# An Experimental Observation of the Evaporation from Snow Surface

Yasutaro MORITA* Nozomi MURAKOSHI** and Eizaburo NISHIBORI***

# 南極における雪面蒸発量測定の試み

守田康太郎*・村越　望**・西堀栄三郎***

雪面からの蒸発量の測定は一般には甚だむつかしい．降雪や飛雪の影響，および蒸発計の影響が大きいからである．西堀は，昭和基地第一次越冬中に，これらの影響から免れて雪面蒸発量を測定する方法を考案し，村越が実際の観測を行った．その方法は，積雪から雪のブロックを正立方形にきりとって空中に吊し，その重量変化を測定するというのである．特殊の条件下においては，その重量変化から，ただちに単位表面からの蒸発量を算出することができる．その条件は，(a) 雪ブロックから融雪水の滴下が起らぬこと，(b) 雪ブロックに降雪や飛雪が附着しないこと，(c) ブロックの外形が相似を保ったまま変化すること，(d) ブロックの密度変化が無視し得ること等である．昭和基地においてはこれらの条件はほぼ満されており，得られた結果はソビエト隊による推測値と比較しても，大体妥当な値と考えられる．気象要素との関係について，飽差と風の函数としてあらわされることが分った．

## 1. Introduction

The water equivalent amount of evaporation from snow surface is one of the important quantities in treating the problem of "SNOW AND ICE BALANCE" in the Antarctic glaciology. But, its accurate determination is so difficult that the reliable method of observation is not hitherto developed. The difficulty is mainly due to the uncertainty of the precipitation measurement, the probable error of which is too large to determine the net amount of evaporation through the successive observation of total amount of snow in a evaporation gauge. Moreover, the existence of the gauge itself disturbs the natural conditions at the snow surface, either aerodynamically or thermally, causing to increase the error of the measurement.

One of the authors, Dr. NISHIBORI, who was the leader of the first wintering team of J. A. R. E., devised a new method which enable us to avert from the above difficulties. Following to NISHIBORI's method, N. MURAKOHI, the meteorologist of the

* Japan Meteorological Agency. Member of the Japanese Antarctic Research Expeditions, 1956–57, 1957–58 and 1960–61.

** Japan Meteorological Agency. Member of the Wintering Party, the Japanese Antarctic Research Expeditions, 1957–58 and 1960–61.

*** Japan Atomic Energy Research Institute. Subleader of the first Japanese Antarctic Research Expedition, and the leader of the Wintering Party the Japanese Antarctic Research Expedition, 1957–58.

wintering team, carried out the experimental observation at Syowa Base. The data are investigated by MORITA, the result of which is given in this paper.

## 2. The method of the observation

A snow block of regular solid, a side of which is 10-20 cm, is extracted from the naturally accumulated snow and is hung in the open air by a string, the one end of which is enclosed in the block (*see* Fig. 1.). The mass of the block is measured at 15 o'clock every-day.

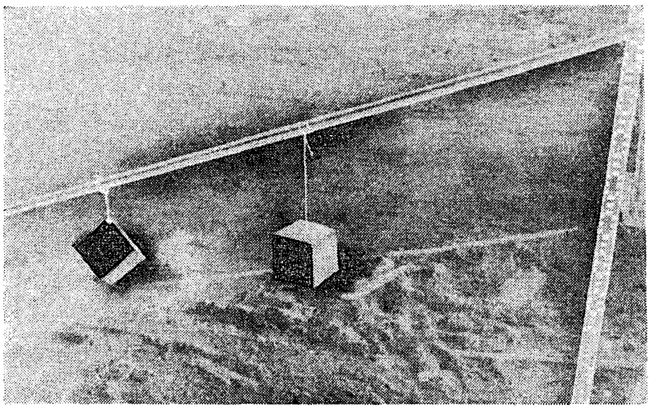

Fig. 1. Snow blocks hung in the open air.

When the block has diminished to about one-tenth of the original one in its volume, a new block is replaced for the diminished one, to reduce the error of the measurement. The effect of the gauge is completely eliminated here because no gauge is used; there is no fear of the adhesion of falling snow, as well as blowing snow particles are usually very dry in such a low temperature as experienced in our observation. Then the observed mass variation is regarded as the very amount of evaporation, and is easily converted to the water equivalent value per unit surface area without any other measurements, provided that:

a. Melting water does not drip from the snow block,
b. The irregular deformation of the snow block does not occur (i.e., the relation between the surface area and the mass in definitely kept),
c. The density of the snow block is conservative.

In our observation, above conditions seems to have been realized approximately. Namely, no dripping was observed even on a day with sunshine; the snow block was observed to keep its cubic form until it diminished to about one-tenth of the original volume; the variation of the density was negligible though a slight increase was seen after warm and shiny days.

However, it must be noted that if either of the above conditions is not realized, as is supposed to be an ordinary case in the warmer region, the problem becomes so complexed that the utility of this method will be much reduced.

## 3. The result of the observation

The observation was carried out during the period from 24th September to 15th November 1957. At first the measurement was made for two samples of snow block simultaneously, after 14th October three samples were used, and after 7th November four samples. The mass variations of each sample are plotted in Fig. 2. In this figure the range of daily air temperature is also given to show the meteorological condition.

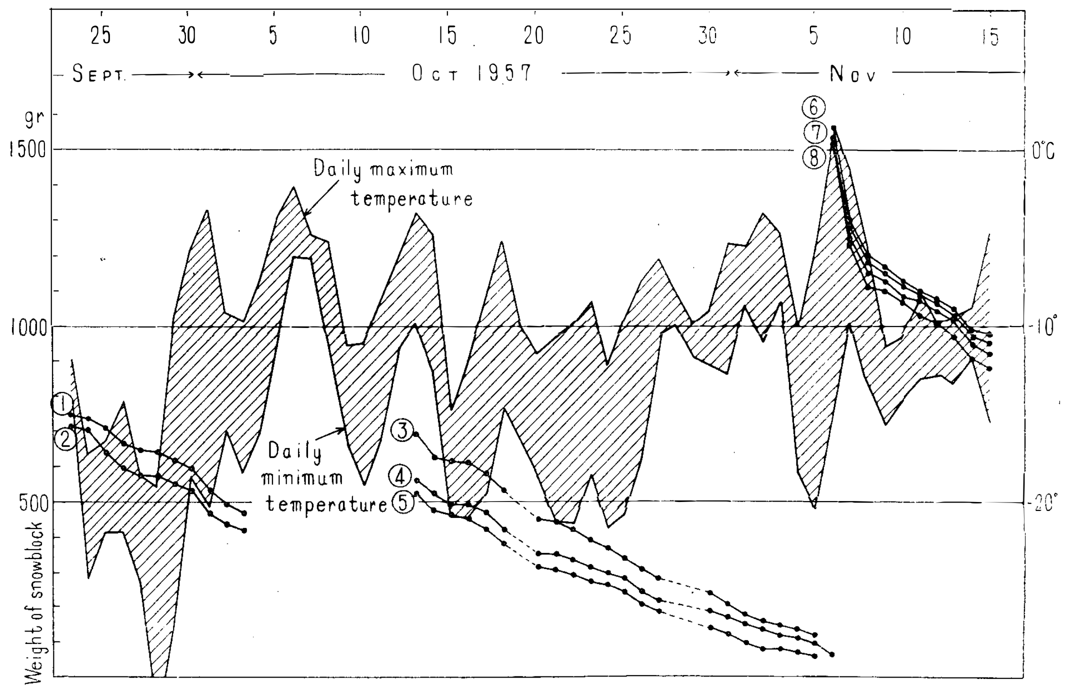


Fig. 2. Variation of the weight of snow blocks hung in the open air.

The relation between the cubic mass and the surface area is given as follows:

$$S=6\left(\frac{M}{\rho}\right)^{\frac{2}{3}}$$

where $S$ is the surface area in $cm^2$, $M$, the mass in gr., $\rho$ the density.

Then the rate of evaporation per unit area per day is obtained by

$$m=\frac{\varDelta M}{S}=\frac{1}{6}\rho^{\frac{2}{3}}M^{-\frac{2}{3}}\varDelta M$$

where $\varDelta M$ is the daily difference of $M$.

Now we assume $\rho$ as 0.4, because it is known that the density of the accumulated snow near the surface is evaluated as about 0.4 or so and is nearly conservative in this season at Syowa Base.*

The observed value of $M$ and the computed values of $m$ are given in the appendix table. The mean of $m$ throughout the period of our observation is thus obtained as 0.048 gr/cm$^2$ day. As for the reliability of the result, the reference is given by the recent paper of U.S.S.R. Antarctic glaciological research on "Snow and Ice Balance",** in which the loss of water equivalent by evaporation is estimated as $24\times10^9$ ton/$43\times10^4$ km$^2$=0.015 gr/cm$^2$ day, which is about one-third of our result. Considering that the wide portion of the research area of U.S.S.R. expedition is held with the inner highland where the climate is far colder than at Syowa Base and accordingly

* This fact was ascertained by the later observation of the third wintering team.

** Ch. Ya. Zakiev: Experiments on Approximate Determination of Snow and Ice Balance in a Part of the Eastern Antarctica. (Buenosaires Antarctic Symposium) the evaporation phenomenon may well be inactive, our result seems to be a reasonable value at the Antarctic coastal region.

## 4. Relation between the evaporation rate and meteorological elements

It is well known that the major meteorological elements which control evaporation are humidity deficit and wind velocity. Humidity deficit is defined as the difference between the saturation aqueous vapour and the existing aqueous vapour. Therefore we have two different values of humidity deficit when the air temperature is below 0°C, corresponding to two values of saturation vapour pressure on water and on ice. If the process of evaporation from snow surface is regarded as sublimation, or the conversion of ice into aqueous vapour, the humidity deficit on ice is to relate to evaporation, while if the process is the conversion of water into vapour, the humidity deficit on water is to relate. The actual phenomenon seems to include both processes, because the snow surface is observed to be frozen fast when the temperature is well below freezing point, but it is occasionally observed to be covered with the thin film of water when the temperature is not so below, especially with strong sunshine. According to the above consideration, both values of humidity deficit on water and on ice were examined in the following treatment.

Partial relation between the daily evaporation rate, $m$, and the daily mean of humidity deficit, $\bar{D}$ or $\bar{D}'$, is given in Fig. 3a and 3b. $\bar{D}$ and $\bar{D}'$ are computed by

$$\bar{D}=\frac{1}{8}\sum(E-e), \qquad \bar{D}'=\frac{1}{8}\sum(E'-e)$$

where $E$ is the saturation vapour pressure (in mb) on water, $E'$ that on ice and $e$ the existing vapour pressure. The partial relation between $m$ and the daily mean of wind velocity, $\bar{V}$ is given in Fig. 4.

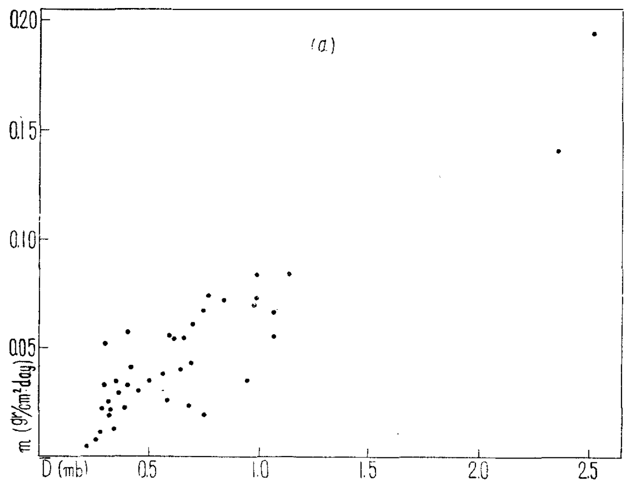


Fig. 3a. Plot of the evaporation rate, $m$, against the daily mean of the humidity deficit on water, $\bar{D}$.

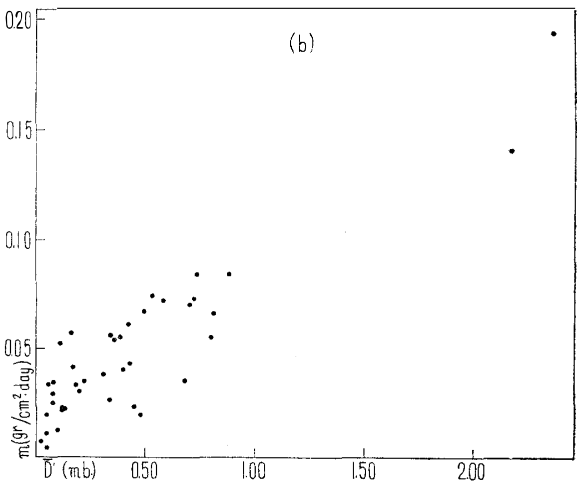


Fig. 3b. Plot of the evaporation rate, $m$, against the daily mean of the humidity deficit on ice, $\bar{D}'$.

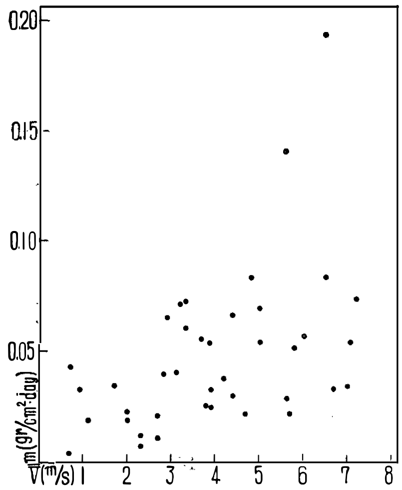


Fig. 4. Plot of the evaporation rate, $m$, against the daily mean of the wind velocity, $\bar{V}$.

Closer relation is conceivable for the combination of humidity deficit and wind velocity, and we introduce following experimental formula:

$$m=K\ \bar{D}^{n_1}\bar{V}^{n_2} \quad \text{or} \quad m-K\ \bar{D}'^{n_1}\bar{V}^{n_2}$$

where the constant $K$ and the coefficients $n_1$ and $n_2$ are to be determined from observations by least square method, thus we get:

$$m=0.0377\bar{D}^{0.9996}\bar{V}^{0.4308}(0.014)\ \ldots\ldots\ldots(1)$$

$$m=0.0393\bar{D}'^{0.5333}\bar{V}^{0.5233}(0.012)\ \ldots\ldots(2)$$

The calculated values of $m$ by the above formulae are compared with the observed ones as are seen in Fig. 5a and 5b., and we find better correlation in case of formula (2) where the humidity

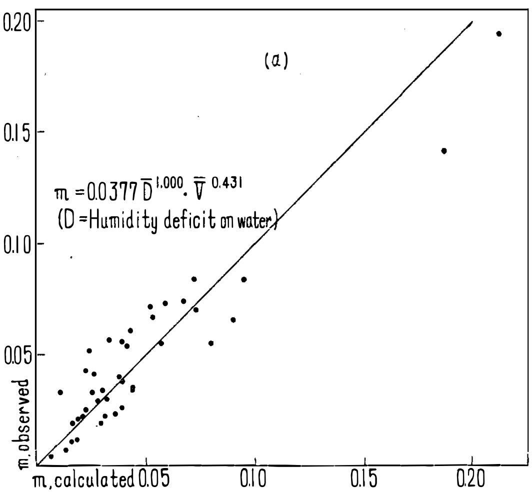


Fig. 5a. Plot of the observed value of $m$ against the calculated one by the formula (1).

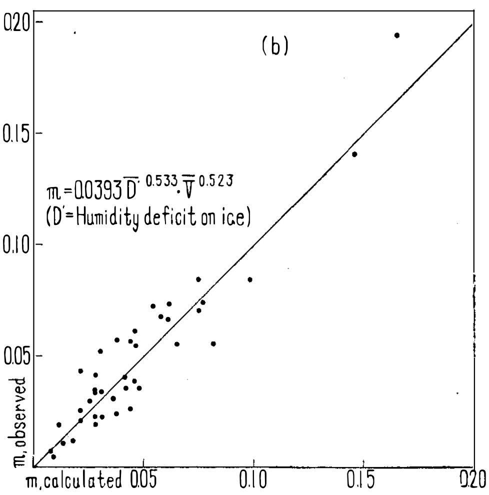


Fig. 5b. Plot of the observed value of $m$ against the calculated one by the formula (2).

deficit on ice is treated. This fact seems to tell us that the phenomenon is mainly taken place in the form of sublimation under the condition of our observation.

In the above treatment the daily mean values of humidity deficit, $\bar{D}$ or $\bar{D}'$ and of wind velocity, $V$, were used. But it seems to be more reasonable to use the product $D^{n_1}$ or $D'^{n_1}$ and $V^{n_2}$ for individual observation. For simplicity, $\sum D\cdot\sqrt{V}$, $\sum\sqrt{D\cdot V}$, $\sum D'\cdot\sqrt{V}$, and $\sum\sqrt{D'\cdot V}$ were computed and the correlation between them and the evaporation rate, $m$, were researched. Thus the best correlation was found for that between $\sum\sqrt{D'\cdot V}$ and $m$ as is seen in Fig. 6, the correlation coefficient being 0.94 in this case.

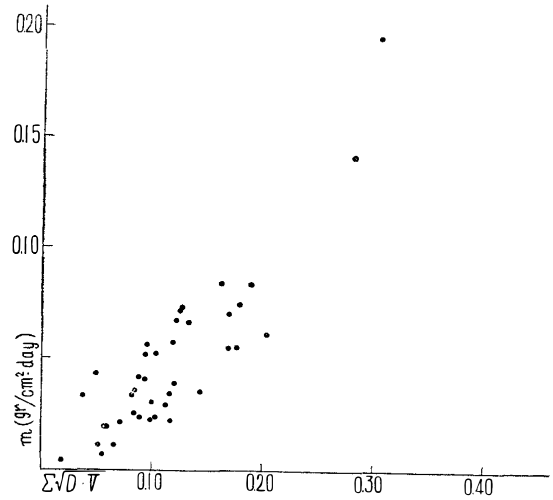


Fig. 6. Plot of $m$ against the daily mean of $\sqrt{V}\cdot\sqrt{D'}$.

## 5. Conclusion

a. NISHIBORI's method is useful to determine the water equivalent amount of evaporation under the special conditions at Antarctica.

b. The evaporation rate from snow surface during the period for September 24 to November 15, 1957 was determined as 0.048 gr/cm$^2$·day which is a reasonable value at the Antarctic costal region.

c. The evaporation rate is well correlated to the square root of humidity deficit on ice and that of wind velocity.

d. Our observation was carried out with a poor balance so that the accuracy of the measurement was not satisfactory, and yet the period of observation was limited. Further observation with better facilities and throughout a year is desirable to determine the annual rate of evaporation from snow surface.

## *Appendix*

$M$: Mass of snow block, observed at 15 o'clock.
$i$ : Number of snow block.
$m$: Evaporation rate computed by formula (A).
(mean of the individual value for each block)
$\bar{D}$: Daily mean of humidity deficit on water, computed from 3 hourly observations.
$\bar{D}'$: Daily mean of humidity deficit on ice, computed from 3 hourly observations.
$\bar{V}$: Daily mean of wind velocity, computed from 3 horuly observations.
$\sum\sqrt{V}\sqrt{D'}$: Daily sum of $\sqrt{V'}\sqrt{V}$ for each observations.

| Date | | $M$(gr) | | | | $m$ (gr/cm$^2$) | $\bar{D}$ | $\bar{D}'$ | $\bar{V}$ | $\sum\sqrt{D'\cdot V}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ① | ② | | | | | | | |
| Sep. | 23 | 712 | 744 | | | | | | | |
| | 24 | 702 | 735 | | | 0.0107 | 0.28 | 0.05 | 2.7 | 0.7 |
| | 25 | 640 | 707 | | | .0523 | 0.30 | 0.11 | 5.8 | 3.9 |
| | 26 | 592 | 660 | | | .0574 | 0.40 | 0.16 | 6.0 | 6.8 |
| | 27 | 575 | 643 | | | .0213 | 0.33 | 0.12 | 2.7 | 4.5 |
| | 28 | 572 | 640 | | | .0038 | 0.22 | 0.05 | 0.7 | 0.4 |
| | 29 | 550 | 611 | | | .0326 | 0.40 | 0.18 | 3.4 | 5.4 |
| | 30 | 530 | 592 | | | .0257 | 0.58 | 0.34 | 3.8 | 6.9 |
| Oct. | 1 | 468 | 532 | | | .0844 | 1.13 | 0.88 | 6.5 | 15.0 |
| | 2 | 435 | 490 | | | .0550 | 1.06 | 0.80 | 5.0 | 15.3 |
| | 3 | 415 | 465 | | | .0347 | 0.94 | 0.68 | 1.7 | 6.9 |
| | | ③ | ④ | ⑤ | | | | | | |
| Oct. | 13 | 560 | 690 | 520 | | | | | | |
| | 14 | 520 | 630 | 470 | | 0.0662 | 1.06 | 0.81 | 2.9 | 11.5 |
| | 15 | 490 | 615 | 460 | | .0254 | 0.32 | 0.08 | 3.9 | 2.4 |
| | 16 | 490 | 610 | 450 | | .0071 | 0.26 | 0.02 | 2.3 | 0.9 |
| | 17 | 470 | 580 | 420 | | .0378 | 0.56 | 0.31 | 4.2 | 7.2 |
| | 18 | 420 | 530 | 380 | | .0703 | 0.97 | 0.70 | 5.0 | 14.4 |
| | 19 | | | | | | | | | |
| | 20 | 350 | 450 | 310 | | .0609 | 0.69 | 0.42 | 3.3 | 7.4 |
| | 21 | 350 | 440 | 300 | | .0119 | 0.34 | 0.10 | 2.3 | 1.9 |
| | 22 | 330 | 420 | 290 | | .0298 | 0.45 | 0.20 | 4.4 | 4.7 |
| | 23 | 310 | 390 | 270 | | .0434 | 0.69 | 0.43 | 0.7 | 3.3 |
| | 24 | 290 | 370 | 260 | | .0325 | 0.30 | 0.06 | 0.9 | 1.1 |
| | 25 | 280 | 340 | 240 | | .0402 | 0.64 | 0.40 | 2.8 | 7.1 |
| | 26 | 240 | 310 | 210 | | .0730 | 0.98 | 0.72 | 3.3 | 10.9 |
| | 27 | 220 | 280 | 190 | | .0541 | 0.61 | 0.36 | 3.9 | 7.4 |
| | 28 | | | | | | | | | |
| | 29 | | | | | | | | | |
| | 30 | 190 | 240 | 140 | | .0354 | 0.50 | 0.22 | 7.0 | 8.6 |
| | 31 | 170 | 210 | 120 | | .0670 | 0.74 | 0.49 | 4.4 | 8.0 |
| Nov. | 1 | 150 | 180 | 100 | | .0737 | 0.76 | 0.53 | 7.2 | 14.4 |
| | 2 | 130 | 160 | 80 | | .0721 | 0.83 | 0.58 | 3.2 | 10.4 |
| | 3 | 120 | 150 | 80 | | .0225 | 0.68 | 0.45 | 2.0 | 6.7 |
| | 4 | 110 | 140 | 70 | | .0406 | 0.42 | 0.17 | 3.1 | 4.4 |
| | 5 | 100 | 120 | 60 | | .0557 | 0.59 | 0.34 | 3.7 | 5.8 |
| | 6 | 70 | — | — | | .1406 | 0.36 | 2.17 | 5.6 | 26.9 |
| | | ⑥ | ⑦ | ⑧ | ⑨ | | | | | |
| Nov. | 6 | 1560 | 1530 | 1520 | 1520 | | | | | |
| | 7 | 1300 | 1280 | 1250 | 1230 | 0.1939 | 2.52 | 2.36 | 6.5 | 29.8 |
| | 8 | 1200 | 1180 | 1150 | 1110 | .0840 | 0.98 | 0.73 | 4.8 | 13.4 |
| | 9 | 1170 | 1150 | 1130 | 1100 | .0185 | 0.32 | 0.05 | 2.0 | 1.2 |
| | 10 | 1130 | 1110 | 1080 | 1070 | .0338 | 0.35 | 0.08 | 6.7 | 5.1 |
| | 11 | 1100 | 1090 | 1070 | 1030 | .0215 | 0.29 | 0.12 | 4.7 | 3.5 |
| | 12 | 1080 | 1060 | 1040 | 1010 | .0217 | 0.39 | 0.12 | 5.7 | 5.9 |
| | 13 | 1050 | 1030 | 1010 | 970 | .0289 | 0.36 | 0.08 | 5.6 | 4.6 |
| | 14 | 990 | 970 | 950 | 910 | .0548 | 0.65 | 0.38 | 7.1 | 12.7 |
| | 15 | 980 | 950 | 930 | 880 | .0189 | 0.74 | 0.48 | 1.1 | 3.5 |