# STUDYING SNOWDRIFTING PROBLEMS WITH SMALL-SCALE MODELS OUTDOORS 1/

By

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## Introduction

The Need for Model Studies.--It is usually impossible to predict, *a priori*, snowdrift patterns formed by structures and terrain features with any certainty because drift geometry is determined by a complex interaction of local wind characteristics, quantity of snow transport, surrounding terrain and object shapes. This has prompted investigators to simulate blowing snow in wind tunnels and water flumes, using reduced-scale models to study drift characteristics. Finney (1934) was the first to publish results of systematic studies of simulated snowdrifts using sawdust and mica in a wind tunnel, and this work has provided many quantitative guidelines that are still used to design snow fences and highways. More recently, Theakston (1967, 1970) has used sand in water flume simulations to qualitatively predict drifts on roofs, around buildings, and on highway and railroad sections.

In addition to being indispensible for solving practical engineering problems on an individual case basis, modeling studies can also provide data needed to develop general empirical expressions describing drift geometry in terms of terrain and barrier (or structure) characteristics. This data is often impossible to obtain from full-scale studies because of the variety of site and weather conditions encountered in the field, and the inability to isolate effects of the individual variables that combine to determine drift characteristics. Because of the annual variability in snow transport quantities, field measurements must be repeated over many years if results are to represent maximum drift development, and even then some uncertainty must remain because snow transport is always limited under natural conditions. It is obviously impossible to observe the ultimate full-scale drift configuration for large objects or major topographic accumulation areas where the capacity for snow accumulation is much greater than the mass transport.

Difficulties in Simulating Blowing Snow.--Considering the many practical applications of reduced-scale modeling for scientific studies of snow transport, erosion and deposition, it may seem curious that so little use has been made of the technique since its introduction by Finney (1934). This disparity, which is particularly obvious in light of the spectacular success in modeling single-phase aerodynamic and fluid dynamic problems, can be explained by the difficulty of simulating blowing snow in wind tunnels or water flumes. The theoretical requirements which must be met to assure quantitative scaling of snowdrifts, as most recently summarized by Iversen (1979, 1980), point up the difficulties in simulating blowing snow. Certain compromises must be made in the similitude requirements, and even then a suitable facility is expensive and not available to most people who could benefit from modeling experiments. This paper introduces an alternative approach that circumvents the formidable problems of simulating blowing snow, and which promises to make model studies possible for anyone who wants to do them.

Aspects of Outdoor Modeling Presented in Paper.--Our studies of drifts formed by full-scale snow fences suggest that dimensions of drifts formed under natural conditions are proportional to object height (Tabler 1980a), prompting us to explore the possibility for studying reduced-scale models outdoors under natural blowing snow conditions. This paper summarizes the theory of natural scaling as a scientific basis for outdoor model studies, and presents examples showing drifts formed by reduced-scale snow fences, topographic features, guardrails, buildings, and other objects. Emphasis is given to the practical aspects of outdoor modeling, including procedures, site selection, and general requirements.

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## Scientific Basis for Outdoor Modeling

Empirical Evidence of Natural Scaling.--Our extensive measurements of drifts formed by snow fences on level terrain have shown drift dimensions to be geometrically scaled with fence height (H) over the range $0.8 < H < 3.8$ m (Tabler, 1980a). For equilibrium (maximum) drifts on the lee side of a "Wyoming" fence (50% porosity, horizontal slats 15 cm wide, and a downwind inclination of 15°, as described by Tabler (1974)), snow depth y, at distance x from the fence is given by

$$\frac{y}{H} = 0.20 + 0.377\left(\frac{x}{H}\right) - 0.0472\left(\frac{x}{H}\right)^2 + 0.002329\left(\frac{x}{H}\right)^3 - 5.392\cdot10^{-5}\left(\frac{x}{H}\right)^4 + 4.840\cdot10^{-7}\left(\frac{x}{H}\right)^5 , \quad \frac{x}{H} < 30 \qquad (1)$$

The drift on the windward side of the fence is approximated by

$$\frac{y}{H} = 0.5 - 0.04\left(\frac{x}{H}\right) , \quad \frac{x}{H} < 12.5 \qquad (2)$$

The drift profile of fully developed drifts on the lee side of "Canadian" fences (60% porosity, vertical slats 3.8 cm wide, and erected vertically, as described by Pugh (1950)), is given by

$$\frac{y}{H} = 0.13 + 0.402\left(\frac{x}{H}\right) - 0.0602\left(\frac{x}{H}\right)^2 + 0.003691\left(\frac{x}{H}\right)^3 - 1.0854\cdot10^{-4}\left(\frac{x}{H}\right)^4 + 1.2498\cdot10^{-6}\left(\frac{x}{H}\right)^5 ; \quad \frac{x}{H} < 26.5 \qquad (3)$$

Equilibrium drifts may therefore be considered geometrically scaled over the range of heights for which full-scale data are available. In addition, studies of 1:30 scale model snow fences on lake ice have shown that these relationships extend to heights as low as 0.06 m (Tabler, 1980b), suggesting the existence of a natural scaling law for snowdrifts (fig. 1). In the following section we will briefly summarize our explanation for this phenomenon, leading to a description of essential requirements for outdoor modeling studies.

Theoretical Requirements for Natural Scaling.--The wind profile for fully rough turbulent flow with neutral stability is given by

$$\frac{u}{u_*} = 2.5 \ln\left(\frac{z}{z_o}\right) , \quad z \geq z_o \qquad (4)$$

where u is mean horizontal wind speed at height z above the surface, $z_o$ is the roughness height (z at u = 0), $u_*$ is the shear velocity ($u_* = \sqrt{\tau/\rho}$, where $\tau$ is shear stress and $\rho$ is air density), and the coefficient 2.5 is the reciprocal of von Karman's constant, usually assumed to be 0.4. Measurements by Budd et al (1966) and Liljequist (1957) convincingly demonstrate that equation (4) adequately describes the wind profile at heights > 5 cm under blowing snow conditions.

For true, quantitative scaling of erosion and deposition features associated with wind-transported snow, models must be scaled to assure geometric, kinematic and dynamic similitude, as described by Langhaar (1951). Geometric similarity exists if all dimensions of the model and prototype have the same shape. Kinematic similarity requires ratios of all corresponding velocities and accelerations to be the same throughout the flow, and dynamic similarity requires ratios of all pertinent forces to be matched.

Simulation of snow transport, erosion and deposition phenomena also requires scaling of particle trajectories and snow concentration profiles. The physical processes involved are complex, and it is not yet possible to specify on theoretical grounds the necessary and sufficient scaling requirements. A variety of scaling criteria have been proposed in the literature, and recent assessments include those by Iversen (1979, 1980), Wuebben (1978), Kind (1976), and Calkins (1975).

In an earlier paper, Tabler (1980b) discussed in detail how some of the more generally recognized criteria may be met under natural conditions, and only a brief summary will be given here. For model and prototype flows to have kinematic similarity, both roughness heights ($z_o$) and shear velocities ($u_*$) in equation (4) must be scaled so that

$$\frac{L_m}{L_p} = \frac{U_m^2}{U_p^2} = \frac{(u_*)_m^2}{(u_*)_p^2} = \frac{(z_o)_m}{(z_o)_p} \tag{5}$$

where U is a reference velocity for the flow field, L is the characteristic reference length, or dimension, used to define the geometric scale, and subscripts m and p refer to model and prototype values, respectively. For the case of blowing snow or sand, the requirements of equation (5) appear to be closely met over a period of time because $z_o$ increases with the square of wind speed as a result of the surface roughness generated by the saltating particles.

Although it is less certain how requirements for scaling particle trajectories and snow concentration profiles may be met under natural conditions, natural sorting may effectively scale particles over a restricted range of wind speeds. If the mass flux of blowing snow is proportional to $U^3$ as commonly reported, snow concentration would be proportional to $U^2$, implying concentration profiles would also be scaled given the requirements of equation (5).

Although these arguments provide only a superficial explanation for the natural scaling of snowdrifts, they indicate certain requirements that must be met for valid outdoor modeling studies, as will be demonstrated in the next section.

## Modeling Procedure

General Requirements for Modeling Sites.--From the preceding discussion, it may be concluded that if drifts behind reduced-scale models are to be geometrically proportional to their full-scale counterparts, the wind profile must be that described by equation (4), and the requirements of equation (5) must be met. A suitable site for outdoor modeling studies must therefore be on relatively flat, uniform terrain without obstructions. According to equation (5), roughness height ($z_o$) of the modeling surface must be reduced in proportion to model scale. Use of 1:30 scale models, for example, would require that the ratio $(z_o)_m/(z_o)_p$ also be 1/30. This requirement can be met by restricting studies to lower wind speeds, because under conditions of blowing snow, $z_o$ varies approximately as $u_*^2$ and u is essentially a linear function of $u_*$. By selecting a partially snow-covered ice surface, even smaller values of $(z_o)_m$ can be obtained (Tabler, 1980b), suggesting an advantage of conducting model studies on a smooth surface.

An ideal modeling site is the center of an ice-covered lake, having relatively low topographic relief upwind for a distance of several kilometers. The required size of the lake depends on the surrounding terrain. The portion of the lake we use for model studies is about 600 m in width, as measured parallel to the wind. Artificial surfaces such as parking lots, paved roads, or specially constructed surfaces could also be used provided they are of sufficient smoothness and extent and are situated on relatively horizontal terrain away from obstacles that might cause a departure from the ideal wind profile of equation (4).

Other requirements of a modeling site include frequent winds with blowing snow, and temperatures remaining well below freezing. The latter condition is needed for a relatively low wind speed threshold for blowing snow so that models can be studied at low wind speeds. Cold temperatures or high humidity also help reduce the possibility of an evaporation-induced temperature inversion that causes the wind profile to depart from the assumption of equation (4). During model studies in sunny weather, air temperatures generally must be colder than −3° C if blowing snow particles are not to melt upon contact with model surfaces. In Wyoming, air temperatures for successful modeling generally extend from mid-December to mid-February at elevations near 2300 m.

Model Scale.--In general, when ice partially covered with snow is used for the modeling surface, the smallest feasible model scale is about 1:30, and this has been used for most of our experiments. Although it is unknown whether natural scaling requirements could be met with smaller models, from our experience 5 cm seems near the minimum practical height considering the precision with which the drifts can be measured and the rate of accumulation relative to the time required for measurement.

Wind speeds near the threshold for blowing snow ($u_* = 25$ cm/s) using 1:30 scale models, would correspond to prototype 10-m winds of about 30 m/s, as calculated from the empirical equations given by Tabler (1980b). This suggests that the 1:30 scale ratio may be approaching the minimum if results are to represent typical prototype winds.

With wind speeds close to the threshold for blowing snow, we have found that about 1 h is required for a 5.5-cm 1:30 scale model snow fence to fill to capacity, as compared to 2.5 h for a 12.4-cm fence. The likelihood that wind conditions will change during a model run increases with the time required for equilibrium drifts to develop, and small models are preferable for this reason. The length of a 2-dimensional model, as measured transverse to the wind, must be at least 30 times its height if a measurement transect through the center of the drift is to be independent of the flow around the ends of the model (Tabler, 1974). This requirement often dictates what model heights are feasible, considering the cost or difficulty of building the model, as exemplified by our use of compacted snow to construct 3-dimensional terrain models. Because both the volume of material and the labor required for construction of solid models increases as the cube of the model height, small scales are essential. The 1:30 scale has proven favorable for topographic models constructed from compacted snow.

Model Construction.--Copper-sheathed printed circuit board is a convenient material for building model snow fences. It is available in thicknesses necessary for 1:30 scaling of common lumber dimensions, and can be readily cut into required widths using a bandsaw. The copper coating allows components to be soldered together to make a durable model. Strip magnets glued with epoxy cement or silicone rubber to the base of the models allow easy attachment to steel plates or strips of sufficient weight to require no anchoring. These base plates can be easily turned for alinement with the wind before each model run.

Inexpensive models of terrain can be made by using a small tractor-mounted snowplow to pile up snow, which is then shaped by shoveling, smoothed by troweling, and stabilized by lightly spraying the finished surface with water. A brown dye such as caramel food coloring or commercial gravy mix added to the water, provides realism and contrast for photography. Disadvantages of snow models, in addition to the rigorous labor required for their construction, include their tendency to melt with warm temperatures and erode with strong winds.

We have tried building simple plywood ramps to study the effect of slope angle on snow fence storage capacity. These are also easy to construct and assemble, but the supports for such a structure may concentrate snow loads to the point where the ice fails. Our single attempt at this type of topographic model resulted in failure of 23-cm-thick ice, with sufficient vertical displacement of large areas of ice to render the model unsuable.

Modeling Technique.--Our outdoor modeling studies have been done on smooth lake ice partially covered with snow. To prevent migrating snow dunes from burying the models, we clear the snow from an area about 10 m square. Using a small tractor equipped with a snowplow, the snow is pushed to the downwind side of the clearing, where it is later distributed over a wider area using a snowblower attachment. Care is taken to avoid leaving any snow berms on the windward side of the clearing.

Light models of structures can be frozen directly to the ice, or attached with magnets to 1.5 mm-thick steel plates or strips. The steel plates are used to provide a uniform surface for more accurate snow measurements behind small models and are painted black with a 10-cm white grid to provide contrast and scale for photographs. There is a tendency for blowing snow to melt and adhere to these dark surfaces in sunny weather when the air temperature is above -4° C.

Snow depths are measured with a thin steel ruler, and data are recorded verbally using a small battery-operated tape recorder to speed measurements and thereby minimize disturbance to the drift. When required, time scales can be estimated as described by Tabler (1980b) if bulk density of the model snowdrift is determined by weighing a snow sample of known volume.

We record wind speed and air temperature profiles throughout each modeling run, using the calculator-controlled instrumentation described in our previous paper (Tabler, 1980b). This allows verification of the logarithmic wind profile assumption (equation 4), and permits scaled prototype wind speeds to be calculated from equation (5). A recording of wind speed at a single height could also be used to estimate prototype winds using the empirical wind profile parameters described by Tabler (1980b). There is, however, an alternative to actual wind measurements. Because profiles of equilibrium drifts behind certain types of snow fences are known, it is possible to use a standard model snow fence of the same scale as the object being tested to provide a calibration reference. If, for example, the fully developed drifts formed by a model "Wyoming" snow fence are found to approximate equations (1) and (2), it may be assumed that typical prototype conditions were represented during the model run, and that the scaling requirements of equation (5) were fulfilled. In testing alternative snow fence designs, we simultaneously run a section (30H in length) of a standard fence for comparison to provide an effective and sufficient calibration of the modeling conditions.

Best modeling results are obtained when wind speeds are just above the threshold to sustain blowing snow (7 to 12 m/s at the 10-m height), when air temperature is below -5° C, and during light snowfall. These latter two conditions help ensure an unlimited supply of blowing snow, low threshold wind speeds, and the neutral stability required for the wind profile described by equation (4).

Examples of Results from Outdoor Modeling Experiments

Quantitative comparisons of drifts formed by outdoor models and their prototypes have been presented in an earlier paper (Tabler, 1980b), and so emphasis here will be on qualitative comparisons and examples demonstrating the wide range of applications for the technique.

Snow Fences on Level Terrain.--The natural scaling of snowdrifts is apparent from a comparison of drifts formed by 3.8-m and 5.5-cm snow fences (fig. 1). The model has about the same lee drift geometry as described by equation (1) for full-scale drifts: maximum depth of 1.2H at 6H from the fence, maximum length of about 30H, and cross-sectional area of about $19H^2$. Model and prototype windward drifts are also similar, both being represented by equation (2). This similarity exists at all stages of drift development, as demonstrated in figure 2 by the presence of a slip-face, or cornice, which is characteristic of drifts behind snow fences up to the time they are 50 - 75% full.

The overall geometry and irregularities of snowdrifts are often difficult to photograph with full-scale drifts, but are easily photographed with reduced-scale models. For example, it is apparent from the model demonstrations in figure 3 that small gaps or holes in a snow fence cause significant erosion of the drift. This effect is exaggered when individual fence panels are staggered as shown by model and full-scale examples in figure 4.

Another important application of outdoor modeling is the visualization of flow fields around objects. The presence of visible snow particles allows us to "see" fluid motion and trajectories of the particles themselves, and outdoor models make these details more visible than in the full-scale. The wake and developing internal boundary layer behind a 6-cm, 1:30 scale model snow fence, before the drift has reached equilibrium, is dramatically evident in figure 5. Flow visualization such as this can lead to a better understanding of the aerodynamics of structures in relation to snow erosion and deposition, and can provide a basis for improving the design of structures to induce or prevent deposition. Snow would seem to be an ideal "tracer" for studying air flow in connection with snow transport problems because the path of solid particles in a gaseous flow may depart significantly from the fluid streamlines because of lift and drag forces exerted on the particles (Merzkirch, 1979). In the following examples we will see other uses for kinematography (the photography of flows), as made possible with outdoor models.

Drifts Formed by Guard Rails and Median Barriers.--Guardrails cause snowdrifts on highways, and there is a need to compare different guardrail designs in this respect. Drifts formed by 1:15 scale models of two common types of guardrail are shown in figure 6 (left). The "box beam" prototype used for shoulder installations consists of a 15-cm x 15-cm box beam installed 76 cm above the ground. The "corrugated beam" guardrail consists of a "W"-shaped beam, 31 cm wide, installed 71 cm above ground line. For the test shown in

Figure 1. Equilibrium drifts formed by a 3.8-m snow fence (left) and a 5.5-cm model (right) are identically proportional to fence height, suggesting a natural scaling law for snowdrifts. Wind is from right to left.

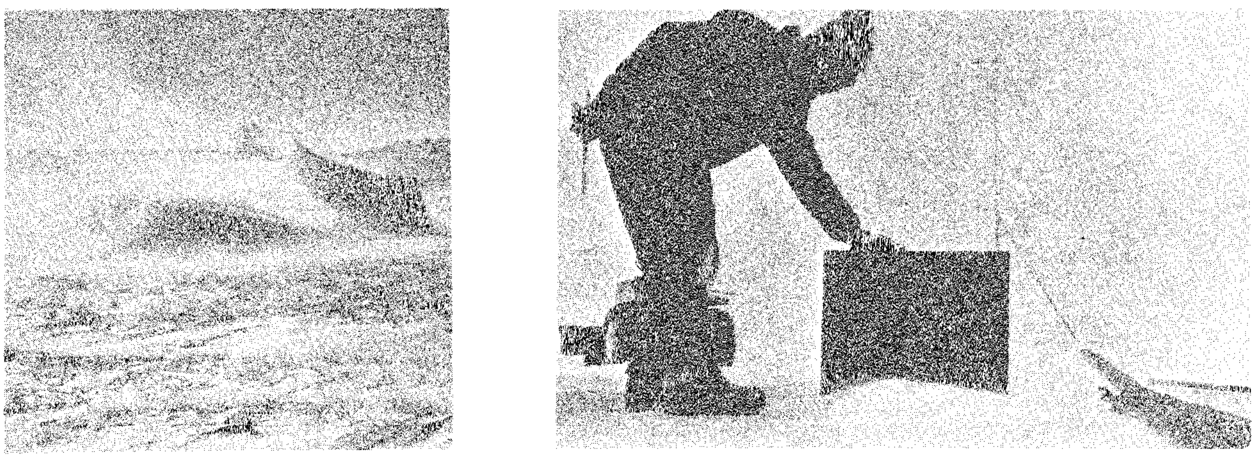


Figure 2. A "slip face" or cornice is characteristic of drifts behind both 3.8 m full-scale (left) and 1:30 scale model (right) snow fences up to the time they are 50 - 75% full, demonstrating similarity of drift geometry at all stages of drift development. Wind is from right to left.

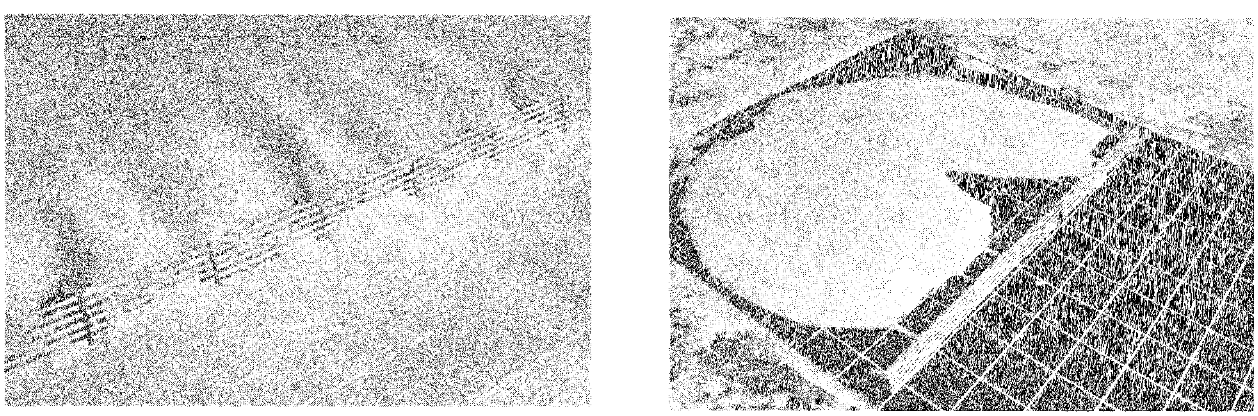


Figure 3. These 1:30 scale models of 1.8-m snow fences show erosion caused by 15-cm spaces between adjacent panels (left), and a 60-cm opening (right). Grid scale is 10 cm, and wind is from lower right corner.

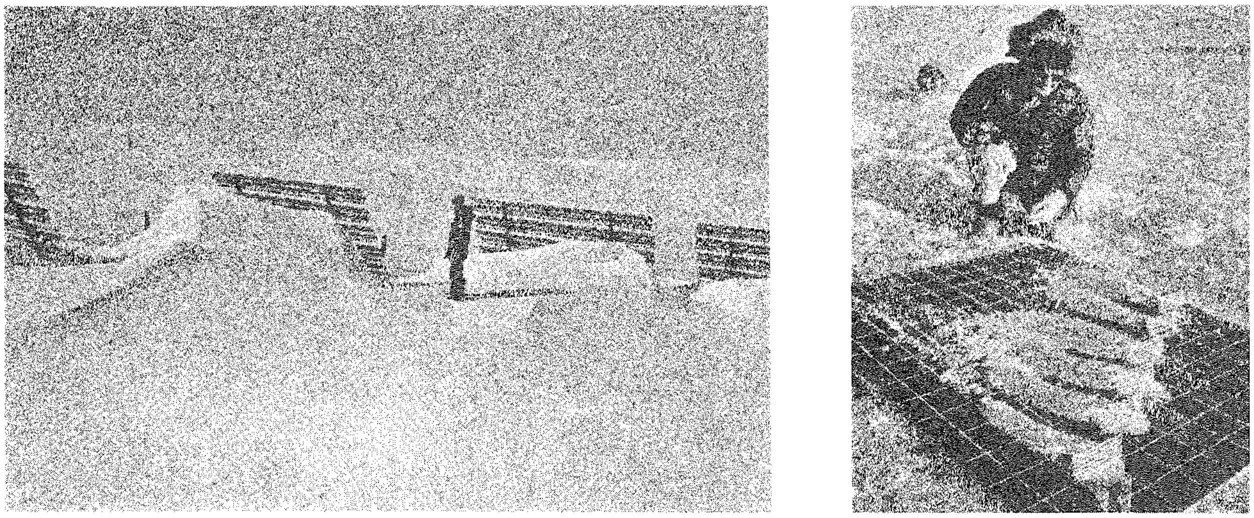


Figure 4. Drifts behind staggered snow fence panels 1.8 m tall and 5 m wide (left). The same drift geometry is indicated by a 1:30 scale model (right).

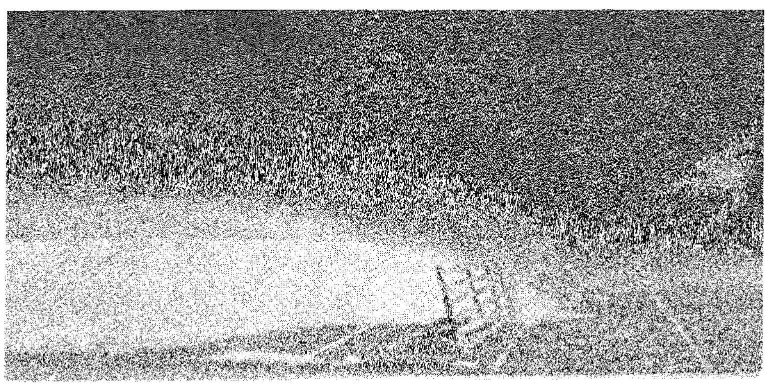


Figure 5. Snow particles make air flow patterns visible in this view of a 6-cm, 1:30 scale model snow fence 75% full (wind is from right to left).

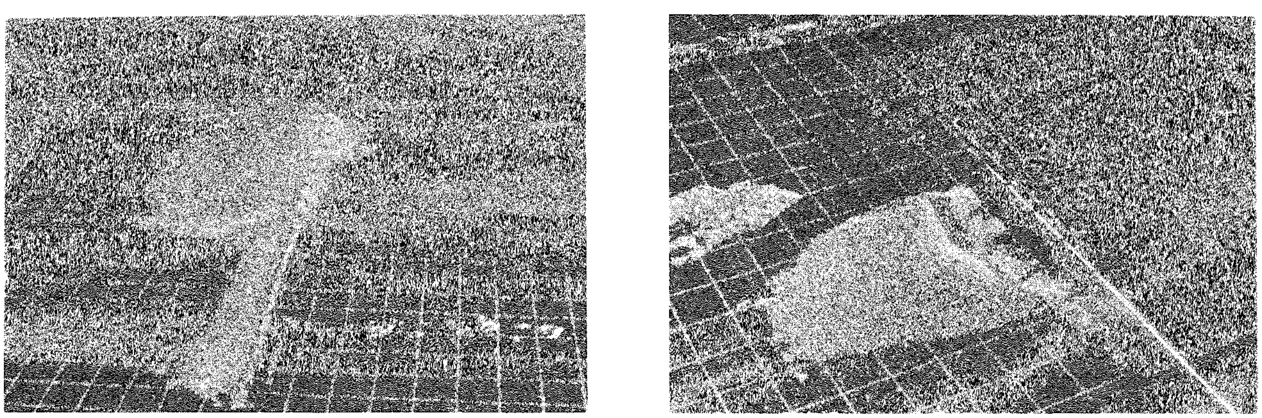


Figure 6. Left: drifts formed by 1:15 scale models of standard "box beam" (foreground) and "corrugated beam" (background) guardrails with curbs (18-cm full-scale height). Right: drifts formed by the "corrugated beam" model with curb (foreground) and without curb (background). Wind is from right to left, and grid scale is 10 cm.

figure 6 (left), a curb (18 cm full-scale height) is included under both guardrails as is typical practice to prevent water erosion of highway embankments.

The tendency for snow deposition is obviously much greater behind the wider "corrugated beam" design. The effect of the curb on snow deposition is evident in figure 6 (right). Comparison of deposition behind the "corrugated beam" with and without a curb suggests the desirability of substituting temporary curbing, such as sandbags, which will disintegrate after new embankments are revegetated. The Wyoming State Highway Department has modified their guardrail practice based on these results.

Snow deposition associated with concrete ("New Jersey") median barriers is accurately predicted by a 1:30 model, shown by the comparison with a full-scale example in figure 7. The model shows motorist visibility may be significantly impaired by snow jetting over the barrier (fig. 8), and this is also verified by a full-scale example.

Drifts Formed by Buildings.--Snowdrifts around 1:16 scale models of Jamesway buildings (portable shelters built of canvas and wood used for research camps in polar regions) (fig. 9), correspond to those formed by the full-size structures. The optimum design and arrangement of buildings for polar facilities has been studied in a wind tunnel using 1:100 to 1:125 scale models and powdered borax (Brier, 1972). These tests have provided guidelines for camp construction to reduce snowdrift problems, but outdoor modeling can provide more reliable quantitative results and permit larger camp layouts to be studied than is possible in the confines of a wind tunnel.

The larger scales that can be used for outdoor models facilitate their construction and make snow depth measurements easier. Details of drift geometry easily visible on the bare ice in figure 9, may escape detection in full-scale observations on snow-covered terrain.

Snow Deposition in Roughness Arrays.--To determine how snow deposition is related to surface roughness characteristics, we have studied snow deposition in arrays of concrete blocks, fence posts, wood stakes, and wires. Because the width and length of these roughness fields should be at least 100 times the object height, the arrays are expensive and laborious to install. Measurements must also extend over a period of years to test an adequate range of element spacings.

Our preliminary experiments with reduced-scale roughness arrays verify that similitude requirements are also met for this case as suggested by the comparison of drift patterns formed in array of 19- x 19- x 40-cm concrete blocks with those in a 1:15 scale model (fig. 10). This is additional evidence for the existence of a natural scaling law, and provides a new technique for studying snow erosion and deposition in relation to the partitioning of aerodynamic drag.

Topographic Models.--An example of a 1:30 terrain model made from compacted snow, before installing identically scaled snow fences, is shown in figure 11. This particular terrain example was selected for study because we have measured snow accumulation at the prototype site for the last 9 years, and have observed the interesting terrain interaction where the upsloping topography in front of the lead 1.8-m fence (fig. 12) caused a much larger drift than would be expected on level terrain. As a consequence, during heavy snow years the second (3.2-m) fence is nearly buried, even though these two fences are spaced about 46 m apart. Another unusual feature is the apparent inefficiency of the third (3.8-m) fence, as indicated by its small drift and an excessive snow accumulation in the road cut.

As shown in figure 12, the model drift is in general agreement with the prototype, predicting burial of the second fence, an abnormally small drift behind the third fence (about 10H shorter than on level terrain), and essentially identical drift slopes in the road cut both with and without fences (fig. 13). The abrupt termination of the prototype drift at the edge of the roadway is the result of snowplows removing the drift. The slope of the snowdrift in the model cut also agrees with that predicted by an empirical regression method for full-scale drifts (Tabler, 1975).

Figure 14 provides a photographic comparison of pre-equilibrium drifts formed by model (1:30) and full-scale fences located on broad ridge crests.

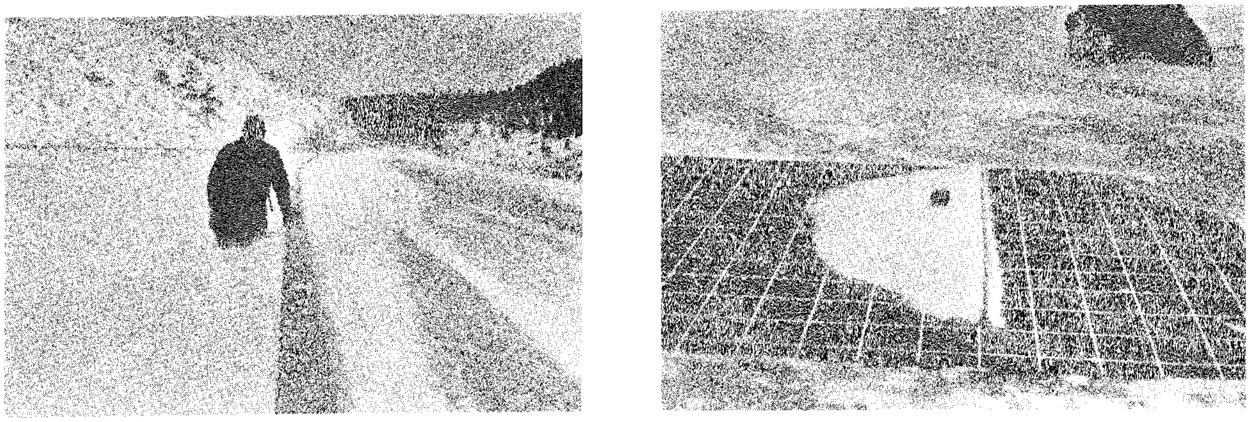


Figure 7. Snow deposition behind concrete ("New Jersey") median barrier. Full-scale example on left, 1:30 scale model on right. Wind is from right to left, and grid scale is 10 cm.

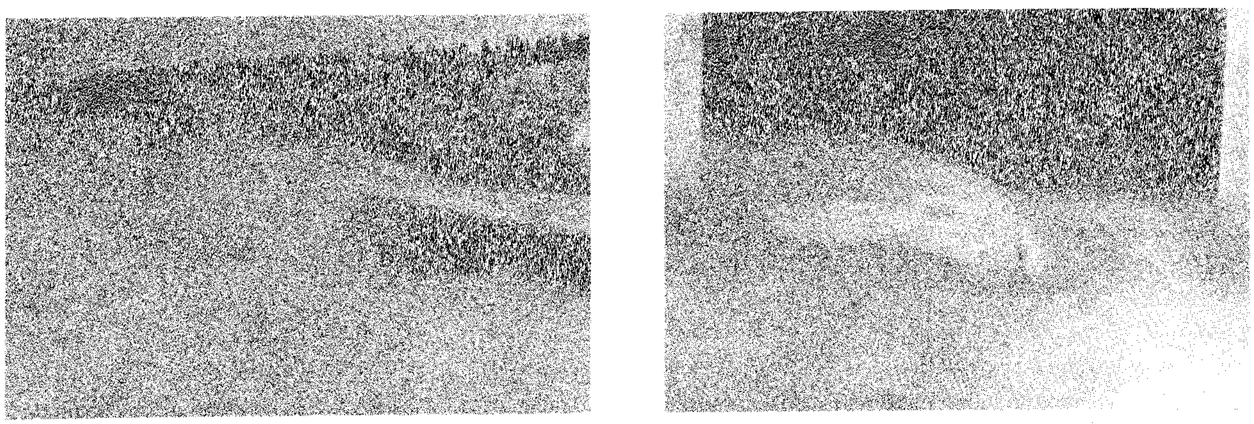
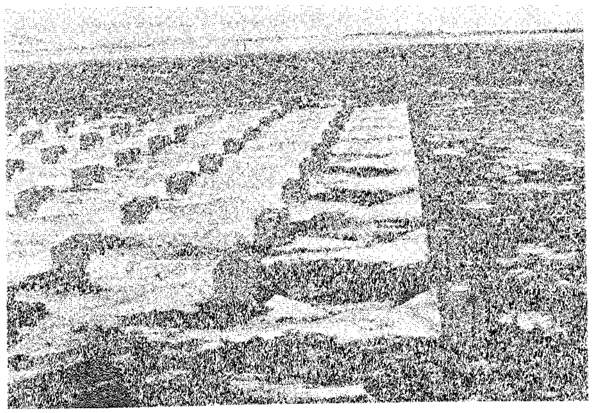


Figure 8. Snow jetting over concrete median barrier. Full scale example on left, 1:30 scale model on right. Wind is from right to left, and grid scale is 10 cm.

Figure 9. Two views of drifts formed by 1:16 scale models of Jamesway buildings.



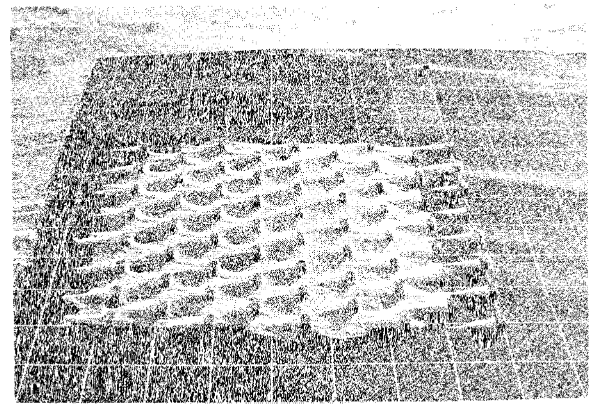


Figure 10. Left: snow accumulation in upwind rows of array of 19 x 19 x 40-cm concrete blocks, spaced 88 cm apart. Right: 1:15 scale model of same array with 10-cm grid. Wind is from right to left.

Figure 11. Topographic model (1:30 scale), made from compacted snow, of site at Mile 253.4, Interstate Highway-80 (Wyoming) before installing snow fences.

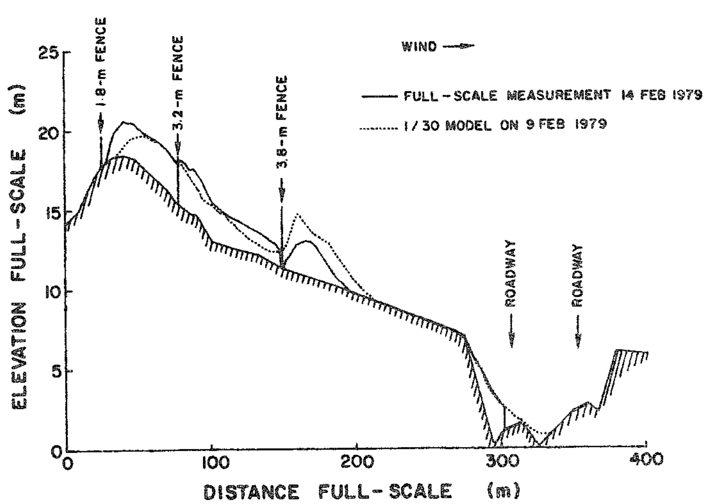
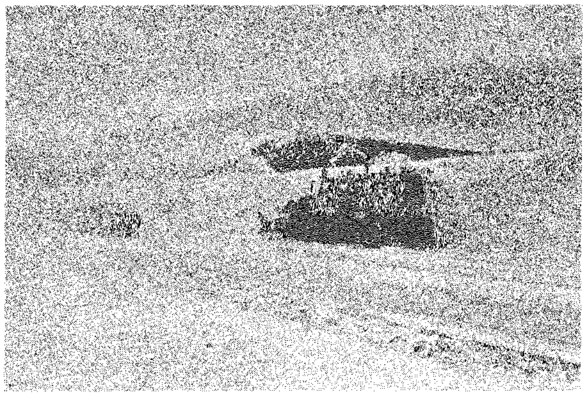



Figure 12. Equilibrium drift profile for the 1:30 scale model of cross-section at Mile 253.4, Interstate Highway 80 (Wyoming) with snow fences. Full-scale measurements near the end of an unusually severe winter are shown for comparison.



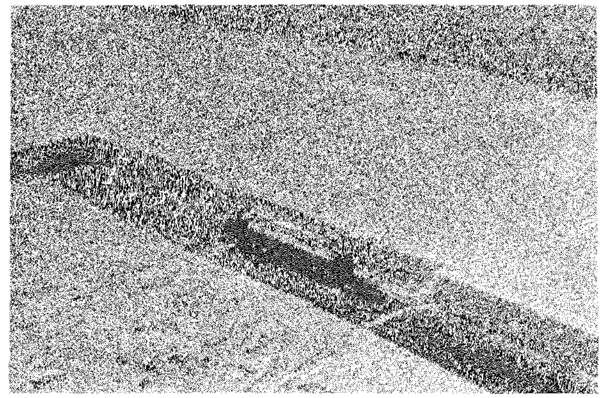
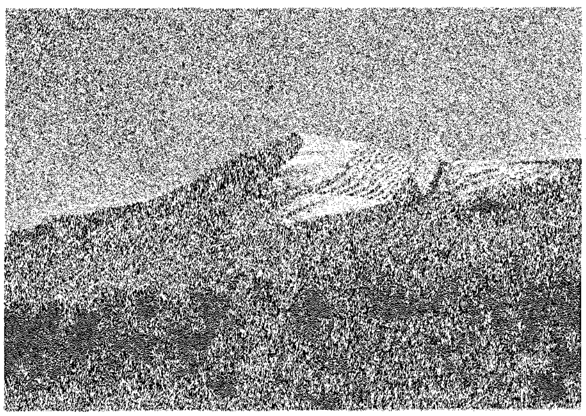


Figure 13. Snow in road cut at Mile 253.4, Interstate Highway-80 (Wyoming). Left: full-scale, before snow fences were installed. Right: 1:30 model. Wind is from right to left.



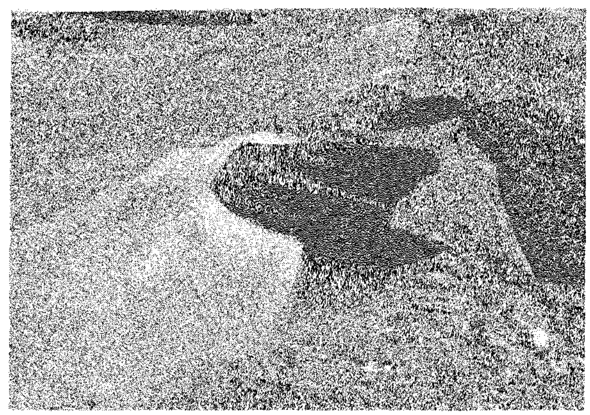


Figure 14. Pre-equilibrium drifts formed by 3.8-m snow fence on broad ridge crest, with full-scale example on left, and 1:30 model on right. Wind is from right to left.

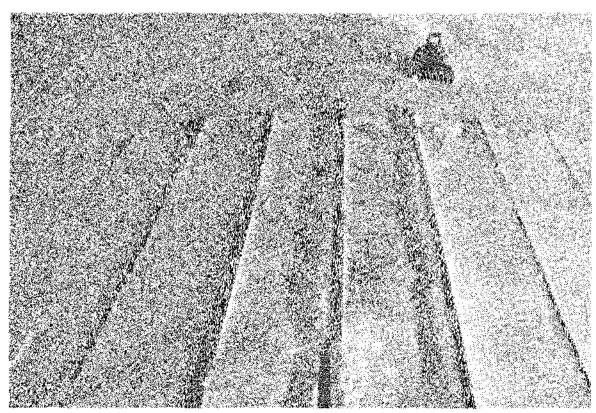


Figure 15. Two views of a 1:10 scale model of surface-mine spoil piles, constructed from compacted snow. The triangular wood strips simulate full-scale contour furrow ridges 0.3 m high spaced 3 m apart. Wind is from right to left.

As a final example, figure 15 shows a portion of a 1:10 scale model of surface-mine spoil piles, constructed from compacted snow. The undulating full-scale topography is essentially sinusoidal, with hills 8 m higher than the valleys and spaced 107 m apart. The triangular wood strips in the photographs simulate full-scale contour furrow ridges 0.3 m high spaced 3 m apart. This test demonstrates the advantage of leaving rough surfaces to accumulate snow so as to make more soil water available for revegetating surface mined areas, and also suggests the need for improved roughness treatments. Although the space between ridges up to the inflection point in the topography essentially filled with snow, drift lengths were shorter on the upper half of the slope, and very little snow accumulated behind the two ridges on the hill crest.

## Conclusions

Natural scaling of drifts suggests snow erosion and deposition can be studied with reduced scale models on smooth surfaces outdoors, provided certain fundamental requirements are met. The examples presented here, in addition to the quantitative evaluation presented in a previous paper, provide convincing evidence of the feasibility and potential for outdoor modeling studies.

Disadvantages.--Compared to the closely controlled conditions available in laboratory facilities, outdoor modeling studies are subject to a wide range of weather conditions over which the investigator has little or no control. Wind speed or direction can change during a run, making it necessary to repeat an experiment several times before conclusive results are obtained. Many trips to the field can be wasted waiting for the right conditions. And finally, outdoor modeling means miserable working conditions for field personnel. The procedure may be simple and inexpensive, but the results are hard-earned.

Advantages.--Outdoor modeling can be used to design more effective and economical snow fences, improve design of structures to minimize drifting problems, and obtain quantitative descriptions of snowdrifts formed by terrain and structures. Blowing snow particles provide an excellent visualization of wind flow patterns around models which cannot be as easily seen by observing the larger prototypes. Outdoor modeling allows photographic documentation of drift patterns and flow fields that are difficult or impossible to photograph for full-scale objects.

The cost of building and running models is minimal. Expensive wind and temperature instrumentation, although desirable for some scientific studies, is not essential provided some standard reference model is run simultaneously to verify satisfaction of similitude requirements and realistic scaled prototype conditions. Field procedure is simple and requires no specialized training or experience. There is no upper limit to model scale, so a scale convenient for construction may be selected. This is in contrast to the very small models (1:100 to 1:250) required for most wind tunnel and water flume experiments.

Outdoor modeling is a promising technique to solve a variety of scientific and practical problems that cannot be practically resolved in full-scale studies or laboratory modeling facilities.

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