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GRD RESEARCH NOTES

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No. 79

A REVIEW OF STUDIES RELATING  
METEOROLOGICAL PARAMETERS TO SNOW CONDITIONS  
ON THE GREENLAND ICE CAP

L. S. Koenig  
Major, USAF

February 1962



GEOPHYSICS RESEARCH DIRECTORATE  
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES  
OFFICE OF AEROSPACE RESEARCH  
UNITED STATES AIR FORCE  
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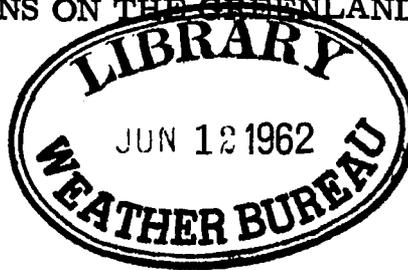
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*U. S. Air Force, Cambridge Research Center  
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Terrestrial Sciences Laboratory  
GEOPHYSICS RESEARCH DIRECTORATE  
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## Abstract

Supply missions to Dew Line sites on the Greenland Ice Cap must land on unprepared landing strips. Although 6-hour weather observations are regularly received at Sondrestrom Air Base (the launch point), forecasting the surface conditions at these places poses special problems because site personnel make no snow observations. In the interests of flying safety a study was started to determine if snow surface conditions could be correlated with the reported weather conditions; but an intensive literature search yielded only meagre pertinent information. Sufficient correlation has been established to warrant further work, including the taking of snow and micrometeorological observations at the sites for a 1-year period and the reduction of this data so that reliable charts will be available to pilots who fly these or similar missions.

# A REVIEW OF STUDIES RELATING METEOROLOGICAL PARAMETERS TO SNOW CONDITIONS ON THE GREENLAND ICE CAP

## Introduction

To forecast surface conditions of snow cover on the Greenland Ice Cap it is necessary to know the nature of snow as it falls onto the surface and its subsequent metamorphism, the meteorological conditions during and after the snowfall, and the amount of snowfall. The problem is greatly simplified because only the area above the firn or melt zone of the Cap need be considered. There is a general increase of snow cover in the area from year to year so that a study of the snowfall and its metamorphosis during one year should yield some tentative conclusions; and further studies should refine these conclusions.

## Snow

Snow is solid precipitation formed in the atmosphere by sublimation of water vapor onto solid minute nuclei.<sup>2,3</sup> Snow appears in many forms;<sup>11</sup> however, the following definitions are sufficient for the purposes of this paper:

1. Snow crystal - a single crystal of snow, either regular or irregular.
2. Snow particle - a combination of crystals of any orientation, grown up as a unit.
3. Snow flake - a cluster of snow crystals that have become stuck together while falling to earth.
4. Granular snow - opaque white grains, 1.0 to 5.0 mm in diameter, soft and frangible, often mixed with ordinary snow falling from cumuliform clouds.

For more information of forms of snow consult the literature.<sup>1, 15</sup>

The scant description of snow forms does not give much indication of conditions of fallen snow as a surface. Newly fallen snow usually settles in a loose layer.<sup>11</sup> The density and bearing strength of snow and its slipperiness are due in great part to the meteorological conditions at the time of fall and after deposition. Traffic or artificial modifications will not be considered because it is outside the scope of this study. Figure 1, however, compares cone index or shearing strength of fresh snow and compacted snow. In general, new snow will be loose and fluffy and of low density if it falls at generally low temperatures, around 14°F or lower; in a calm or very light wind condition; in the form of feathery flakes. Such snow frequently has a density in the neighborhood of 0.07 (Table 1). Snow

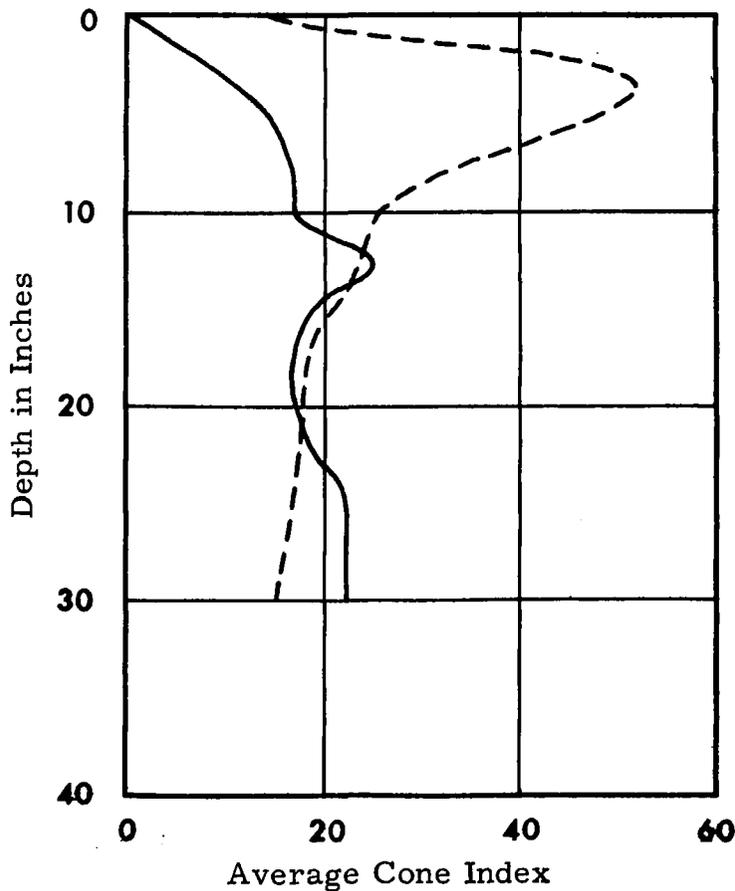


FIG. 1. Six-hour hardening vs virgin snow. Solid line: Virgin snow. Dashed line: Snow compacted by one pass each of D6 cat and M76 Otter with footprint pressures of 3.17 and 1.72 psi respectively. Average free air temperature during test: 21°F.<sup>2</sup>

TABLE 1. Density of new snow vs temperature. <sup>11</sup>

Mean daily temp. °C	Density gm/cc	Average gm/cc
T -10	0.01 - 0.23	0.075
-10 to -5	0.01 - 0.29	0.087
- 5 to -2	0.03 - 0.26	0.104
- 2 to 0	0.04 - 0.45	0.128
0 to +2	0.07 - 0.53	0.183

will be more dense if it falls at generally high temperatures, near 32°F, and/or with a wind condition of 15 to 20 kt or higher, and/or in granular form. Snow density depends most of all on the strength of winds at the time of fall. See Table 2. This increase in density occurs when the snow flakes have their feathery appendages knocked off by the tumbling action of the wind and by collision with other flakes, either in the air or on the ground. A finer-grained and, consequently, denser deposition results. The packing action of wind further increases the density.

TABLE 2. Density of snow vs wind speed during snowfall.<sup>11</sup>

Wind Condition	Density(gm/cc)
Calm 0 - 4 kt	0.04 - 0.07
Breeze 4 - 16 kt	0.04 - 0.13
Medium wnd 17 - 27 kt	0.12 - 0.18
Strong wnd 28 - 47 kt	0.15 - 0.22
Full Gale 48 - 55 kt	0.30 - 0.39

### Metamorphism of Snow

Snow that is undisturbed by insolation, wind, liquid precipitation, or external mechanical forces will nevertheless undergo radical changes in form, density, and physical properties with time. This metamorphism has been studied and described by many authors.<sup>1, 11, 14</sup> The process results in a lower energy state for the snow and densification. There is also generally an increase in bearing strength. In the area under consideration, the average ambient air temperature seldom rises above freezing during the summer;<sup>13</sup> however, a certain amount of melting metamorphosis does take place in the top 2 to 5 inches of the snow surface as a result of insolation. This melting during the warmest period of the day is followed by a refreezing (crust formation) as the sun sets, or at low elevations of the sun. The density of the crust varies from 0.35 to 0.55 and generally has sufficient bearing strength for ski operations.

Snow is rarely disturbed by liquid precipitation at Dew Line east sites 2 and 3. Rain in any quantity will form a crust on the topmost layer in a very short time.

Aside from human activity, the only important factor that disturbs the snow on the Ice Cap is the wind. The new snow cover is considerably moved about by winds. Feathery and powdery snow is easily picked up and moved by winds over 5 kt. Figures 2 and 3 indicate the wind conditions that can be expected to occur. At wind speeds of 15 to 20 kt the snow will be picked up and blown in great enough amounts to reduce visibility and obscure the sky. At such times it is often impossible to distinguish between falling and blowing snow.<sup>9</sup> The sliding, tumbling action of snow particles as they are borne along by the winds results in the formation of smaller, denser, and harder snow particles which, when redeposited, form a much more compact surface whose hardness depends on the wind speed and time since deposition.<sup>11, 14</sup> A concomitant result of wind transport of snow, either new or old, is the formation of sastrugi (Table 3). The formation of

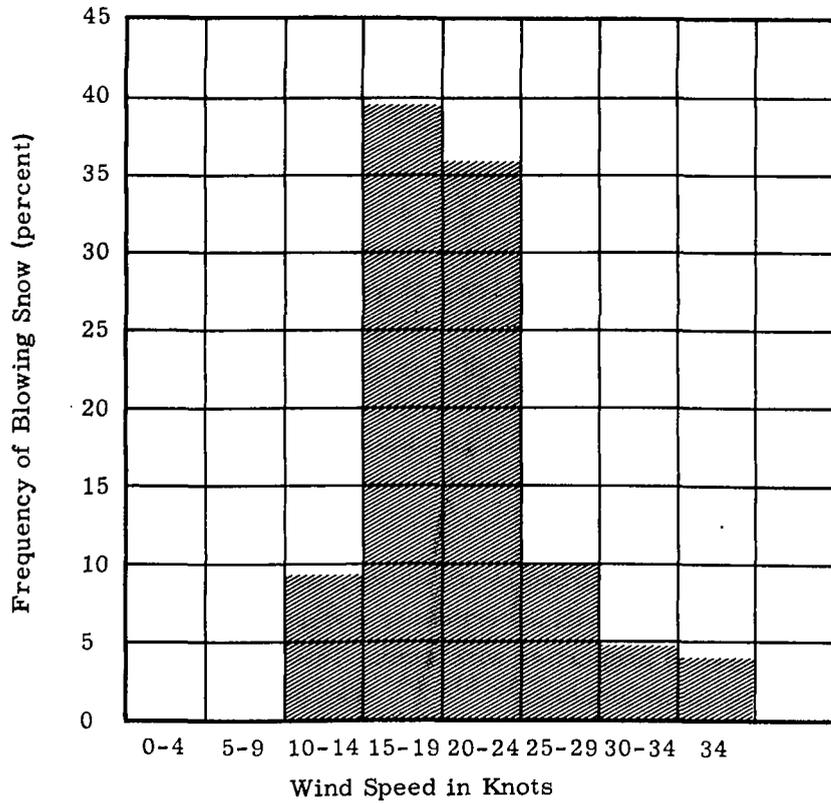


FIG. 2. Frequency of blowing snow on the Ice Cap above Melt Zone.<sup>9</sup>

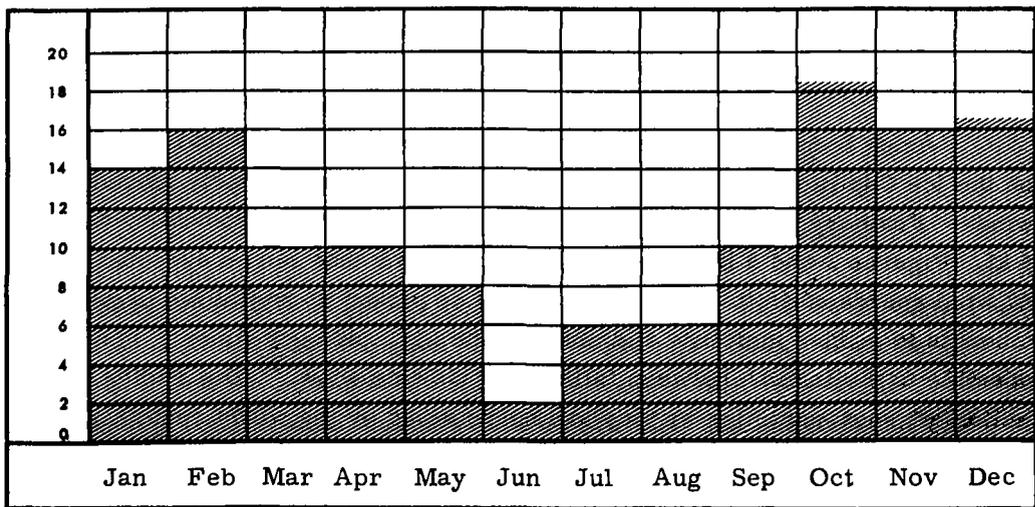


FIG. 3. Mean number of days of blowing snow each month on the Ice Cap above the Melt Zone.<sup>9</sup>

TABLE 3. Types of sastruga development in relation to wind velocity and precipitation.<sup>7</sup>

		Precipitation (Snow)			
		None; trans- ported snow	Light (0-0.5")	Medium (0.5-2")	Heavy (2-5+")
Wind velocity in knots Duration one day	Light 4-9kt	Small sheets	Small sheets	Large sheets	Diffused sheets
	Medium 10-15kt	Small barchans	Small barchans	Large barchans	Ragged barchans
	Strong 16-30kt	Linear ridges	Small linear ridges	Long linear ridges	Diffused linear ridges

different types of sastrugi is illustrated by the excellent photographs in "Project Mint Julep."<sup>7</sup> Disturbed snow almost always results in a harder surface which becomes still harder with aging.

During the height of summer heating (late June until the first week of August),<sup>7</sup> a certain amount of melting will take place. On a clear day this melting process stops because of radiational heat loss when the sun is low on the horizon. During periods with abnormally high temperatures (near 32°F) and overcast sky conditions, there will be considerable thawing action at this season due to the "greenhouse effect" in which the the cloud layer keeps the long-wave radiation trapped between the snow surface and the cloud base.

## Summary

In general, the snow cover on the Ice Cap will not create great difficulties to ski operations for most of the year. During the early part of the winter, usually starting around the middle of August, the first snowfalls may be heavy, up to 12 inches or more of fluffy snow which resists compaction because it flows away from the skis like water.<sup>3</sup> A light fall of this snow usually does not present any undue difficulty.

In the later winter months when the ambient temperatures are always under 14°F the snow is generally drifted and packed by the winds during or after the

snowfall (Figs. 2 and 3 and Table 3). Sastrugi constitute the most prominent difficulty during most of the year.<sup>7</sup> At the height of the summer the surface will occasionally be sticky, but this lasts at most only five or six hours in the middle of the day.

## Recommendations

There is much literature on the snow and ice conditions on the Ice Cap; however, very little has been done to indicate the relationship of the weather conditions to the snow surface conditions. If snow surface conditions are to be forecast for safe ski operations using only weather reports from the landing area, more field investigations are needed. Such a forecast capability could also be used to forecast over-surface trafficability of self-propelled vehicles. To acquire this capability the following are recommended;

1. Standard weather observations at several sites on the Ice Cap for at least one year at each site. This is already being done in some places.
2. Snow measurements in the immediate area of the site where observations are being made. These measurements would be made using a cone penetrometer and a drop cone penetrometer in order to obtain the bearing strength of the surface and the shearing strength of the surface and the shearing strength of the top three feet of the snow cover.
3. Measurements of the rut depth made by aircraft landing on the unprepared snow surface near the area of observation. Note should be made of the type of aircraft, footprint pressure, and the pilot's remarks relative to the aircraft operation on the surface for landing and takeoff.
4. Reduction of the information gained in the three recommendations above arrive at charts and/or graphs that relate the surface condition to meteorological parameters and operational performance of aircraft.

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- No. 72. Micrometeorite Measurements from the Midas II, (1960 Zeta 1) Satellite, *R. K. Soberman and L. Della Lucca, Nov 61.*

<p>AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate  A REVIEW OF STUDIES RELATING METEOROLOGICAL PARAMETERS TO SNOW CONDITIONS ON THE GREENLAND ICE CAP, by L. S. Koenig, Major, USAF. February 1962. 8 pp. incl. illus. (GRD Research Notes No. 79; AFCRL-62-259)  Unclassified report</p> <p>Supply missions to Dew Line sites on the Greenland Ice Cap must land on unprepared landing strips. Although 6-hour weather observations are regularly received at Sondrestrom Air Base (the launch point), forecasting the surface conditions at these places poses special problems because site personnel make no snow observations. In the interests of flying safety a study was started to determine if snow surface conditions could be correlated with the reported weather conditions; but an intensive literature search yielded only meagre pertinent information. Sufficient correlation has been established to warrant further work, including the taking of snow and (over)</p>	<p>UNCLASSIFIED</p> <ol style="list-style-type: none"> <li>1. Arctic Regions</li> <li>2. Snow</li> <li>3. Meteorological Parameters</li> <li>4. Landing Fields</li> </ol> <p>I. Koenig, L. S.</p>	<p>AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate  A REVIEW OF STUDIES RELATING METEOROLOGICAL PARAMETERS TO SNOW CONDITIONS ON THE GREENLAND ICE CAP, by L. S. Koenig, Major, USAF. February 1962. 8 pp. incl. illus. (GRD Research Notes No. 79; AFCRL-62-259)  Unclassified report</p> <p>Supply missions to Dew Line sites on the Greenland Ice Cap must land on unprepared landing strips. Although 6-hour weather observations are regularly received at Sondrestrom Air Base (the launch point), forecasting the surface conditions at these places poses special problems because site personnel make no snow observations. In the interests of flying safety a study was started to determine if snow surface conditions could be correlated with the reported weather conditions; but an intensive literature search yielded only meagre pertinent information. Sufficient correlation has been established to warrant further work, including the taking of snow and (over)</p>	<p>UNCLASSIFIED</p> <ol style="list-style-type: none"> <li>1. Arctic Regions</li> <li>2. Snow</li> <li>3. Meteorological Parameters</li> <li>4. Landing Fields</li> </ol> <p>I. Koenig, L. S.</p>
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