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STRONG SNOW-STORMS, THEIR EFFECT ON SNOW COVER AND SNOW ACCUMULATION

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Abstract. Snow-drifts have been studied by many researchers both in field and laboratory conditions, however these investigations have been carried out mostly at wind speeds up to 20 m/s whereas in many areas of our planet snow-storms occur at winds up to 40 m/s and more. During the winter seasons of 1972–76 the authors carried out a great number of experiments with an artificial snow-storm in a special wind tunnel 27 m long. The wind speeds reached 40 m/s (60–65 m/s at the 10 m anemometer height). The existing theories and hypotheses of snow-drifting, and in particular the "diffusion" model, were tested in a series of the experiments. These have not confirmed the assumption of the Australian scientists on the decisive role of diffusion in drift mechanism at large wind speeds. The problem of strong snow-storm effect on snow accumulation on avalanche-danger slopes, in particular, wind redistribution of snow is no less important.

The results obtained may be used for the determination of snow accumulation in avalanche starting zones due to deflation. This is especially important for forecasting very dangerous and frequently-occurring avalanches due to snow-storms. The investigations performed enable us to estimate the snow deposition produced by strong and superstrong snow-storms, to account for the peculiarities of such snow-storms and the means of protection, to forecast snow distribution in mountainous regions, and to define the role of snow-storms in glacier mass balance.

Résumé. *Fortes tempêtes de neige, leurs effets physiques sur le manteau neigeux et l'accumulation de la neige sur les pentes dangereuses pour les avalanches.* La formation de congères de neige a été étudiée par de nombreux chercheurs à la fois sur le terrain et en laboratoire, cependant ces recherches ont surtout été faites à des vitesses de vent atteignant 20 m/s tandis qu'en bien des points de notre planète des tempêtes de neige se produisent par des vents de plus de 40 m/s. Pendant les hivers 1972 à 1976 les auteurs de ce rapport ont effectué un grand nombre d'expériences avec des tempêtes de neige artificielles dans un tunnel spécial de 27 m de long. Les vitesses de vent ont atteint 40 m/s (60 à 65 m/s à 10 m d'altitude de la girouette). Les théories et hypothèses existantes sur le chasse-neige, le modèle "diffusion" en particulier ont été essayées dans la série des essais. Ils n'ont pas confirmé les hypothèses des savants australiens sur le rôle décisif de la diffusion dans le mécanisme du chasse-neige aux grandes vitesses de vent. Le problème de l'effet des fortes tempêtes de neige sur l'accumulation de la neige dans les pentes dangereuses pour les avalanches, en particulier la redistribution de la neige par le vent n'est pas moins important.

Les résultats obtenus peuvent être utilisés pour le détermination de l'accumulation de la neige dans les zones de départ d'avalanche en raison de la déflation. Ceci est spécialement important pour la prévision des avalanches très dangereuses qui suivent souvent les épisodes neigeux avec tempête. Nos investigations nous permettent d'estimer l'importance des dégâts de neige engendrés par les tempêtes de neige fortes et très fortes, de prendre en compte les particularités de ce type de chutes de neige et les moyens de s'en protéger, et de définir le rôle des tempêtes de neige dans les bilans glaciaires.

Zusammenfassung. *Starke Schneestürme, ihr physikalischer Einfluss auf die Schneedecke und die Schneeakkumulation auf lawinengefährlichen Hängen.* Die Schneedrift ist von vielen Wissenschaftlern sowohl im Feld wie unter Laborbedingungen untersucht worden, doch wurden diese Studien meist bei Windgeschwindigkeiten bis zu 20 m/s durchgeführt, während in vielen Gebieten unseres Planeten Schneestürme mit Winden bis zu 40 m/s und mehr vorkommen. In den Wintern von 1972 bis 1976 nahmen die Autoren dieses Beitrages viele Versuche mit künstlichen Schneestürmen in einem Windkanal von 27 m Länge vor. Die Windgeschwindigkeiten reichten bis zu 40 m/s (60–65 m/s in 10 m Höhe über dem Boden). Die vorhandenen Theorien und Hypothesen der Schneedrift, besonders das "Diffusionsmodell", wurden in dieser Versuchsserie überprüft. Es ergab sich keine Bestätigung der Annahme australischer Forscher einer wesentlichen Rolle der Diffusion im Duft-Mechanismus bei hohen Windgeschwindigkeiten. Die Frage des Einflusses starker Schneestürme auf die Schneeakkumulation an lawinengefährlichen Hängen, besonders die Umlagerung des Schnees durch Wind ist nicht weniger wichtig.

Die gewonnenen Ergebnisse können zur Bestimmung der Schneeakkumulation in Bereichen herangezogen werden, in denen durch Entblössung Lawinen ausgelöst werden. Dies ist besonders wichtig für die Vorhersage sehr gefährlicher und häufiger Lawinen, die von Schneestürmen ausgelöst werden. Die durchgeführten Untersuchungen ermöglichen die Abschätzung der Schneeablagerung durch starke und überstarke Schneestürme, die Berücksichtigung der Besonderheiten solcher Schneestürme und der entsprechenden Schutzmassnahmen, die Vorhersage der Schneeverteilung in Gebirgsregionen und die Bestimmung des Anteils von Schneestürmen an einem Gletscherhaushalt.

List of symbols

t	time coordinate
x_k	space coordinate
γ	mean weight concentration of bearing phase, g/cm³
γ_{sol}	mean weight concentration of solid phase, g/cm³
γ_a	concentration of falling snow particles, Mg/m³
γ_s	mean density of snow, Mg/m³
q_i, q_k	components of mean weight flux of bearing (air) phase, g/cm² s
q_{si}, q_{sk}	components of mean weight flux of solid (snow) phase, g/cm² s
Q_{max}	maximum solid flux of snow-storm, g/m s
Q_s	total solid flux of snow-storm, g/m s
Q	weight of blown snow, Mg/m³
v_i, v_k	components of mean velocities of bearing phase, cm/s
v_{si}, v_{sk}	components of mean velocities of solid phase, cm/s
$v_1(x_3)$	wind speed at x_3-level, m/s
v_h	wind speed at the height h from the snow surface, m/s
v_0	wind speed at beginning of snow transport, m/s
$v_{0.2}$	wind speed at 0.2 m height, m/s
v_{10}	wind speed at 10 m height, m/s
v_g	group speed of the snow particles, m/s
v_m	mean speed of snow-storm current, m/s
u_*	friction velocity, cm/s
w	falling velocity of snowflakes, m/s
g, g_i	magnitude and i-component of the gravitational acceleration, m/s²
M'_k	sum of correlation moments between weight concentration pulsations and velocities of both bearing and solid phases, g/cm² s
M''_{ki}	sum of correlation moments between the weight-flux pulsation and velocities of bearing and solid phases, g/cm² s
Π_{ki}	tensor of molecular stresses in a two-phase medium, g/cm²
τ_{ki}	generalized tensor of stresses, g/cm²
s	dimensionless volumetric concentration of snow particles in mixture "snow+air"
ρ	mass density of air, g s²/cm⁴
ρ_s	mass density of snow, g s²/cm⁴
τ_{s3}	quasi-static pressure difference, g/cm²
μ_3	diffusion coefficient, cm²/s
K	Kármán's constant
Υ	criterion of stability of saltation layer
x_0	linear index of roughness, cm
h	thickness of the snow cover, cm
d	size of snow particle, cm
δ_s	size of surface snow particles, cm
α	slope angle, grade
$\mathscr{L}_n$	limit length of transporting uniform snow, m
x_p	growth length of snow-storm, m

1. Utilitarian problems

The larger part of the Soviet Union lies in the zone of snow-storm activity that greatly interferes with the normal functioning of traffic, industrial and power units. In economic development of high-latitude areas of the Northern Hemisphere, man in his practical activity will have to face the effect of especially strong snow-storms on engineering structures.

The scientific and applied significance of such natural two-phase flow as snow-storms is enormous. The formation of glaciers and snow avalanches, the regime of water-flow from snow melt, water conservation on agricultural land, snow-drifts on settlements, roads and enterprises—this is not a complete list of the phenomena greatly dependent on snow-storms.

The regularities of mountain snow-storms and snow-drift during the strong blizzard conditions are not sufficiently studied. Methods of control of heavy snow-storms are not fully worked out. All these utilitarian problems are consequences of one important theoretical problem—the mechanism of deflation in suspended streams. Therefore interest in the theory of snow-storms is quite natural.

Any generally adopted concept of the main causes of solid-particle movement in two-phase flow is until now missing. Shulyak (1971) supposes that deflation is a consequence of a development of the initial disturbance of the surface of the loose medium. Radok (1970) considers that the main cause of deflation is turbulent diffusion of the suspended particles. We are convinced of the decisive role of the quasi-static pressure field in the boundary layer of two-phase flow.

Theoretical, field and experimental researches on snow-storms (Dyunin, 1963; Dyunin and others, 1973) show that the main zone of deflated snow-storm action is a comparatively thin boundary layer 2–3 m thick; more than 90% of the total drifting snow being the lowest sublayer about 10–20 cm thick.

In the strongest winds some small snowflakes can rise to a considerable height, but they constitute only an insignificant part of the total solid flux of the snow–wind flow. The deflated particles move over the ground unevenly by means of "saltation". This essentially facilitates the study of such complex phenomena as up-snow-storms in hilly and mountainous regions. Up-snow-storm is the atmospheric snow-flake drift until the moment they touch the Earth's surface. Deflation and up-snow-storms have strictly defined zones of action and do not essentially "hamper" each other.

2. Basic theories of snow-storms

2.1. *General theory of two-phase flow*

The theoretical foundations of snow-storm mechanics are the common equations of mass, impulse and energy balances of the multicomponent continuous medium. The differential equations of continuity and balance of impulse flows for a two-phase medium averaged in space and time terms are (Dyunin and others, 1965):

$$\frac{\partial(\gamma+\gamma_s)}{\partial t}-\frac{\partial(\gamma v_k+\gamma_s v_{sk})}{\partial x_k}=-\frac{\partial M'_k}{\partial x_k}, \tag{1}$$

$$\frac{\partial(q_i+q_{si})}{\partial t}+\frac{\partial(q_k v_i+q_{sk}v_{si})}{\partial x_k}=(\gamma+\gamma_s)\,q_i-g\,\frac{\partial}{\partial x_k}\,\Pi_{ki}-\frac{\partial M''_{ki}}{\partial x_k}, \tag{2}$$

where t, x_k are time and space coordinates respectively; γ, γ_s mean weight concentrations bearing air and solid phases; (q_i, q_k), (q_{si}, q_{sk}) components of mean weight flux of bearing (air) and solid (snow) phases respectively, (v_i, v_k), (v_{si}, v_{sk}) components of mean velocities of the bearing and solid phases respectively, g, g_i modulus and i-component of the gravity acceleration respectively, M'_k sum of correlation moments between weight concentration pulsations and of both phase velocities, M''_{ki} is the sum of correlation moments between the weight flux pulsation and velocities of both phases, Π_{ki} is the tensor of molecular stresses in a two-phase medium that is considered to be continuous.

Equation (2) supplies information on the analysis of the suspension of heavy impurities. Let τ_{ki} be the generalized tensor of stresses defined as

$$\tau_{ki}=\Pi_{ki}+\frac{M''_{ki}}{g}. \tag{3}$$

It should be noted, that

$$\gamma = (1 - s)\,\rho g; \qquad \gamma_s = s\rho_s g, \tag{4}$$

where s is volumetric concentration of impurities in mixture, ρ, ρ_s are mass densities of air and snow respectively.

Let us consider a flat and stationary flow directed along the x_1-axis, over the horizontal plane $x_3 = 0$. Using the ergodics of the stationary process, let us choose a region of space for averaging in the form of a thin parallelopiped whose extension along the x_1-axis is large enough to neglect the dependence of averaged terms on x_1, and conform to the condition $q_s = q_{s3} = 0$.

Having a projection of Equation (2) on the x_3-axis directed vertically upwards and using Equations (3) and (4) we can easily find for the given case that

$$\gamma_s = -\frac{1}{1-(\rho/\rho_s)}\left(\rho g + \frac{\partial \tau_{s3}}{\partial x_3}\right). \tag{5}$$

Equation (5) shows that the quasi-static pressure excess τ_{s3} ought to be considered the main factor in suspending impurities, since $\rho \ll \rho_s$. Impurity suspension will only be possible when $\partial\tau_{s3}/\partial x_3 \gg \rho g$. The measurements show that this excess differs from zero only at the contact with the bed surface, i.e. there are no essential factors promoting the continuous soaring of impurities inside the snow–air flow (Dyunin and others, 1965; Dyunin, 1966).

The above theory is very consistent with the field and laboratory data.

2.2. *Diffusion model of snow-storms*

A simplified "diffusion" snow-storm model is possible, the most recent using only the continuity equations (1). Let us assume, that

$$M'_k = -\mu_s \frac{s\gamma_s}{\partial x_k}, \tag{6}$$

where μ_s is the diffusion coefficient. Taking the previous assumption of a stationary regime we find γ_s from Equation (1) with accuracy to a constant vector.

$$\gamma_s = \frac{\mu_s}{v_{s3}} \cdot \frac{\partial \gamma_s}{\partial x_3}, \tag{7}$$

since $\gamma v_k \ll \gamma_s v_{sk}$.

Taking Equation (7) as the initial equation Radok (1970) supposed that

$$\mu_s = \frac{K^2 x_3 v_1(x_3)}{\ln \dfrac{x_3}{x_0}}, \tag{8}$$

$$v_s g = w, \tag{9}$$

where $v_1(x_3)$ is the wind speed at the x_3 level, K Kármán's constant, x_0 the linear index of roughness, w the fall velocity of the snowflakes. The model of impurities diffusion is considered to be similar to the Kármán's model of the turbulent diffusion of homogeneous flow. According to Equation (8) the diffusion coefficient is intensively increasing with height so that the greater part of snow mass must be transported as a suspension in the upper boundary layers of the atmosphere.

Analysing the diffusion equations, the Australian researchers (Budd and others, 1964) indicate that weight concentration of the impurities in some layer does not depend on wind speed. Therefore weight concentration in this layer is not increased with wind speed and an addition to drifting matter has been produced by diffusion of solid particles to the upper layers.

Owen (1964) introduced the criterion for saltation layer stability

$$\gamma = \frac{\rho u_*^2}{\rho_s g d}, \qquad (10)$$

where u_* is the friction velocity, d is the particle size.

According to Budd and others (1964)

$$u_* \approx 3.78 v_{10},$$

where v_{10} is the wind speed at the 10 m height. Making the substitution $u_* = 3.78 v_{10}$ in Equation (10) gives

$$\Upsilon = 1.83 \times 10^{-5}\, v^2{}_{10}/\rho_s a.$$

The zone of possible saltation is up to the inequality

$$0.01 \leqslant \Upsilon \leqslant 1.0. \qquad (11)$$

When $\Upsilon > 1.0$ the shearing force exceeds the particle weight and all particles will be carried into suspension. Let us calculate the values of v_{10} when $\Upsilon = 0.01$ or $\Upsilon = 1.0$ and $\rho_s = 0.9$ g/cm^3 (the density of Antarctic snow particles) and $d = 0.01$ cm.

We have

$$v_{10} = 2.21 \text{ m/s when } \Upsilon = 0.01 \qquad \text{and} \qquad v_{10} = 22.1 \text{ m/s when } \Upsilon = 1.0.$$

Thus, saltation is possible under the range of wind speed from 2.21 to 22.1 m/s (at 10 m height) when $d = 0.1$ mm. Therefore when $v_{10} > 22.1$ m/s snow particles will be carried into suspension since $\Upsilon > 1.0$.

We shall call the boundary of such a transition the threshold of mass suspension. An experimental verification of the diffusion model would be reduced to detecting the deep qualitative changes in the mechanism of snow drifting when the wind speed reached the threshold of mass suspension. The vertical distribution of solid flux in a layer near the snow surface would be uniform all over the section. In other words when $v_{10} > 22.1$ m/s the distribution of solid flux with height in a sectional wing-like trap of the kind used by R. Bagnold will be uniform.

This hypothetical statement was subjected to experimental test in a wind tunnel. The results of these experiments are given in section 3.

The verification of the theoretical models in a wind tunnel is possible when the following conditions are assured: (1) the vertical profile of wind speed is similar to the wind profile in Nature; (2) the turbulent two-phase boundary layer has time to stabilize, i.e. the growth length (acceleration length) of a snow-storm is confined to the working zone of the wind tunnel.

3. Experimental results

All these conditions were satisfied in the wind tunnel designed by Istrapilovich (1972). The length of the working zone of the wind tunnel is 27 m, its cross-section 0.5×0.6 m^2. The fan Ц 9-57 N 8 with its maximum rate of revolution (1 000 r.p.m.) and with completely open throttle has provided a flow velocity up to 43 m/s. The cooling is natural.

The distribution of solid flux with height is found by means of a Bagnold wing-like trap. The effect of tunnel dimensions (its cross-section) on wind-speed profile was studied on several wind tunnels with different cross-sections. A scale factor was defined on tunnels with sections from 0.15×0.5 m^2 to 0.5×0.6 m^2. Some of the experimental results are published in Dyunin (1974).

At present a wind tunnel of length 27 m and cross-section 1.0×1.5 m^2 is being used. This tunnel will permit an approach to natural conditions on the scale 1 : 1 and allow us to simulate flow around the small models of the mountainous regions.

The experimental results are given in Figure 1, which also shows theoretical curves of maximum solid flux calculated from the equations

$$Q_{\max} \approx 0.34(v_{0.2}-3)^2 \qquad \text{(Dyunin, 1963)} \tag{12}$$

$$\left.\begin{aligned} \log Q^{0.125}_{10^{-3}} &= 1.36+0.054\,5 v_{10} \\ \log Q^{300}_{2} &= 0.255+0.127 v_{10}. \end{aligned}\right\} \qquad \text{(Budd and others, 1964)} \tag{13}$$

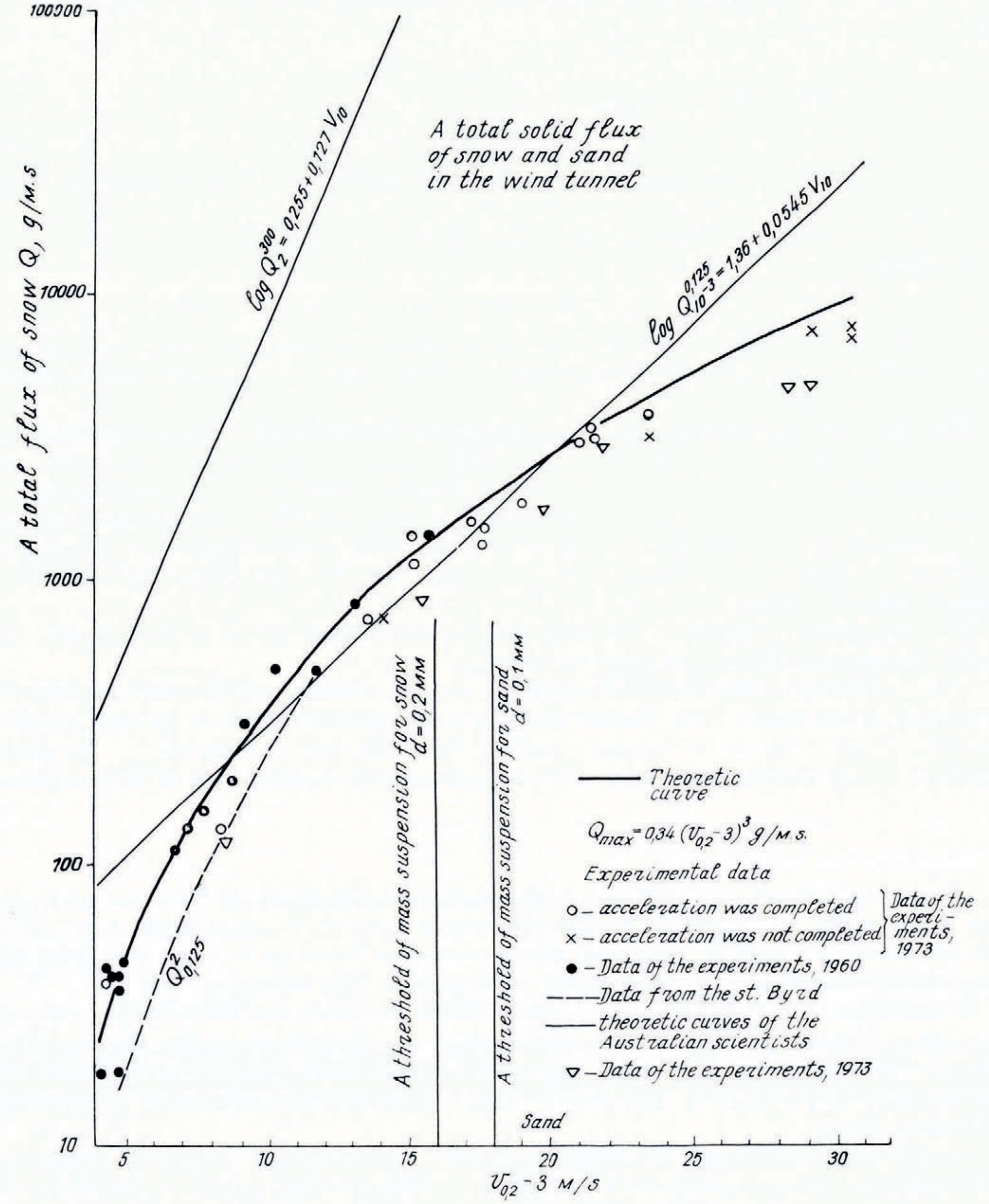

Fig 1. Graph of dependence of maximum solid flux on wind speeds.

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As Figure 1 shows, the measurements lie far beyond the limits of the threshold but significant deviation from the "pre-threshold" tendency was not detected.

Figure 2 shows the snow and sand contents in the trap sections (in %) from the total weight of the material collected by the Bagnold trap. The distribution of solid flux with height appeared to be similar both at weak and strong wind speeds. The main part of the snow is transported near the snow surface.

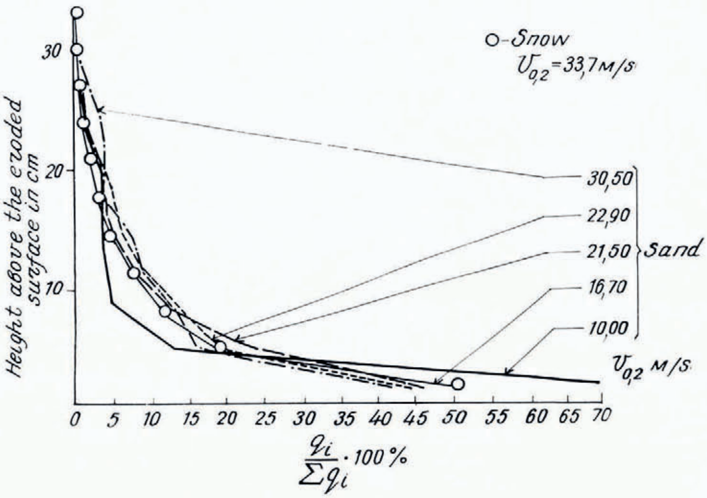

Fig. 2. Vertical distribution of solid flux at different wind speeds.

Nevertheless the boundary-layer structure is essentially reconstructed when the Owen–Radok criterion $\Upsilon > 1$ is satisfied. When $\Upsilon > 1$ at the beginning of deflation, the zone of negative quasi-static pressure differential is more strongly marked. Pressure differential is also observed inside snow cover, where it inevitably influences the snow metamorphism. These internal pressure differentials play a decisive role in the formation of cones of erosion around obstacles. In the literature the role of vortex rollers in the formation of erosion cones is grossly exaggerated although they are only secondary phenomena.

4. Influence of snow-storms on snow cover in mountains

In mountainous regions, snow-storms influence the redistribution of snow on the slopes and in the valleys. They also greatly influence the avalanche regime.

Investigations on mountainous snow-storms are very difficult because of the extreme variety of mountainous microclimate in small space and time intervals.

Let us consider the plane movement of a snow-storm along a slope inclined to the horizon at an angle α (Fig. 3).

Having calculated the solid flux in the parallelopiped *abcd* we find (Dyunin and others, 1973):

$$\frac{\mathrm{d}h}{\mathrm{d}t} = \frac{\gamma_a w}{\gamma_s} \frac{1}{\gamma_s \cos \alpha} \left(\frac{\partial Q_1}{\partial x_1} + \frac{Q_1}{\mathscr{L}_n} \right), \tag{14}$$

where h is the thickness of the snow cover on the slope measured vertically, γ_a the concentration of falling snow particles, w the falling speed of these particles, γ_s the mean density of snow, Q the weight of snow blown through the edges of the parallelopiped *abcd*, $\mathscr{L}_n$ the limit length of transporting uniform snow.

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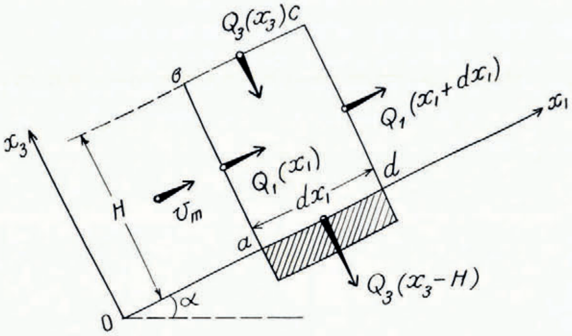

Fig. 3. Theoretical model of snow-storm on a mountainous slope.

With a constant falling speed of the snow particles w, and average snow-cover thickness H we have:

$$\frac{\partial Q_{\mathrm{I}}}{\partial x_{\mathrm{I}}} = \frac{\partial Q_{\mathrm{s}}}{\partial x_{\mathrm{I}}} + H\left(\theta\,\frac{\partial \gamma_{\mathrm{a}} v_{\mathrm{m}}}{\partial x_{\mathrm{I}}} - w \cos\alpha\,\frac{\partial \gamma_{\mathrm{a}}}{\partial x_{\mathrm{I}}}\right), \tag{15}$$

where $\theta = v_{\mathrm{g}}/v_{\mathrm{m}}$ is constant and where Q_{s} is the total solid flux of snow-storm, v_{m} the mean speed of snow-storm current, and v_{g} the group speed of the snow particles.

The total solid flux Q_{s}, according to our field data and modelling the snow-storms in a specially inclined wind tunnel, depends slightly on the slope angle at $\alpha < 30$–$40°$.

In general form:

$$Q_{\mathrm{s}} = \frac{\Phi(v_h - v_0)^3}{\left(\frac{1}{\rho} - \frac{1}{\rho_{\mathrm{s}}}\right)\ln\frac{h}{\delta_{\mathrm{s}}}}, \tag{16}$$

where v_h is the wind speed at the height h from the snow surface, v_0 the wind speed at the beginning of snow transport, ρ and ρ_{s} the mass densities of air and snow respectively, and δ_{s} the size of the surface snow particles.

Φ is the compound periodic function of x_{I} given in Figure 4. The distance x_{p} called as a growth length and the wave length depend on the spectrum of turbulent wind pulsations, its gusts. In the mountains, wind gusts are extremely marked.

Equations (14)–(16) give the following important parameters when the influence of snow-storm on the snow cover must be taken into consideration: the values of Φ and x_{p}, the absolute value of wind speed v_h and its direction, the gradient $\partial v_h/\partial x_3$ (vector pulsations of

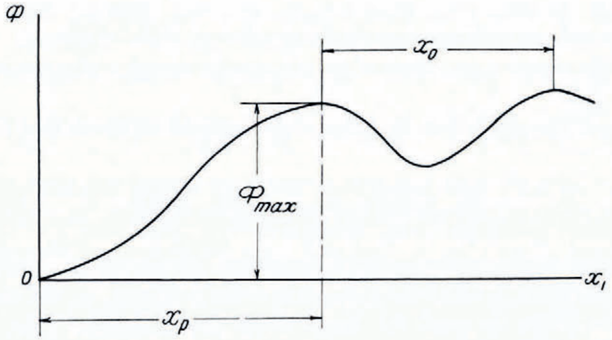

Fig. 4. Graph of approximate dependence of Φ on limiting length of snow transport x_{I}.

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wind speed), the gradient $\partial Q_s/\partial x_1$, evaporation intensity during snow-storms, growth length $\mathscr{L}_n$, the gradient $\partial v_m/\partial x_1$ of blowing solid precipitation.

The role of up-snow-storm in snow accumulation in the mountains differs from the influence of deflated snow-storm. Snow transport during deflated snow-storm is carried along mainly by saltation. During up-snow-storm a simple falling of snow particles is observed, which is however sharply distorted near large obstacles. Deflated and up-snow-storms have strictly defined action zones.

5. Conclusions

1. Drifting snow is transported mainly by saltation at all conceivable wind speeds.

2. The gravitation field, the kinematic field of the wind speed, its pulsations, and the quasi-static pressure field in the snow-storm stream and the loose-medium influence the formation of deflational snow-storm and snow cover.

3. Up-snow-storm and deflational snow-storm can be considered as independent factors when the distribution of snow in the mountains is estimated.

REFERENCES

Budd, W. F., *and others*. 1964. *Byrd Snow Drift Project, by W. F. Budd, R. Dingle and U. Radok.* Melbourne, University of Melbourne, Meteorology Dept. (University of Melbourne. Meteorology Dept., Publication No. 6.)

Dyunin, A. K. 1963. *Mekhanika meteley* [*Mechanics of snow-storms*]. Novosibirsk, RIO Sibirskogo Otdeleniya Akademii Nauk SSSR.

Dyunin, A. K. 1966. Suspension factor in two-phase flow. *Buletinul Institutului Politehnic din Iaşi*, Ser. Nona, Tom. 12(16), Fasc. 1–2, p. 367–78.

Dyunin, A. K. 1974. Mekhanika silnyh meteley [Mechanics of strong snow-storms]. *Trudy Novosibirskogo Instituta Inzhenerov Zheleznodorozhnogo Transporta*, Vyp. 159.

Dyunin, A. K., *and others*. 1965. *Osnovy mekhaniki mnogokomponentniykh potokov* [*Fundamentals of mechanics of multi-component flows*]. [By] A. K. Dyunin, Yu. M. Borshchevskiy, N. A. Yakovlev. Novosibirsk, RIO Sibirskogo Otdeleniya Akademii Nauk SSSR.

Dyunin, A. K., *and others*. 1973. Influence of snow storms on snow cover formation in mountains, [by] A. K. Dyunin, A. A. Komarov and E. P. Isayenko. (*In* [International Hydrological Decade.] *The role of snow and ice in hydrology. Proceedings of the Banff symposia, September 1972.* Paris, UNESCO; Geneva, WMO; Budapest, IAHS, Vol. 1, p. 76–81.)

Istrapilovich, M. G. 1972. Aerodinamicheskaya truba nauchno-issledovatel'skoy laboratorii po bor'be s zanosami i lavinami [Wind tunnel of the Snow and Avalanche Laboratory]. *Trudy Novosibirskogo Instituta Inzhenerov Zheleznodorozhnogo Transporta*, Vyp. 141, p. 175–79.

Owen, P. R. 1964. Saltation of uniform grains in air. *Journal of Fluid Mechanics*, Vol. 20, No. 2, p. 225–42.

Radok, U. 1970. *Boundary processes of drifting snow. Studies of drifting snow.* Melbourne, University of Melbourne, Meteorology Dept. (University of Melbourne. Meteorology Dept., Publication No. 13.)

Shulyak, B. A. 1971. *Fizika voln na poverkhnosti sypuchey sredy i zhidkosti* [*Physics of waves on surface of loose medium and fluid*]. Moscow, "Nauka".