

ON THE RELATIONSHIP OF SNOW ACCUMULATION TO SURFACE TOPOGRAPHY AT "BYRD STATION", ANTARCTICA

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ABSTRACT. Recent measurements of snow accumulation on undulating surfaces around "Byrd station", Antarctica indicate that the undulations are tending to be filled in. These results are discussed in the light of current knowledge of the origin and migration of such features.

RÉSUMÉ. *Relation entre l'accumulation de la neige et la topographie superficielle à la station "Byrd", Antarctique.* De récentes mesures d'accumulation de la neige sur la surface ondulée autour de la station "Byrd", indiquent que les ondulations ont une tendance à être comblées. Ces résultats sont discutés à la lumière de la connaissance courante de l'origine et de la migration de telles formes.

ZUSAMMENFASSUNG. *Der Zusammenhang zwischen Schneeauftrag und Oberflächenrelief an der "Byrd-Station", Antarktika.* Neue Messungen des Schneeauftrages über gewellten Flächen um die "Byrd-Station" zeigen an, dass eine Tendenz zur Auffüllung der Wellentäler besteht. Diese Ergebnisse werden im Lichte der bisherigen Kenntnis über die Entstehung und Wanderung solcher Erscheinungen diskutiert.

STEPPED surfaces and undulations of wavelengths of 5–30 km. are now known to characterize much of the surface of the Greenland and Antarctic Ice Sheets, particularly the latter, and there has been some speculation as to how these features might form. Nye (1959) for example would attribute surface waves of these dimensions (mean amplitudes of about 20 m.) to irregularities in the underlying bedrock, but Bader (1961) believes that drifting snow is responsible for the formation of wavy surfaces in the high interior of Greenland.

A fairly considerable surface relief is to be observed in the general area of new "Byrd station", Antarctica. New "Byrd station" was constructed under the snow near the bottom of a broad depression and between it and the old "Byrd station" located 10 km. to the west there are two smaller valleys. An examination of the surface in February 1962 indicated that the valleys were accumulating much more snow than the crests of these undulations. In order to obtain some quantitative data on this relationship between accumulation and surface topography, two stake lines were set up, one oriented parallel to the prevailing wind direction and the other normal to it. The "east–west" line, (Fig. 1) comprising 21 stakes emplaced at intervals of 0.5 km. extended from the south-east corner of the stake farm at old "Byrd" to a point about a kilometer north of the radio noise tower at new "Byrd station". The second line of 22 stakes was begun just to the east of the V.L.F. antenna and extended down-wind in a southerly direction for a distance of 10.5 km. The elevation at each stake was measured barometrically. In Figures 1 and 2 these elevations have been converted to absolute values based on the elevation at the gravity pier at new "Byrd station".

As indicated in Figure 1, the "east–west" line traversed two small valleys superimposed on a surface that sloped upward to the east. The relief along the "north–south" line of stakes (Fig. 2) differed somewhat in that it took the form of a fairly steeply sloping surface intersected by two small steps. The impression gained in the field was that the "north–south" stakes traversed a major structural feature of the surface and that the undulations along the "east–west" line were superimposed upon this structure. However, it is difficult to say from observations over such a limited area of the surface whether or not the undulations are oriented in any particular direction. Nevertheless, after just three years of observations the stake measurements have yielded some interesting data.

First, the pattern and magnitude of accumulation for the three years ending 30 January 1963, 30 January 1964 and 9 January 1965 are remarkably similar. Along the "east–west"

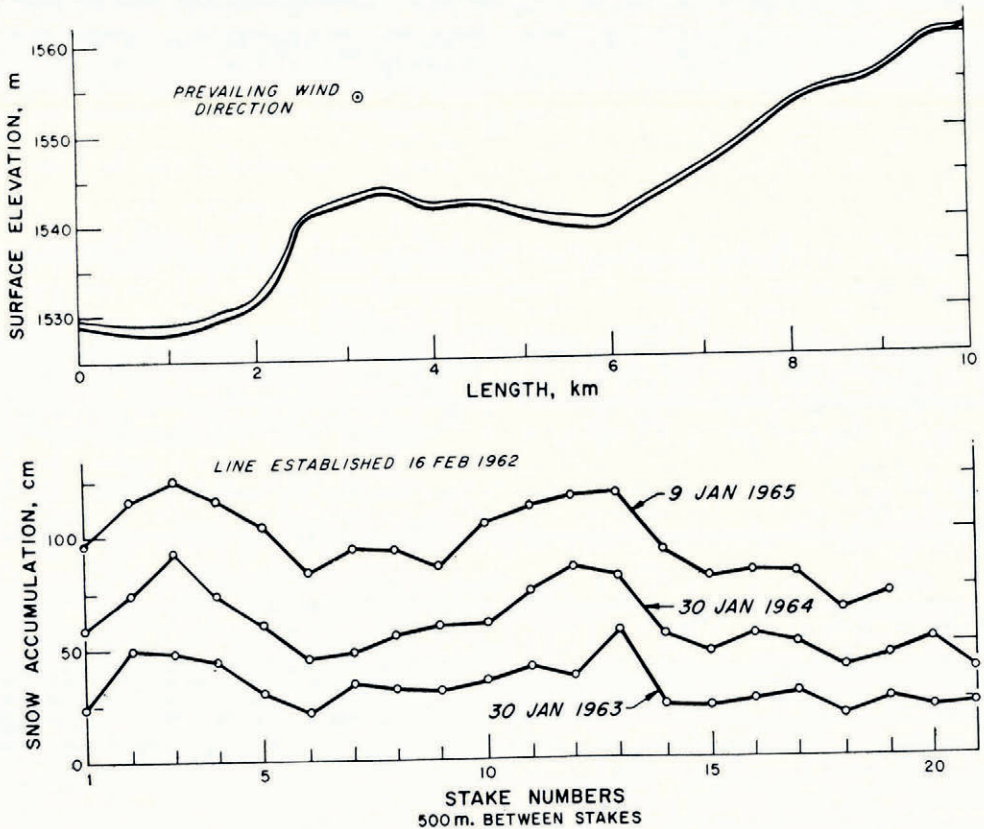


Fig. 1. Profiles of surface relief and snow accumulation along the "east-west" stake line. The thin line above the curve of surface elevation represents three years accumulation drawn to scale

line the accumulation averaged 11.0 g. cm.^{-2} for 1962, 9.7 g. cm.^{-2} for 1963 and 13.1 g. cm.^{-2} for 1964 which gives a three-year mean accumulation of $11.3 \text{ g. cm.}^{-2} \text{ yr.}^{-1}$. Along the "north-south" line the three-year mean accumulation amounted to $10.7 \text{ g. cm.}^{-2} \text{ yr.}^{-1}$ with annual increments of 10.4 , 9.0 and 12.6 g. cm.^{-2} for 1962, 1963 and 1964 respectively. These values were much smaller than expected. Several years' measurements at 100 stakes in a 1.0 km.^2 grid at old "Byrd" had yielded an average rate of accumulation of nearly $18 \text{ g. cm.}^{-2} \text{ yr.}^{-1}$. Gow (1961) obtained a value of $14.4 \text{ g. cm.}^{-2} \text{ yr.}^{-1}$ from studies of pits and cores spanning 67 yr. of continuous accumulation, a figure that falls in between those obtained at the stake farm and along the stake lines. Although the accumulation for the period 1962-64 may have been lower than usual, the present results would indicate that measurements in grids as large as 1.0 km.^2 may not yield fully representative values of snow accumulation in areas of undulating surface topography.

Secondly, both stake lines, particularly the "east-west" line, reveal a strong topographic control on accumulation rates. While slopes of constant gradient tended to accumulate snow at fairly uniform rates, abrupt changes in surface slope were invariably accompanied by pronounced changes in accumulation, with the troughs accumulating appreciably more snow than the crests. The results from the "east-west" line of stakes are specially interesting because these stakes cross the undulations at right angles to the direction of the storm winds.

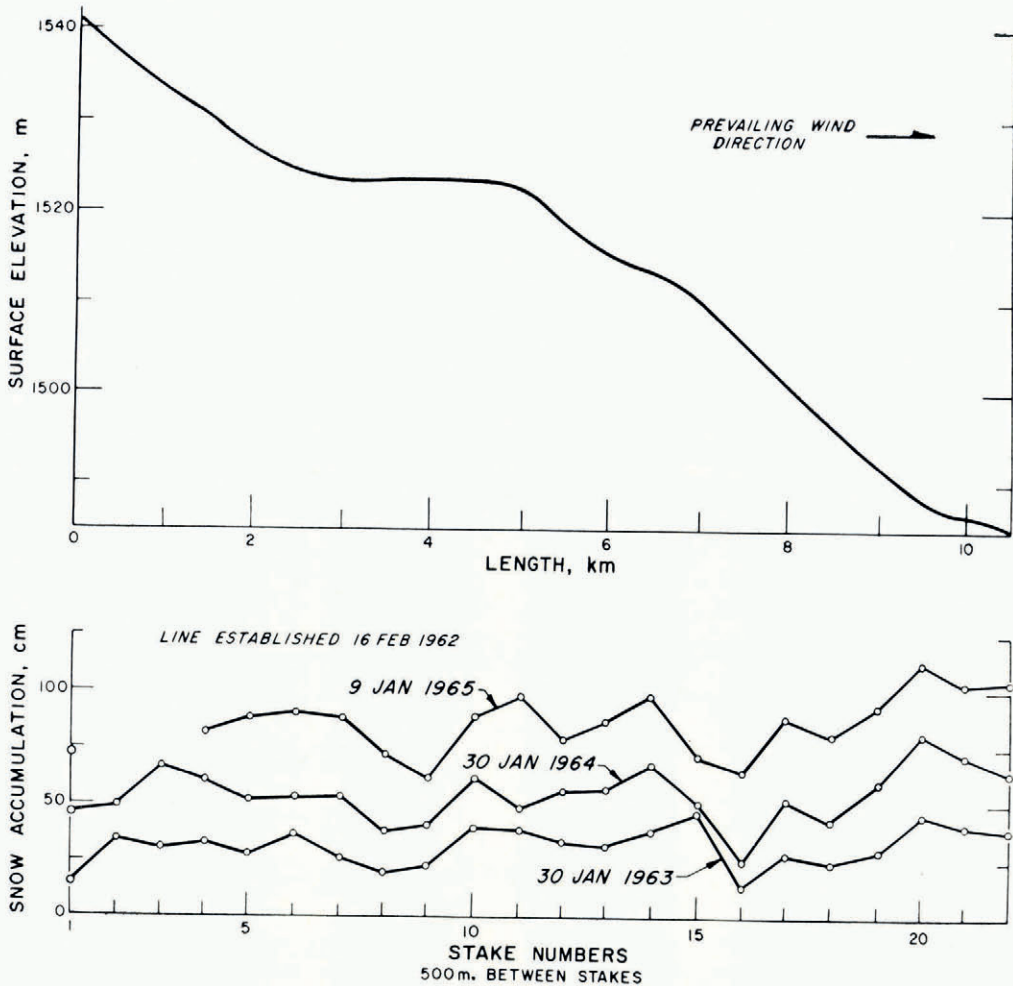


Fig. 2. Curves of accumulation and surface elevation along the "north-south" line of stakes

According to Nye (1959) surface undulations of wavelengths 3–40 km. and mean amplitude of 20 m. should not survive for much longer than a year if they represent departures from the equilibrium form of the ice sheet. Since waves of these dimensions cannot be built up by drifting snow in as little as a year, Nye concludes that such undulations can best be interpreted as stationary waves; related directly to irregularities in the underlying bedrock. However, in the interior of Antarctica where the surface movement is likely to be very small (of the order of a few meters per year only), any relief due to stationary waves might tend to be self-destructive, simply because of the variations in the surface accumulation such relief would create; i.e. surface drifting could be expected to fill in the troughs. This appears to be the case at "Byrd station". Some simple calculations indicate that at the current rates of accumulation, the surface wrinkles could be substantially smoothed out in as little as 50 yr. In Figure 3 the surface profiles after 20 yr. and 50 yr. are compared with the present day profile along the "east-west" stake line. In calculating these profiles corrections were made for the densification of the snow at the rates observed by Gow (1961) in pits and drill cores

at "Byrd station". Even after 20 yr. humps would begin to develop in the hollows if the present rates of accumulation were maintained. Of course any such changes in the surface relief would tend to be offset by changes in the pattern of accumulation but in a direction apparently that might eliminate the waves in even less time than 50 yr. During this period the surface of the ice sheet would probably have moved less than a kilometer. This displacement, of an order of magnitude smaller than the wavelength of surface undulations at "Byrd station" would have little effect on the overall accumulation. Since an appreciably undulating surface does exist around "Byrd station" this might suggest then that these undulations are not directly related to irregularities in the underlying bedrock. The fact that Bentley (1962) was not able to find any obvious relationship between the surface relief and the seismically sounded bedrock at "Byrd station" would tend to bear out this conclusion.

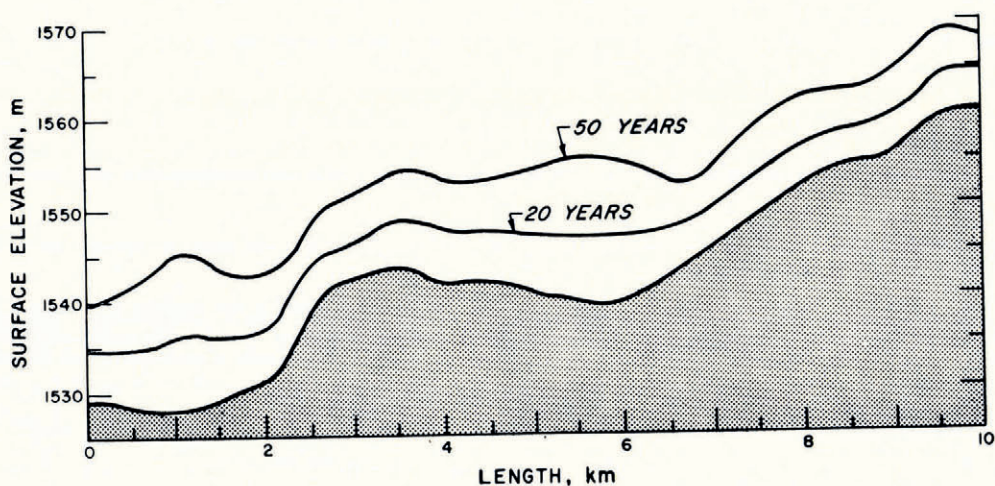


Fig. 3. Surface profiles after 20 yr. and 50 yr. of accumulation along the "east-west" stake line. The curves were calculated on the basis of present-day rates of snow deposition and have been corrected also for compaction

It now appears however that other factors are involved in the maintenance of undulations on the surface of the Antarctic Ice Sheet. According to Black and Budd (1964) accumulation of snow on undulating surfaces near Wilkes Station is related more closely to slope than simply to the existence of humps and hollows on the surface. They found that for undulations of wavelength of 5–15 km. the net accumulation maxima occurred slightly down-wind of the bottoms of the troughs, with minimum deposition occurring down-wind of the tops of the crests. Rather than filling in the waves this should, according to Black and Budd, perpetuate them and also move the waves up-slope into the wind at a rate of about 25 m. per year. It might be possible to explain some undulations by superimposing the effects of surface drift on standing waves formed on a sloping surface. The formation of stationary waves as postulated by Nye does furnish a convenient means of creating large-scale fluctuations in surface relief and if accumulation fails to subdue these waves but creates instead a wave of accumulation slightly out of phase with the stationary waves then a "migration" of the kind envisaged by Black and Budd could conceivably occur. In this way an undulation could come to occupy some new position on the surface of the ice sheet where it no longer bears any relationship to the underlying topography. This might explain the situation at "Byrd station".

Measurements along both stake lines will be continued for as long as possible. Any changes in the shapes of undulations in the past could be profitably investigated in cores taken from

depths of 20–25 m. at intervals along the surface. It would be interesting to compare past records of accumulation at say a crest and a trough and to determine what changes if any had occurred in the shape of the intervening surface. More direct measurements of this kind are needed if the questions of origin and movement of undulations in Antarctica are to be answered satisfactorily.

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