Shorter Contribution

551.579.2 : 551.584.41

On the Forest Cover Effect on Snow-Melt

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(*Manuscript received 22 December 1960*)

Abstract

In order to represent the forest cover effect on the snow-melt quantitatively and to make it a basis of snow-melt estimation for the whole basin, two experiments were tried in the forest in Okutone region (the headwaters of the Tone River), one to determine the beech-forest cover density by balloon measurements from the sky and the other to compare the amounts of snow-melt and several meteorological factors between inside and outside the forest. The result suggests that our theoretical estimation of the amount of snow-melt in the forest is successful.

1. Introduction

The subject of snow-melt was first discussed in detail by Sverdrup[1] (1934). He derived the theoretical equation which explains the snow-melt by the transfer of sensible and latent heat from air to snow surface. Light[2] (1941) applied this theory to the practical use and compared it with the water discharge amount of an actual river basin. He assumed in his paper that the whole amount of snow-melt arises from the mechanism of turbulent transfer.

Since several years ago this problem has been treated in Japan for utilization of the basin water (mainly for the electric power). The result of our experimental research on snow-melt, which was performed in Okutone drainage basin in 1956–1958, showed that, although the snow-melt caused by turbulent transfer can be explained sufficiently by Light's equation, insolation has also a great influence upon it, and that through the period of snow-melt most part of this amount is caused by these two factors. Several field experiments on snow-melt, containing ours, have been performed in open snow fields. While most river basins in Japan are almost covered by forests, and so, to discuss the snow-melt over the whole basin, the forest cover effect must be considered. According to our experiences, there is less snow at the period of the maximum equivalent water of snow but it remains later in the forest than in the open field.

In this paper, the forest cover density will be defined and the relation between snow-melt and each meteorological factor in the forest will be described.

2. Definition and measurement of forest cover density

To serve our purpose, the forest cover density will be defined macroscopically as the ratio of projection area of trees to the ground surface in the forest.

The following letters will be used for the computation.

m=forest cover density,

γ=average albedo for the forest area,

γ_t=albedo of trees,

γ_s=albedo of snow surface.

Some part of insolation incident upon the forest is reflected or absorbed by trees, and the residual part arrives at the snow surface through the forest screen, and after the reflection by the snow surface, it outgoes through the forest screen again. During these processes the insolation decreases by the steps as shown in Fig. 1. The ratio of the outgoing radiation out of the forest by reflection to the incoming one can be represented as the next equation.

$$\{m\gamma_t I+(1-m)^2\gamma_s I\}/I=\gamma \qquad (1)$$

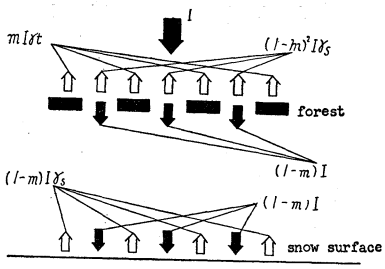

Fig. 1. Incidence and reflection of insolation in the snowy forest.

Solving for m,

$$m=(2\gamma_s-\gamma_t-\sqrt{(\gamma_t-2\gamma_s)^2-4\gamma_s(\gamma_s-\gamma)})/2\gamma_s \quad (2)$$

Hence the average value of m can be determined from measurements of γ, γ_t and γ_s for a large forest area. For a forest of uniform density, it also can be done from comparative measurement of insolations inside and outside the forest.

3. Snow-melt in the forest

The radiation energy received or emitted by the snow surface in a forest can be classified into three parts; the first is the insolation through the forest screen, the second is the outgoing radiation from the snow surface to the sky, and the third is the long wave radiation from the forest trees to the snow surface.

The heat amount given to the snow surface by insolation is

$$Q_I=(1-m)I(1-\gamma_s) \quad (3)$$

After Brunt[4], the outgoing radiation from the snow surface under the clear sky is represented by the next equation:

$$Q_R=(1-m)\sigma T_s^4(1-a-b\sqrt{e}) \quad (4)$$

where σ is Stefan-Boltzmann's constant, T_s the absolute temperature of snow surface, e the vapor pressure in mb and a and b are constants. The long wave radiation from trees to snow surface is

$$Q_t=m\sigma(T_t^4-T_s^4) \quad (5)$$

where T_t is the absolute temperature of trees. Since we have no measurements of T_t, it is assumed that it is equal to the average air temperature.

Both sensible and latent heat energies transferred by turbulent diffusion in the forest are expressed in the same form as in the open snow field:

$$Q_T=A(U_f+C)(T-T_s) \quad (6)$$

$$Q_e=B(U_f+C)(e-e_s) \quad (7)$$

where U_f is the wind velocity in the forest, T and T_s are the air and snow surface temperatures respectively, e and e_s the air and snow surface vapor pressures respectively. A, B and C are the constants which have been known by our experiments in 1956 and 1957[3].

4. Measurement of forest cover density

For the determination of forest cover density, m by equation (2), it is necessary to know γ, γ_s and γ_t. The photocell illuminometer is used for albedo measurement; first it is faced to the zenith and the light intensity from the sky is measured, and next faced downwards to measure the reflected light. γ_s can be measured by this method in a small open area in the forest. It is difficult to measure γ_t, but it is regarded as about 10 percent after many investigators. The value of γ, which is the most necessary for equation (2), can be determined as the average for a large area by measuring the albedo from a considerably high altitude above the forest. The aeroplane measurement for a whole basin is the best way, but as it was impossible in time of our experiment, the balloon measurement was adopted in place of that. The light weight illuminometer made of photocell about 17 gram was hung down below the balloon which was moored by a pemp yarn and two thin copper wires of 0.18 mm diameter. The sketch of photocell illuminometer is shown in Fig. 2. Actual measurements by balloon were performed in the beech forest in Okutone basin (headwaters of the Tone River) from 50 m altitude (Fig. 3), where the forest density is small, about one beech tree an are, and the average height of trees is 15 m. The balloon

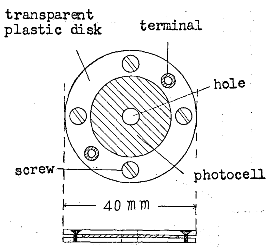

Fig. 2. Sketch of the photocell illuminometer.

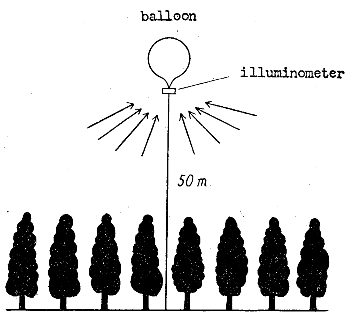

Fig. 3. Measurement of albedo by balloon.

measurement of albedo is unsuitable in cloudy sky or in strong wind, and it was performed only three times during our experimental period. It was resulted that γ_s is 0.81 and γ is 0.54 as the average of our measurements. Assuming γ_t is 0.10, m becomes 0.20 by equation (2).

5. Measurement of meteorological factors and snow-melt

In order to compare the amounts of snow-melt between inside and outside of the forest, considering meteorological factors such as insolation, air temperature and wind velocity, the afforestation area of cryptomerias was selected, where the forest density m determined from the comparison of insolation measurements is 0.82. The wind velocity was measured by Robinson anemometer at two points of 3 m height above snow surfaces, and the ratio of the wind runs through the period of our experiment was 0.40. Although the relations between U_f and m in equations (6) and (7) are not determined accurately, the wind velocity outside the forest U_0 is equal to U_f if m is zero. Assuming a linear relation between U_f and m, we get the next equation from our experiment:

$$U_f = U_0(1 - 0.73\,m) \qquad (8)$$

The result of our comparative observations of air temperature between these two points is as follows. In daytime it is warmer at the outside point than in the forest, as is evident from Table 1 (a). Few data have been obtained at night, but it seems that the tendency is similar under cloud and inverse under clear sky (Table 1 (b) and (c)). This temperature difference, however, is not too great to influence upon snow-melt by itself, and important factors contributing to the difference of snow-melt may be wind speed,

Table 1. Comparison of air temperature above snow cover between inside and outside the forest.

(a) Daytime observation (Mar. 14～Apr. 2, 1958)

time	number of observation	mean temperature inside the forest	mean temperature outside the forest
0900	21	2.0°C	2.8°C
1300	21	4.1	5.3
1700	20	3.2	3.5

(b) Cloudy night observation (Mar. 10, 1960)

time	number of observation	mean temperature inside the forest	mean temperature outside the forest
2130 ～2150	2	1.7°C	2.2°C

(c) Clear night observation (Mar. 19, 1960)

time	number of observation	mean temperature inside the forest	mean temperature outside the forest
1920 ～2000	4	−0.5°C	−0.8°C

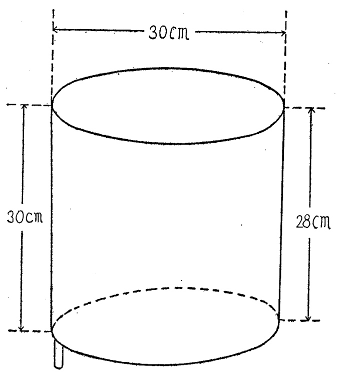

Fig. 4. Sketch of the snow-melt gauge made of transparent plastic.

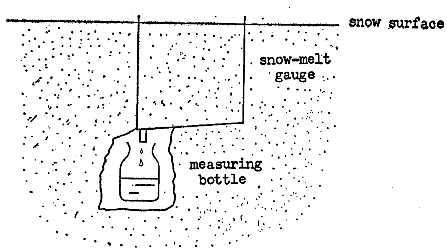

Fig. 5. Cross section of snow-melt measurement.

insolation and outgoing radiation rather than air temperature.

The measurement of snow-melt amount was made by means of a plastic vessel with a draining tap at the bottom, both 30 cm in diameter and in depth as shown in Fig. 4. In measurement, this vessel is first pushed into the snow pack upside down, and a snow mass is cut off in the form of cylinder. Then it is reentered into the vessel so as to keep the original surface upward. Next the vessel is sunk into the snow so that the snow surface in it may be in the same plane with the natural snow surface. On the other hand, snow-melt water out of the draining tap is received by the bottle whose capacity is about 2,000 cc.

Such an apparatus is set both inside and outside the forest. Its cross section is shown in Fig. 5. During the snow-melt period in 1958, measurements of melted water by these apparatuses were made twice a day, 0900 LMT and 1700 LMT. The theoretical amount of snow-melt is computed by equations (4)–(7). Namely, the amount of heat energy received by a unit area of snow surface for a unit time is expressed by the next equation.

$$Q=Q_I+Q_t+Q_T+Q_e-Q_R \tag{9}$$

The first term of this equation is larger in the treeless field than in forest. The second exists only in the forest. The third and fourth are larger in the treeless field regardless of the time of day, because temperature and vapour pressure are about the same in both fields, while wind velocity is greater in treeless field. The last term is much discharged from the bare snow surface. It is concluded from this equation that, in general, in daytime the amount of snow-melt is greater on bare snow surface than in the forest, but inverse at calm night. The results of our measurements show this relation obviously as shown in Table 2. It was March 21st when the continuous snow-melt began in the forest in our experimental period. So the computed

Table 2. Comparison of snow-melt between inside and outside the forest.

Date			Snow-melt inside the forest	Snow-melt outside the forest	Date			Snow-melt inside the forest	Snow-melt outside the forest
			(mm)	(mm)				(mm)	(mm)
Mar.	13	0900	—	—	〃	24	0900	1.4	5.7
〃	13	1700	0.0	15.0	〃	24	1700	8.3	19.8
〃	14	0900	0.0	0.0	〃	25	0900	3.5	2.1
〃	14	1700	9.2	16.0	〃	25	1700	7.7	5.3
〃	15	0900	0.0	0.0	〃	26	0900	8.4	0.1
〃	15	1700	0.0	1.0	〃	26	1700	8.4	28.3
〃	16	0900	0.0	0.1	〃	27	0900	4.0	5.4
〃	16	1700	0.0	15.3	〃	27	1700	0.0	7.5
〃	17	0900	0.0	0.0	〃	28	0900	0.0	3.1
〃	17	1700	4.2	6.8	〃	28	1700	0.0	0.0
〃	18	0900	?	3.5	〃	29	0900	0.0	0.0
〃	18	1700	0.0	5.7	〃	29	1700	0.0	1.7
〃	19	0900	0.0	0.0	〃	30	0900	0.0	0.0
〃	19	1700	0.0	0.0	〃	30	1700	0.0	0.0
〃	20	0900	0.0	0.0	〃	31	900	0.0	0.0
〃	20	1700	0.0	5.6	〃	31	1700	0.0	0.0
〃	21	0900	1.1	0.0	Apr.	1	0900	0.0	0.0
〃	21	1700	2.8	17.1	〃	1	1700	0.0	4.1
〃	22	0900	0.0	2.4	〃	2	0900	0.0	0.0
〃	22	1700	6.0	7.1	〃	2	1700	1.4	7.1
〃	23	0900	8.5	4.2					
〃	23	1700	11.2	15.5	Total amount			86.1	205.5

The figure of each column represents the snow-melt for the preceding 8 or 16 hours.

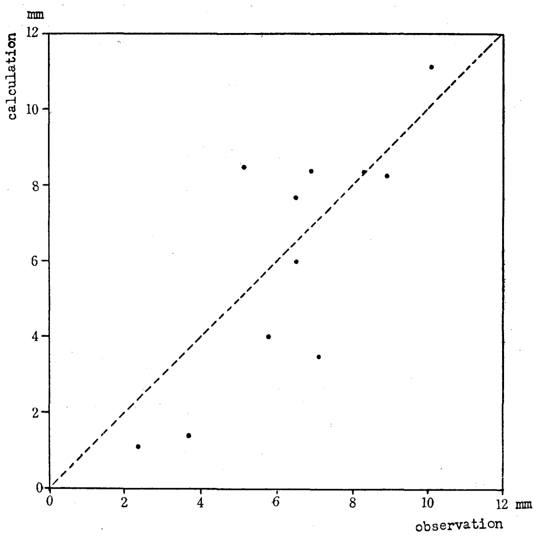

Fig. 6. Relationship between calculated and observed values of snow-melt in the forest.

and observed values of snow-mlet are compared, separating each day into two parts (0900–1700 and 1700–0900 (next day)), where the calculation was performed by equations (4)–(7) using hourly observation data. Fig. 6 shows this relationship, and although the plotted points are somewhat scattered, the total amount for this period is 68.9 mm in calculation and 67.4 mm in observation.

6. Conclusion

The total amount of snow-melt through our experimental period from 13 Mar. to 2 Apr. 1958 is 205.5 mm in the outside and 86.1 mm in the inside. On the other hand, the equivalent water of snow at the beginning of this period is 430 mm in the former and 254 mm in the latter. The reason why there is less snow in the forest at the beginning of the period of snow-melt has not been made clear until now, though there have been many reports that such phenomena are found in other snowy regions in Japan. Hence in the forest, there is less snow in earlier period of snow-melt compared with the treeless field near it, but as the melting rate is smaller, the snow remains until late. And the process of snow-melt during this period both inside and outside the forest can be expressed successfully by thermodynamical theory.

Acknowledgement

The experiment which is the basis of this report was performed as a part of the hydrological research in Okutone region managed by the cooperation of Tokyo District Meteorological Observatory and Tokyo Electric Power Company. I wish to express my hearty thanks to Dr. Hatakeyama, the director of the former and the research members of both offices.

References

(1) H.U. Sverdrup (1934): The eddy conductivity of the air over a smooth snow field. Geofys. Publ., **11.**

(2) Ph. Light (1941): Analysis of high rates of snow-melting. Trans. Amer. Geophys. Union, **22,** 195–205.

(3) N. Ito (1960): Experimental research on snow-melt. Synthetic report of hydrological research in Okutone region, Part 1, Section 2.

(4) D. Brunt (1940): Physical and dynamical meteorology, Chap. 6.

融雪に及ぼす森林の効果について

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日本の主要な水源地となつている中部山岳地方は，大部分森林におおわれている。水利用の立場から流域全体についての融雪状況を推定する基礎として，融雪に及ぼす森林の効果を量的に表現する目的で２つの実験を行つた。その１つは森林密度を定義し，実際に流域中の森林において，気球によつて森林密度を測定したものであり，第２は密度

のわかつた森林の内外での融雪量および気象要素の比較のために行つたものである。一般に融雪期に入る直前には，積雪相当水量は林外の開地の方が林内よりも大きい(この原因はまだ明らかでない)。しかし融雪の速度は林外の方がはるかに大きいために，林内の方が遅くまで積雪が残ることになる。筆者はここできめた定義による森林密度を使つて森林内の融雪速度を推定し，上記のような森林内での融雪過程を十分説明し得ることを示した。