was calculated from air temperature and vapor pressure data measured at the every three hours and the corresponding form of precipitation events were noted. These data were collected over the latest 10 winter seasons(1978-1988) at the 30 meteorological stations of JMA.

Fig.2 Calculated(solid line) and observed(circle) snow-load in TAKADA.

Table 1 Difference of calculated and observed values on maximum snow-load and snow melting day.

location	year	Maximum snow load (Kg/m^2)		Dif. snow melting obs.- cal.(day)
		observed	calculated	
TAKADA	1986	980	1004	-5
	1984	1025	962	-3
	1983	293	293	+1
	1981	809	744	-1
	1980	593	465	+3
	1977	721	831	-5
NAGAOKA	1985	751	788	± 0
	1984	960	922	+5