A Technique for Estimating Snow Transport Rate from the Mass Flux at a Given Height

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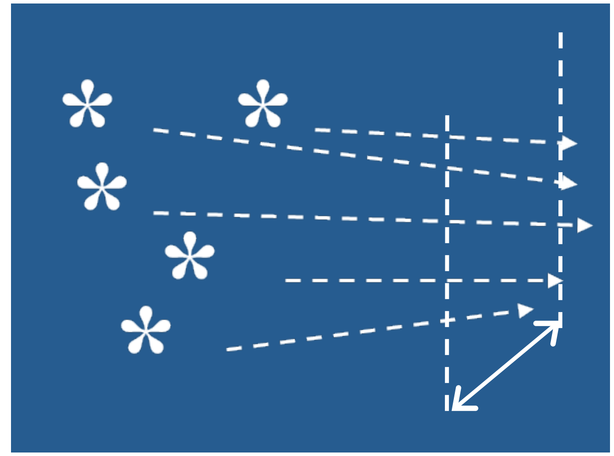
Introduction

Snow transport rate (Q): the mass of blowing snow particles that pass through a unit width per unit time
($g\ m^{-1}\ sec^{-1}$)



Required fence heights for the snow transport severity classes.

Classification	Snow transport (t/m)	Fence height (m)
Very Light	< 10	1.1
Light	10 - 20	1.5
Light-to-Moderate	20 - 40	2.0
Moderate	40 - 80	2.8
Moderately Severe	80 - 160	3.8
Severe	160 - 320	5.2
Extreme	> 320	> 5.2

Tabler (1994)

When planning and designing blowing-snow control facilities, i is necessary to know the cumulative annual snow transport.

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Introduction

The snow transport rate (Q) is generally estimated by using empirical equations.

- Budd et al. (1966) $\log Q = 1.22 + 0.0859 V_{10}$
- Tabler (2003) $Q = 0.00428 V_{10}^{3.8}$
- Takeuchi (1980) $Q = 0.0029 V_{1}^{4.16}$
- Kobayashi (1972) $Q = 0.03 (V_{1} - 1.3)^{3}$
- Matsuzawa et al. (2010) $Q = 0.05 V_{1.2}^{4}$

V_x: wind speed at the height of x (m)

Accurate determination of actual snow transport rate by using wind speed is difficult.

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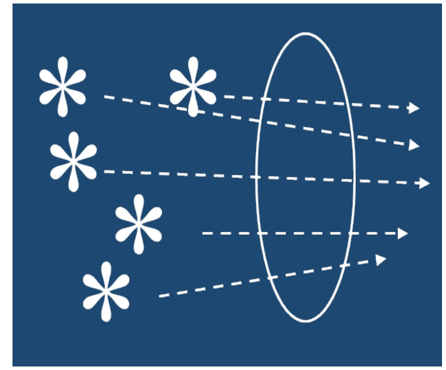
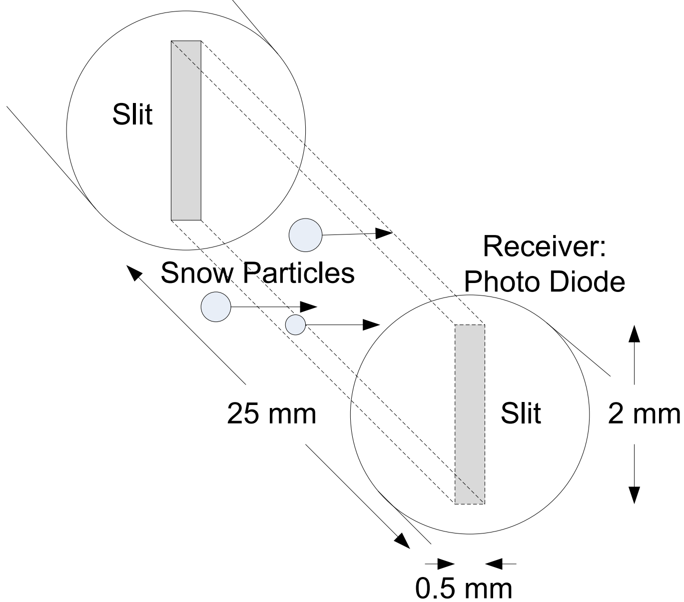
Mass flux and the snow particle counter (SPC)

Mass flux (q) : mass of the snow particles that pass through a unit area per unit time (g m^{-2} sec^{-1})



An SPC can measure mass flux continuously.



The SPC optically measures the number and size of airborne snow particles that pass between transmitter and receiver.

To clarify the relationship between the mass flux at a given height and the snow transport rate of blowing snow

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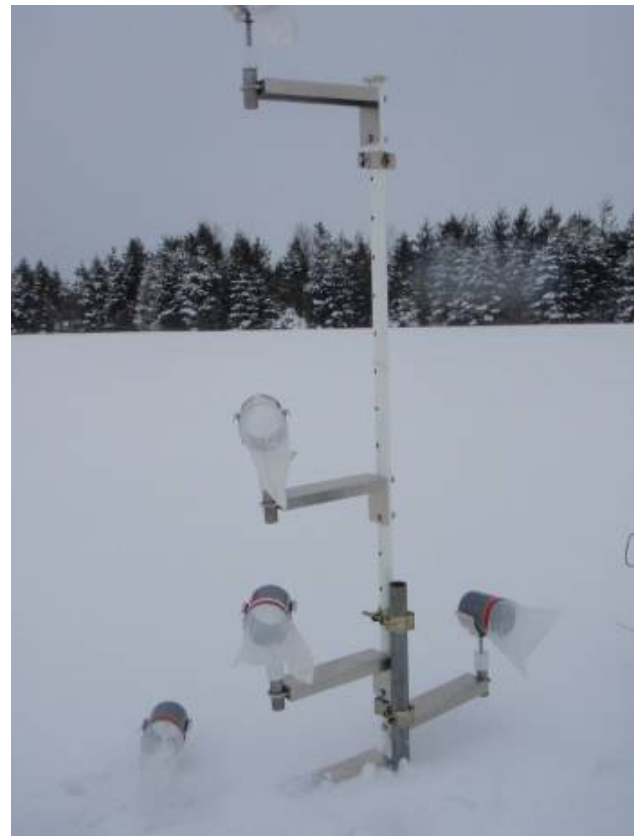
Field observation overview

The mass flux of snow was measured at the heights of 0.02, 0.05, 0.07 and 0.1 m using a box-shaped net-type blowing snow trap, and at the heights of 0.1, 0.3, 0.5, 1.0 and 2.0 m using a cylindrical net-type blowing snow trap.

Box-shaped net-type blowing-snow trap



Cylindrical net-type blowing-snow trap

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Meteorological data for the days of measurement

Date	Air temperature (°C)	Wind speed at the height of 1 m (m/s)	Precipitation (mm/h)
Feb. 21, 2012	-4.9 ~ -6.5	9.2 ~ 12.9	0.0
Feb. 3, 2013	-6.3 ~ -7.8	9.7 ~ 10.5	0.0
Jan. 31, 2014	-4.9 ~ -5.9	6.1 ~ 12.5	0.0 ~ 1.2
Mar. 6, 2014	-4.8 ~ -5.9	5.6 ~ 7.7	0.0 ~ 0.6

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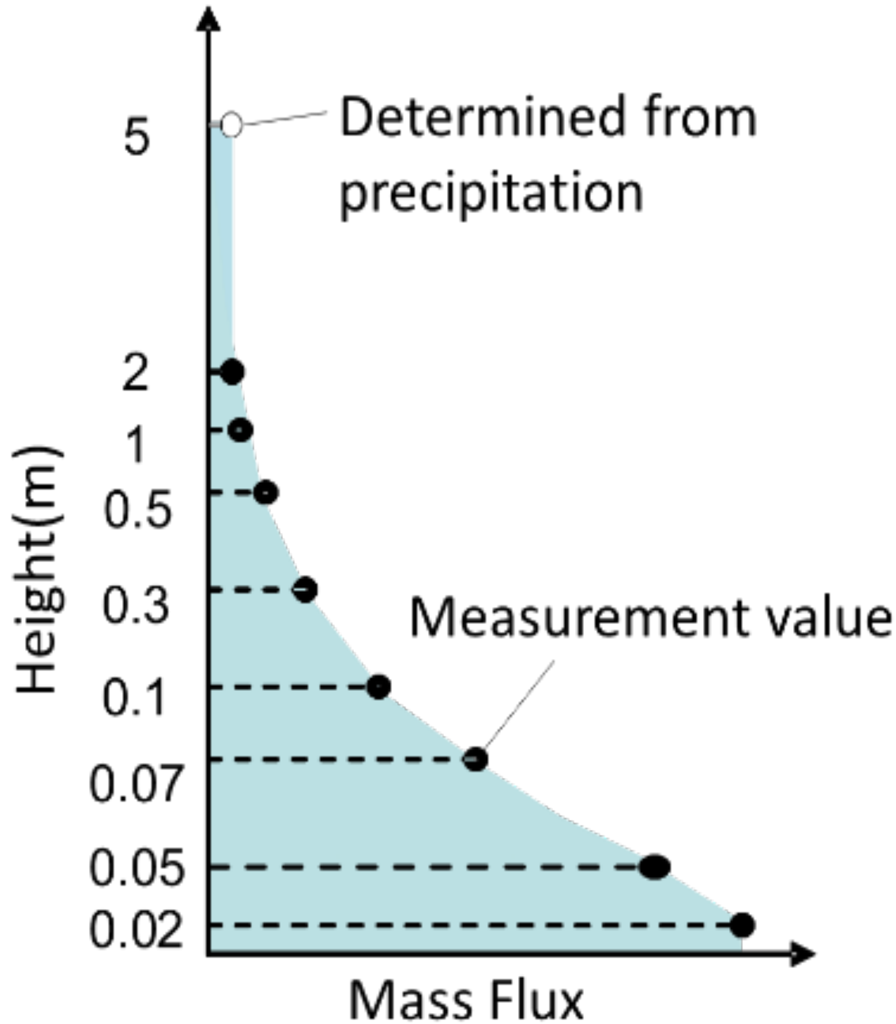
Calculation method to determine snow transport rate from mass flux of snow



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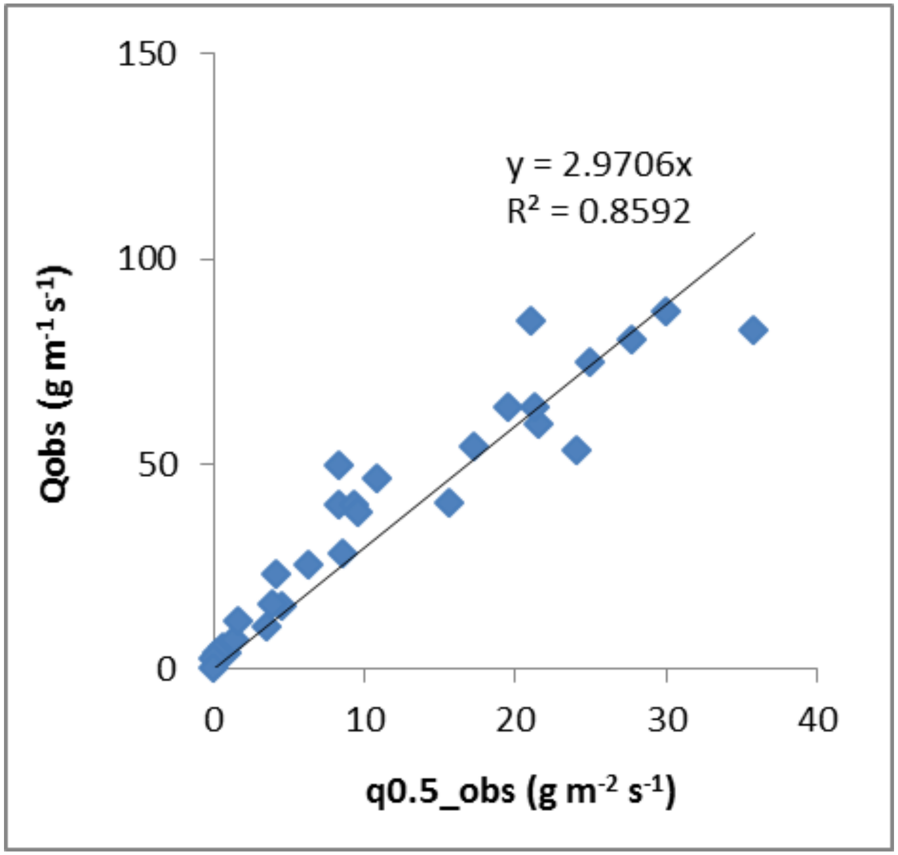
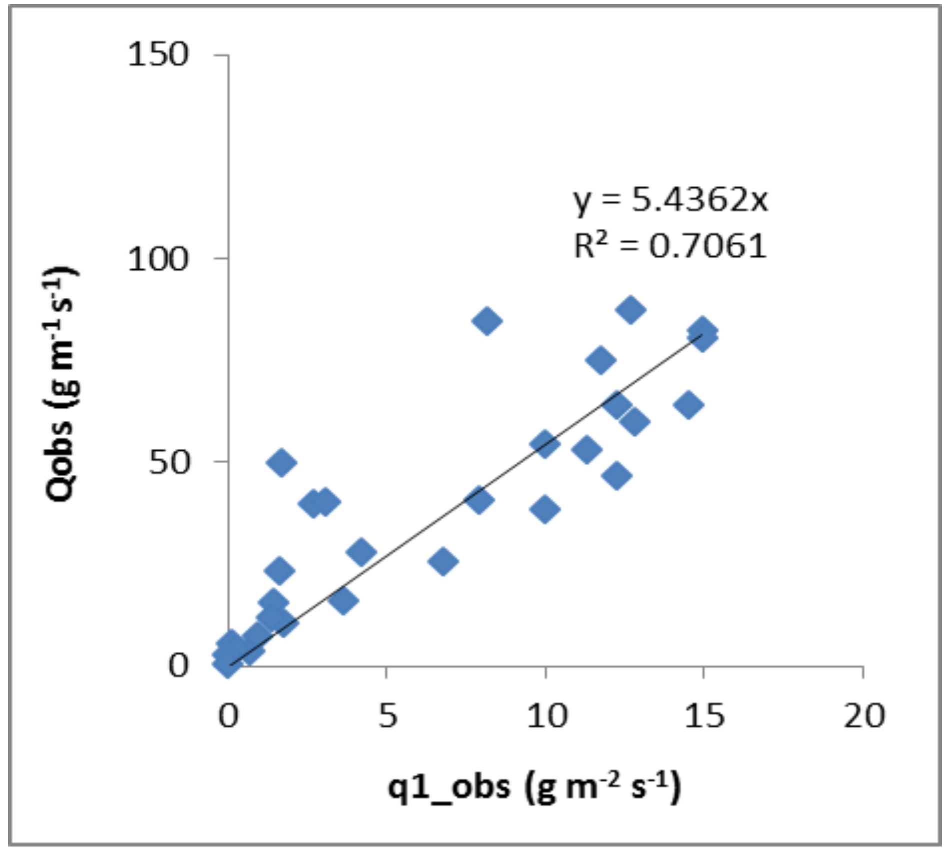
Results

The relational equation $Q = kq$ (k is a proportional constant) was obtained for the height of 0.5 m and the height of 1.0 m





$Q = 3.0\ q_{0.5}$

$Q = 5.4\ q_1$

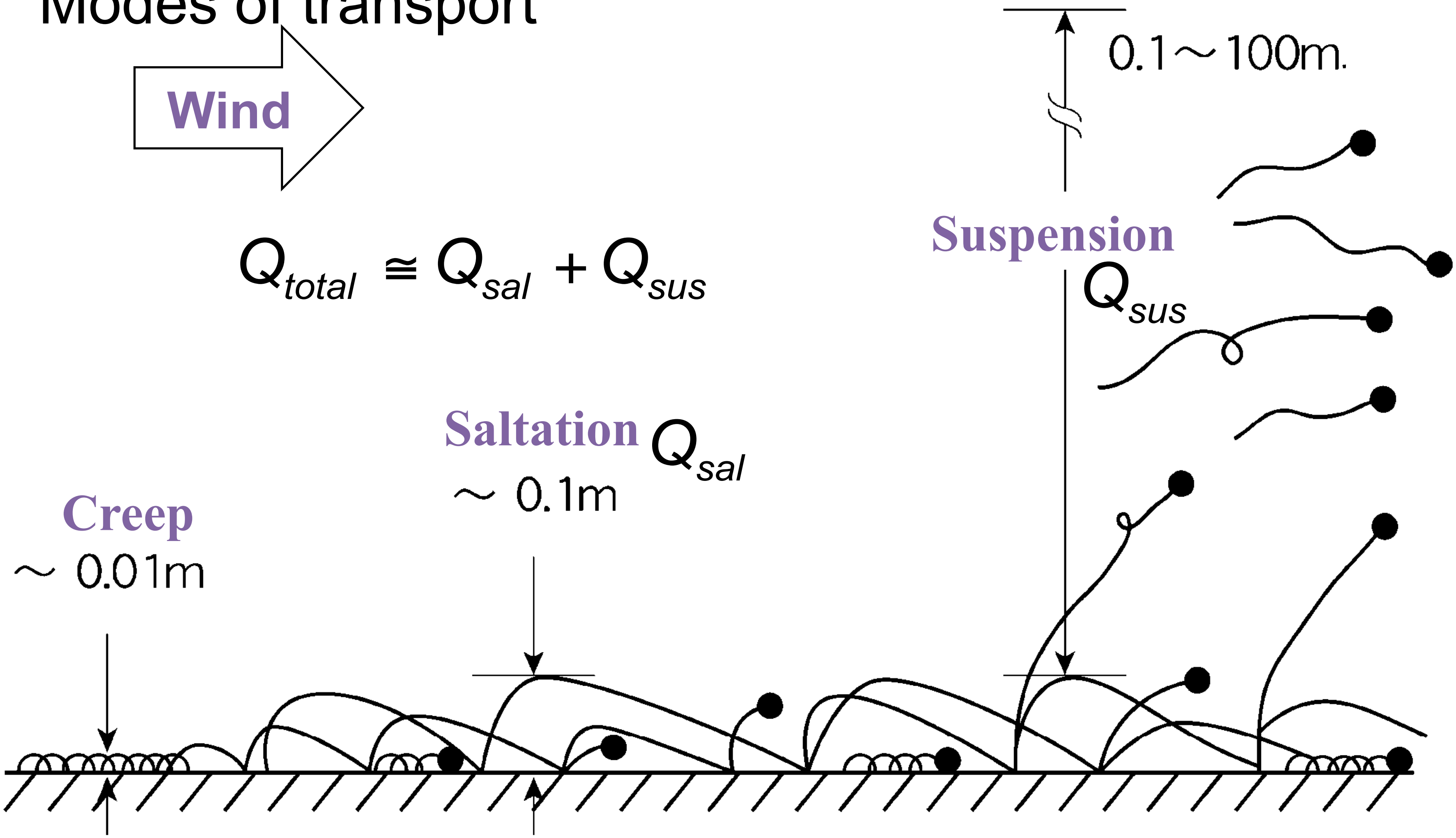
$q_{0.5}$: Mass flux at 0.5m height

q_1: Mass flux at 1.0 m height

Discussion

Estimation model of snow transport rate

Modes of transport



Takeuchi (1990)

Discussion(cont')

Estimation model of snow transport rate,

1) Q in the suspension layer: Q_{sus}

$$q(z) = N(z) \cdot V(z) \quad \cdots (1)$$

$$Q_{sus}(z) = \int q(z)dz = \int N(z) \cdot V(z)dz \quad \cdots (2)$$

$$N(z) = \frac{P}{w_f} + \left(N_t - \frac{P}{w_f}\right)\left(\frac{z}{z_1}\right)^{-\frac{w_b}{ku_*}} \quad \cdots (3)$$

Matsuzawa and Takeuchi (2002)

$$V(z) = \frac{u_*}{k}\ln\left(\frac{z}{z_0}\right) \quad \cdots (4)$$

where, $N(z)$: blowing snow density, $V(z)$: wind velocity,
P: precipitation intensity, N_t: blowing snow density at reference height z_1,
w_f: falling speed of snowfall particles,
w_b: falling speed of suspended particles
k: Karman coefficient (0.4), u_*: friction velocity, z_0: surface roughness

Discussion(cont')

1) Q in the suspension layer: Q_{sus}

$$q(z) = \frac{Pu_*}{kw}(\ln z - \ln z_0) + \frac{a}{z_1^b} \cdot z^b \ln z - \left(\frac{a}{z_1^b} \ln z_0\right) \cdot z^b \quad \cdots (5)$$

where, $a = \left(N_t - \frac{P}{w_f}\right)\frac{u_*}{k}$ $\quad b = -\frac{w_b}{ku_*}$

$$Q_{sus} = \left[\frac{Pu_* z}{kw_f}\left(\ln\frac{z}{z_0} - 1\right) + \frac{a}{b+1}\frac{z^{b+1}}{z_1^b}\left(\ln\frac{z}{z_0} - \frac{1}{b+1}\right)\right]_{z_1}^{z_2} \quad \cdots (6)$$

2) Q in the saltation layer: Q_{sal}

$$Q_{sal} = 0.03(V_1 - 1.3)^3 \quad \cdots (7)$$

Kobayashi (1972)

$$Q = Q_{sal} + Q_{sus} \quad \cdots (8)$$

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Calculation

$$Q_{sus} = \left[\frac{Pu_* z}{kw_f} \left(\ln \frac{z}{z_0} - 1 \right) + \frac{a}{b+1} \frac{z^{b+1}}{z_1^b} \left(\ln \frac{z}{z_0} - \frac{1}{b+1} \right) \right]_{z_1}^{z_2} \quad \cdots (6)$$

Where, $a = \left(N_t - \frac{P}{w_f} \right) \frac{u_*}{k}$ $\quad b = -\frac{w_b}{ku_*}$

$$Q_{sal} = 0.03(V_1 - 1.3)^3 \quad \cdots (7)$$

The following values are assigned to equation (6).

$z_0 = 1.5\text{x}10^{-4}$ (m) , $w_f = 1.2$ (m/s), $w_b = 0.25$ (m/s)
$z_1 = 0.15$ (m), $z_2 = 5.0$ (m)
$u_* = 0.036\ V_{10}$ (m/s)
$N_t = 0.021 \exp(0.401\ V_{10})$ (g/m^3)

Cases for calculation of *Q*

Precipitation: 0, 1, 2 (mm/h)
Wind velocity (V_{10}): 5.7 – 16.7 (m/s)

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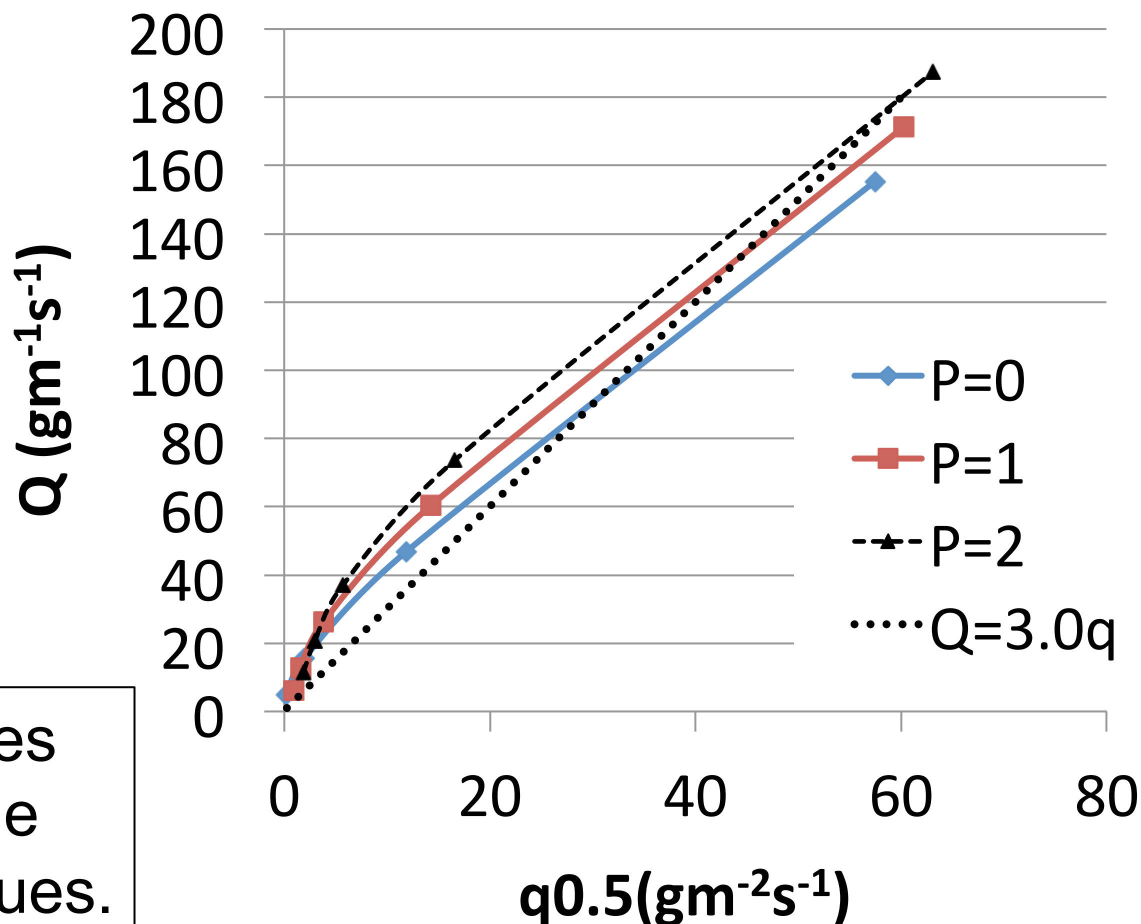
Mass flux of snow at the height of 0.5 m ($q_{0.5}$) vs. snow transport rate Q

From observed data:

$$Q = 3.0\ q_{0.5}$$



The calculated values are roughly the same as the observed values.

P is precipitation (mm/h).

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Summary

- The following relational equations between the snow transport rate Q and the mass flux q at a given height were obtained from field observations.

$$Q = 3.0\ q_{0.5} \qquad Q = 5.4\ q_{1}$$

Where,

$q_{0.5}$: mass flux of blowing snow at the height of 0.5m

q_{1}: mass flux of blowing snow at the height of 1 m

- Additionally, a model for estimating the snow transport rate from the mass flux was derived.
- The calculated values are found to be roughly the same as the observed values.
- It is considered that the empirical equations obtained from this study can be used to estimate the snow transport rate.

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Thank you for your attention!