WHITE-OUT IN GREENLAND; CAUSE AND POSSIBILITIES FOR CONTROL BY WEATHER MODIFICATION

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Introduction

It is probable that white-out, a term used to describe a condition in which there is a lack of contrast between the sky and a snow surface, imposes one of the greatest handicaps on operations in Polar regions. Some forms of white-out reduce ground transportation to a snail's pace or may even cause total stoppage of surface movement of vehicles and man for hours or days. All forms of white-out ground all types of aircraft. Pilots caught aloft with white-out enveloping their destination must return to their point of departure or an alternate field, taxing the fuel capacity of the aircraft and imposing extreme physical stress on the crews of smaller ski equipped planes.

There are a number of atmospheric phenomena which, when they occur above an unbroken snow cover, reduce visibility and perceptability. Under some conditions both horizontal and vertical visibility are reduced about equally. Under other conditions horizontal visibility may be unlimited although judgement of distance, either vertically or horizontally is limited to objects only a few feet from the observer.

The white-outs of Polar regions may be divided into the following classes:

1. Overcast white-out. The product of light reflection between the base of a uniform layer of strato-form clouds and the snow surface. Perspective involving the judgements of distance is limited to a few feet vertically or horizontally, but actual horizontal visibility of dark objects is not materially reduced.

2. Fog white-out. Produced by clouds in contact with the snow surface. This type of white-out is divided into two sub classes:

   a. Water-fog white-out. The fog consists of extremely small supercooled water droplets. Air temperature may be as

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much as 20° F below the freezing point. Visibility, both horizontally and vertically is affected by the size and distribution of the water droplets suspended in the air and the vertical thickness of the cloud or fog layer.

b. Ice-fog white-out. The fog consists of minute ice crystals suspended in , or falling through the air above the snow surface. It is frequently accompanied by brilliant spectral reflections and bright bands or spots of refracted light. This type of white-out frequently intergrades with the water-fog form. There is usually an improvement in visibility when the super-cooled water-fog is replaced by the ice-fog.

3. Precipitation white-out. All forms of falling snow reduce visibility. Wind velocity during the precipitation period may influence this type of white-out, hence, it is feasible to divide it into two sub classes:

a. Falling snow. Snow falling from low clouds above which the sun is shining producing multiple reflection of light between the cloud base, the snow surface and the falling snow particles.

b. Blowing snow. Actual precipitation may be too light to reduce visibility. Snow picked up from the surface by high winds and suspended in the air along with falling precipitation will reduce visibility in the same manner as heavier precipitation. However, since blowing snow seldom lifts to more than five or six feet, bright skies or sun above the blowing snow layer may cause greater spectral reflections than in falling snow with corresponding reduction in visibility.

Photographs taken on the Greenland Ice Cap during the summer of 1957 are presented (Figures 1, 2 and 3) to illustrate the major types of white-out.

The Genesis of white-out

The overcast and fog types of white-out impose severe impediments to air and ground transportation in Polar regions primarily because these forms occur more frequently than those caused by precipitation. Some knowledge of the meteorological processes which are associated with the genesis of the overcast and fog type white-outs might lead to development of methods for forecasting their occurrence with resulting improvement in the scheduling of aircraft movement or even to means for inducing artificial dispersion of these types of white-out.

Byers (1944) has stated that it is difficult to define a fog, for it is really a stratus cloud that forms at or close to the ground surface. A review of the fog-producing processes described by Willet (1928) and by Petterssen (1940) indicates that the fog, and possibly the low-stratus forms of white-out may be the product of any one, or a combination of several of the following processes:

a. Advection of warm sea air over a cold snow surface.

b. Radiation cooling of a snow surface and of the layer of air above the surface.

c. Upslope movement and adiabatic expansion of rapidly uplifted moist air.

d. Frontal passage with mixing of warm and cold air or with accompanying clouds forming a complete overcast.

Results of studies on white-out in Greenland

Studies made by SIPRE on white-out at its Greenland Ice Cap research station at Site2, located at an elevation of 7000 ft about 230 miles east of Thule, indicates that there may be some potentially useable relationships between certain observable meteorological phenomena and the occurrence of white-out on the Ice Cap. The results of some of these studies have been presented in previous papers by Gerdel and Diamond (1956) and Reiquam (1957).

It has been determined that the fog type white-out occurs most frequently on the north, high Ice Cap when the air temperature is above + 20° F. The wind shifted clockwise from the east to the southeast or south within 3 to 11 hours prior to the onset of the fog type white-out in 65 percent of the reported incidences of reduced visibility on the ice cap over a period of 2 years. (Figure 4 and Table 1). This shift in wind was observed in 97 percent of the occurrences at some time within the 24 hour period prior to the onset of the fog type white-out at the inland, high Ice Cap station.

Table 1, Wind Shift Prior to Fog with
Visibility of 1 Mile or Less, Ice-Cap Research Site.
January 1954 to December 1955.

	More than 24 hr	12 to 24 hr	6 to 11 hr	3 to 5 hr	Less than 3 hr
Frequency of Occurrence	6	29	56	82	39
Frequency Percent	3	14	26	39	18

At a site on the Ice Cap nearer to the West Coast, fog and overcast white-outs were observed to occur when the wind shifted from the east to either the south or the north quadrant, although white-out was most frequently associated with a wind shift to the south. (Figure 5).

The advection of warm, moist, maritime air from the coastal areas, with uplift onto the cold ice cap, may be associated with the change in wind direction. Winds from the S-SE octant probably derived their moisture from Baffin Bay. Winds from the N-NE octant may have picked up moisture from the Kane Basin. The combination of convective lift to elevations above 4500 ft and advective transport from the coast could produce and maintain a fog on the Ice Cap, or a low stratus cloud above the cap, from air that was less than saturated at sea level. It is possible that both fog and low-stratus white-outs which are reported from stations higher at elevations on the Ice Cap, when lower stations report unlimited ceiling and visibility are the product of such uplifted maritime air.

A map of Greenland (Figure 6) shows how winds from either the north or the south may move across open water during the summer and pick up sufficient moisture to affect the weather on the Ice Cap in Northwest Greenland.

The wind velocity, during fog type white-out, usually is less than 4 knots, however, velocities up to 12 knots have been measured during periods of intense white-out. High wind velocities during white-outs are associated with rapid alternations between supercooled water-fogs and ice crystal fogs and in visibility from a few feet to several thousand feet. Frequently observers on the ground can see patches of blue sky overhead, while horizontal visibility is limited to a few hundred feet.

Byers (1944) states that an up-slope fog is about the only one that can be maintained in relatively high wind velocities, since the more rapidly the air moves up a slope, the faster is the cooling process and the greater the counteraction of any downward transfer of heat by turbulence. Petterssen (1940) points out also that an up-slope wind has a marked effect on fog production. These observations may explain why white-outs persist at an elevation of 6800 feet on the Greenland Ice Cap during periods of high wind velocity.

The duration of a fog or overcast white-out accompanied by high wind velocity depends upon how long the synoptic situation remains in a position to supply sufficient moisture to replace that lost by condensation on the cold snow or by exchange with dryer layers of air.

Reiquam (1957 made a detailed study of a single fog white-out which occurred at the SIPRE Ice Cap research site on 10 August, 1956 and of the associated synoptic situation as derived from the synoptic charts prepared by the Air Weather Service Detachment at Thule, Greenland.

He calculated the water made available by adiabatic expansion and lifting of a parcel of air along a moist adiabat from the coast to the elevation of the SIPRE research site (6800 feet) and, applying Sverdrup's equation for the mass flux of water to the snow surface found that a fog layer 200 to 300 feet thick could be maintained over snow by recharge from the coastal air.

The results of studies in Greenland indicate that a satisfactory technique might be developed for forecasting the occurrence of white-out caused by overcast conditions or fog over the Ice Cap. Although forecasting the occurrence of white-out may reduce the number of aircraft accidents and aborted flights, it will not result in any improvement in the support of remote artic stations. Improvements in support of bases and mobile activities in Polar regions by air or ground is dependent upon modification rather than forecasting of adverse weather conditions.

Possibilities for Dispersal of White-out

Between 1945 and 1950, studies on methods of fog dispersal were made at several coastal stations in California. Project FIDO, as one investigation was designated, was directed toward improvement in visibility at airfields in California which were frequently closed by the persistent coastal stratus or low fogs moving in from the Pacific Ocean. Various cloud modification methods were tried including efforts to raise the air temperature above the dew point by burning large volumes of fuel oil in the vicinity of the airfields. The results of these studies indicated that the inflow of moisture may be so great that replenishment equals or exceeds achievable rates of dispersion and that the addition of water to the air from burning fuel may equal the increased moisture holding capacity of the warmed air.

In Japan, studies have been made on the capture of sea fogs by forests (Hori, 1953). A coastal forest belt appears to be effective horizontally for 20 to 30 times tree height in reducing the density of fog on the lee side of the forest. Vertically, such obstructions are not effective much above their actual height and fogs several hundred feet thick are converted to low stratus on the lee side of the catchment.

In Polar regions, the use of oil fired heaters to expand the air and increase its capacity to hold water in vapor form and thus to dissipate a fog or low stratus defeats its own purpose. For each gallon of oil burned a gallon of water is released as a product of combustion. The extra water added to the atmosphere must be absorbed by the warmer air or it will increase the density of the fog. In addition, the hydrocarbons released by burning fuel may contribute to a decrease in visibility by the production of smog. Probably the greatest deterrent to reduction in fog density by warming the atmosphere is the fact that high density fogs may occur under conditions of less than 100 percent relative humidity.

Reiquam (1957) (1958) has shown that the white-out fogs on the Ice Cap persist with relative humidity as low as 85 percent and that a relative humidity of more than 95 percent is seldom encountered during even the most dense fog white-outs. From his studies, we may assume that warming the atmosphere can reduce the relative humidity without sufficiently rapid vaporization of the fog water droplets to produce an increase in visibility.

Trees or any other type of physical catchment devices for fogs, even if available in the Arctic, would leave a residual low stratus as the upper levels of fog moved over the obstruction converting the fog white-out into an overcast white-out without improving vertical visibility for incoming aircraft.

If dissipation of the overcast or fog type white-out can be achieved at all, it is probable that seeding with freezing nuclei will be the most successful procedure. Artificial nucleation might be accomplished by;

1. Release of dry ice from aircraft.
2. Release of silver iodide from aircraft.
3. Use of silver iodide generator at ground level.
4. Release of seeding nuclei from balloons or other lifting devices.

Seeding from aircraft requires that all planes flying into the Polar regions be provided with equipment for the production and release of dry ice nuclei or AgI crystals. Such equipment would further reduce pay load capacity in planes already overloaded with survival gear, extra fuel tanks, Jato bottles and survival rations. Further, since the aircraft pilot would be unable to see the landing strip, he could not determine the most suitable area for nucleation.

The most satisfactory seeding procedure would appear to be the use of devices controlled from the ground. To investigate the possibility of the use of ground controlled seeding of stratus and fog white-outs, USA SIPRE made some artificial nucleation tests at its Ice Cap research station in the summer of 1956 and 1957.

The 1956 studies reported by Reiquam (1957) indicated that a small commercially available silver iodide generator did not produce AgI crystals at a sufficient rate to induce consistent modification of a fog white-out and, that the frequent presence of a surface inversion during both fog and overcast white-outs effectively prevented convective lifting of the AgI into contact with the stratus clouds. In only one of the many trials made in the summer of 1956 were snow showers observed to occur down wind following a seeding trial on a stratus overcast. It was not possible to determine whether the showers were the product of nucleation or were of natural occurrence.

In the summer of 1957 efforts were made to lift a rebuilt, light weight, high capacity AgI generator into the stratus clouds with a captive balloon. The lift capacity of a balloon which, it was believed could be safely handled by one or two men was greatly reduced by the near 7000 foot elevation of the Ice Cap research site. The low lift capacity of the balloon combined with the surprisingly high winds that occur during overcast white-outs and frequently during a fog white-out prevented raising the generator to a height that would permit satisfactory seeding.

Numerous methods for lifting artificial nucleating agents to an effective height are being investigated at the present time and those which appear to have possibilities will be tried out in Greenland during the summer of 1958.

Summary

White-outs impose severe handicaps on movement of personnel and supplies in Polar Regions.

Three types of white-outs with several sub-classes have been defined.

An analysis of the genesis and morphology of white-outs on the Greenland Ice Cap indicates that both the fog type and overcast type of white-out may be dispersable by seeding with freezing nuclei.

Seeding from ground installations rather than from aircraft appears to be the best solution to improvement of visibility of established landing strips on snow or ice.

Surface inversions and high winds have prevented satisfactory lift of nucleating agents into the low clouds or fog.

Further studies are in progress on methods which will provide higher lift of freezing nuclei into low stratus and fog.

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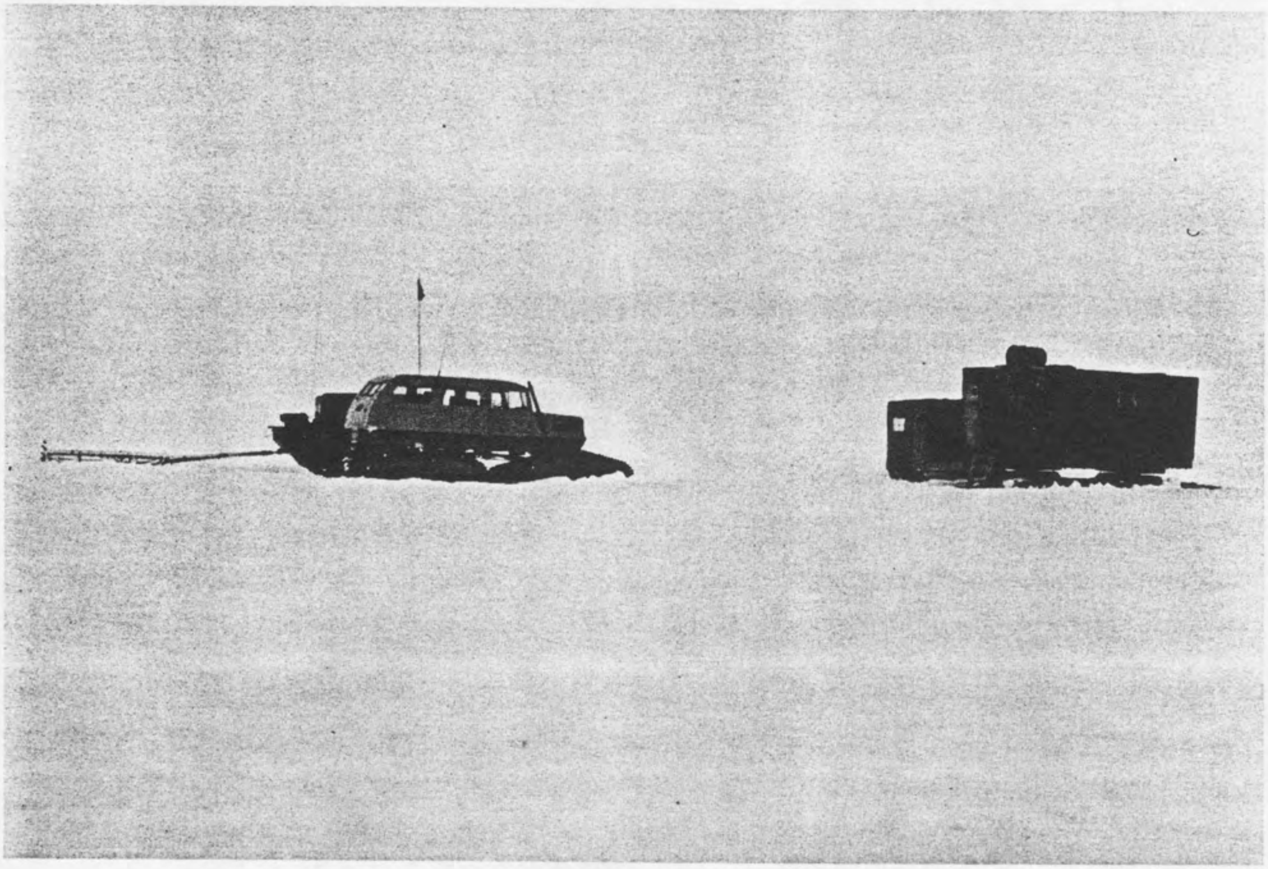

Figure 1. Overcast White-out, Showing Absence of Horizon and Lack of Surface Contrast

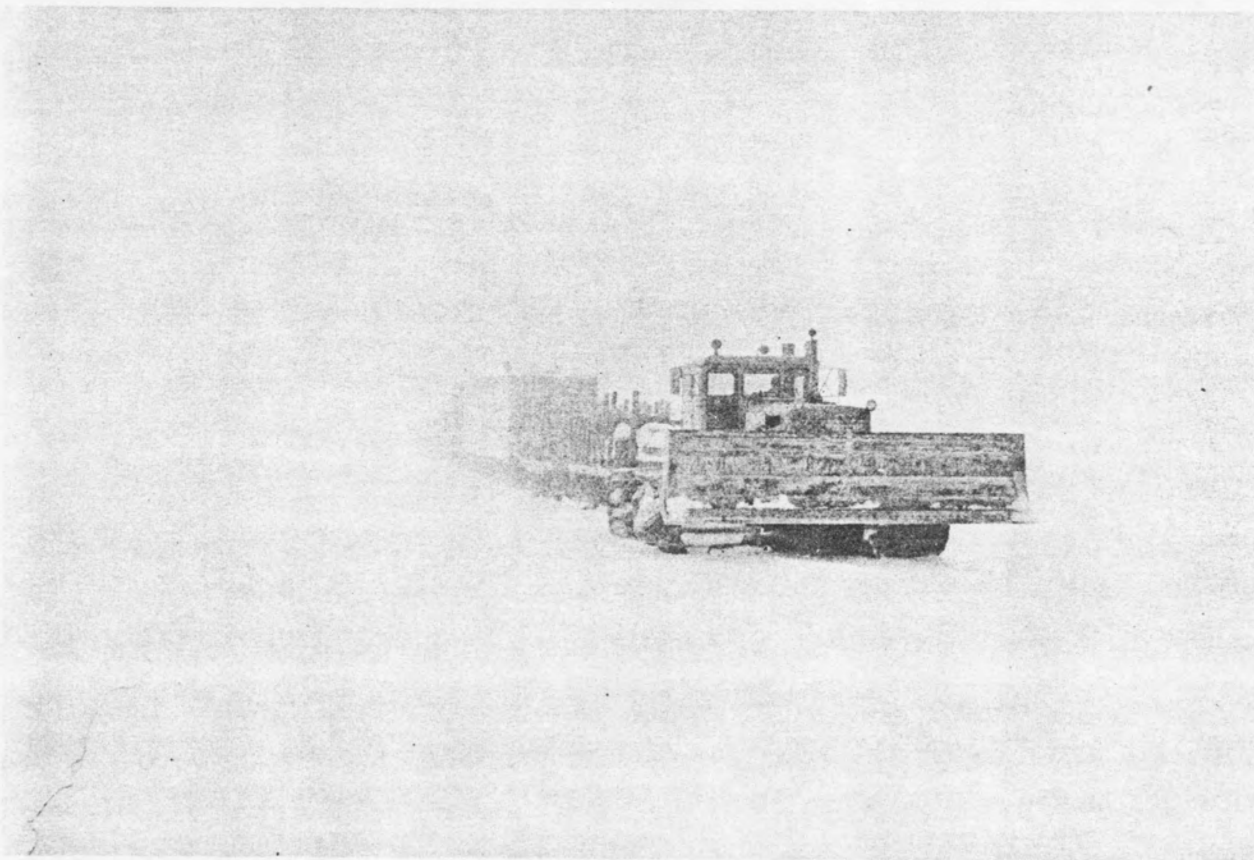

Figure 2. Water-fog White-out

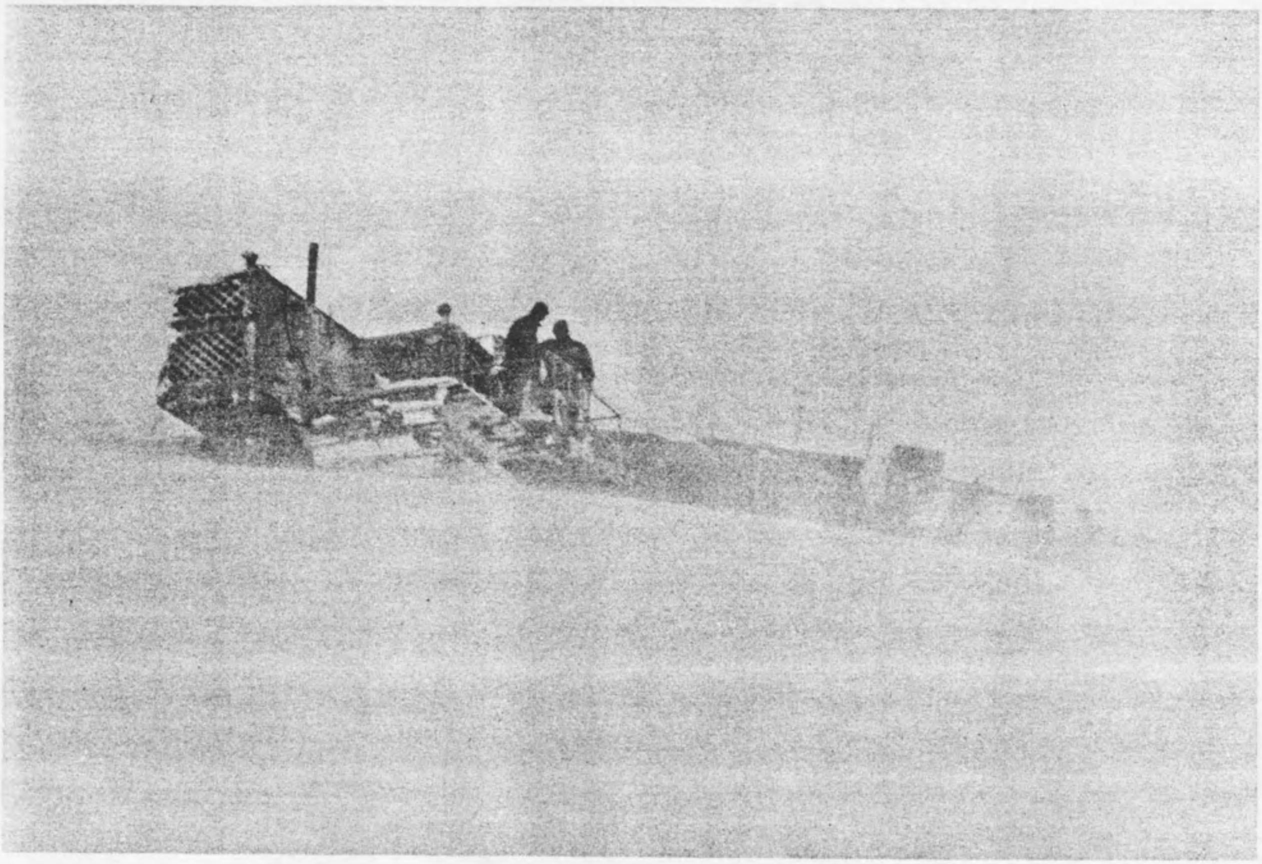

Figure 3.   Blowing Snow White-out

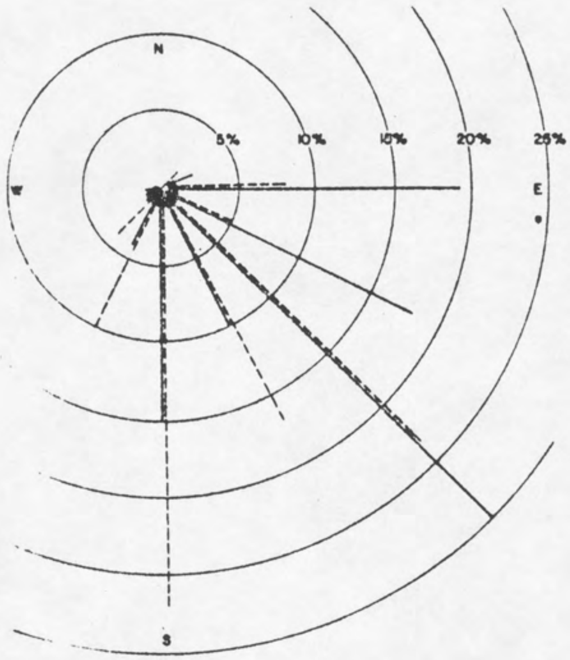

Figure 4 Comparison of wind direction during fog with mean wind direction when visibility was more than 1 mile, Site 2.
—— Mean wind rose with visibility greater than 1 mile, January 1954-December 1955.
----Wind rose January 1954-December 1955 during fog white-out.

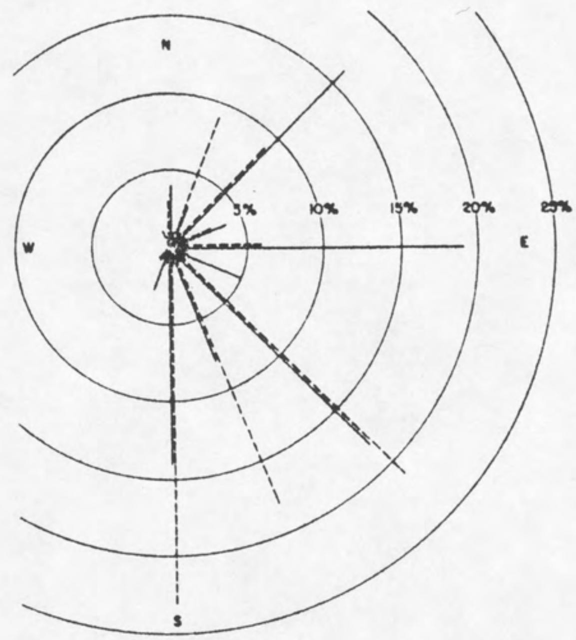

Figure 5 Comparison of wind direction during fog with mean wind direction when visibility was more than 1 mile, Site 1.
—— Mean wind rose with visibility greater than 1 mile, 20 July 1953 to 31 August 1954.
----Wind rose during fog white-out, 20 July 1953 to 31 August 1954.

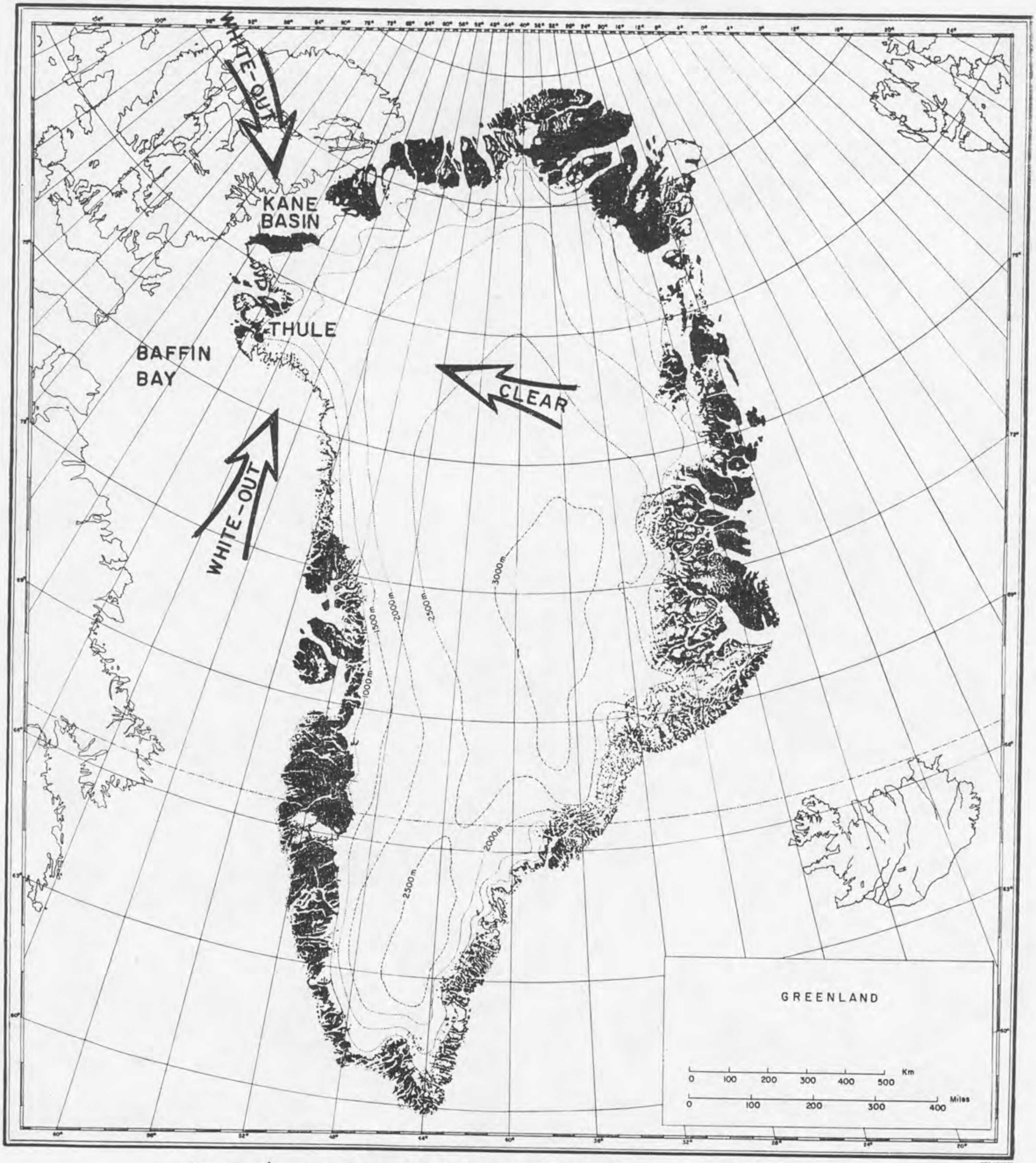

Figure 6. The Association Between Windflow and White-out on the Greenland Ice Cap