Polarforschung 55 (1): 27—32, 1985

Roughness Length of an Antarctic Ice Shelf

By Gert König*

Summary: From 1888 windprofiles, measured in 1982 under neutral conditions on a 15 meter mast near the German Antarctic research station "Georg von Neumayer", the roughness length z_0 of the Ekström Ice Shelf is calculated. The mean value of z_0 is $1*10^{-4}$ m. The roughness length shows a dependence on wind velocity which is strongly correlated with snow drift. The remarkable increase of z_0 with decreasing wind as mentioned by HOLMGREN (1971) and other authors for the low wind regime, was not observed, but between 20 and 30 m/s, z_0 increases rapidly with increasing wind. Generally, the roughness length over the Ekström Ice Shelf is smaller than over the sea and far smaller than over pack-ice. The Charnock relation, which generally characterizes the increase of the roughness length with increasing wind speed above the sea surface well, is in a qualified sense also valid for conditions over the Eckström Ice Shelf.

Zusammenfassung: Aus einer Analyse von 1888 Windprofilen bei adiabatischer Schichtung, die 1982 an der deutschen Antarktis-Forschungsstation „Georg von Neumayer" an einem 15 Meter-Mast gewonnen wurden, wird die Rauhigkeitslänge z_0 des Ekström-Schelfeis bestimmt. Sie liegt im Mittel bei $1*10^{-4}$ m, ist jedoch von der Windgeschwindigkeit und der damit eng korrelierten Schneedrift abhängig. Eine bemerkenswerte Zunahme von z_0 mit abnehmender Windgeschwindigkeit, wie sie HOLMGREN (1971) und andere Autoren bei geringen Windgeschwindigkeiten erwähnten, wurde nicht beobachtet, jedoch steigt z_0 zwischen 20 und 30 m/s mit wachsender Windgeschwindigkeit sprunghaft an. Meistens ist die Rauhigkeitslänge des Ekström-Schelfeises geringer als die einer Ozeanoberfläche und viel geringer als die von Packeis. Die Charnock-Relation, die über offenem Ozean den Anstieg der Bodenrauhigkeit mit der Windgeschwindigkeit im allgemeinen gut wiedergibt, läßt sich mit Einschränkungen auch auf die Verhältnisse über dem Ekström-Schelfeis anwenden.

INTRODUCTION

At the German Georg-von-Neumayer Research Station (70.6 S, 8.4 W) energy budget measurements have been conducted since March 1982. The station is equipped for continuous measurements of the radiation budget, firn temperatures and vertical profiles of wind speed, wind direction and air temperature. In this paper the data analysis is restricted to the wind velocity profiles under neutral conditions with special consideration of the effects of drifting snow.

WEATHER CONDITIONS

The weather around the Georg-von-Neumayer Station is strongly influenced by cyclone activities. Most of the cyclones move eastward north of the station which is the main cause for frequent blizzards from easterly directions (Fig. 1). Some cyclones passing south of the station create westerly storms which are rather seldom and not as severe as easterly storms. Winds from the north hardly exist while winds from the south are quite common. Without exception they are weak and occur only under stable conditions. They belong to local downslope currents of cold air near the ground.

The persistence of the easterly storms creates a strong north-south orientation of the sastrugies.

INSTRUMENTATION AND DATA COLLECTION

The meteorological mast is situated at a distance of about 65 m south-east of the Georg-von-Neumayer Station. In Fig. 1 the sector of the station buildings as seen from the mast is shown. There are no other obstacles or significant surface elevations around within a radius of about 7 km. The Ekström Ice Shelf is horizontally homogenous. Therefore the results obtained near the Georg-von-Neumayer Station should be valid for nearly the entire Ekström Ice Shelf and for other comparable ice shelfs.

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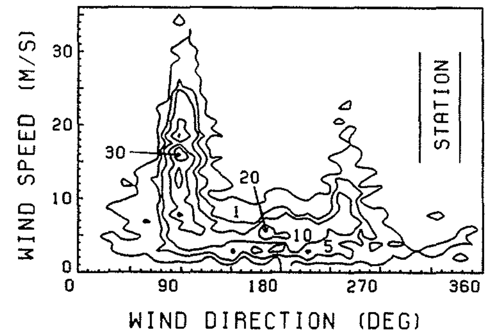

Fig. 1: Two dimensional frequency distribution of wind speed and wind direction 1982. Isolines correspond to numbers of observations in intervals 1, 5, 10, 20, 30. Total numbers of observations = 2933, classwidths = 10 deg., 1 m/s

Abb. 1: Zweidimensionale Häufigkeitsverteilung der Windstärke und Windrichtung 1982. Die Isolinien entsprechen der Anzahl der Beobachtungen in den Intervallen 1, 5, 10, 20, 30. Anzahl aller Beobachtungen = 2933, Klassenbreiten = 10 Grad, 1 m/s

The mast is a 15 m grid tower, 0.3 m wide, which was erected and equipped in January 1982. Wind speed and wind direction were measured with cup-anemometers and wind vanes (Thies 4.3323.11.41) mounted on six 1.30 m long booms pointing south-eastward. Six artificially ventilated platinum resistance thermometers were used to measure the air temperature profiles. A calculator-controlled data acquisition system made one scan per minute and signal. Based on these actual data 10 minute averages were calculated.

Due to snow accumulation the height of the instruments on the tower above ground varied with time. In order to exclude these variations the amount of snow accumulation around the site was measured.

The data acquisition system did not include snowdrift registrations. The snowdrift was classified according to Tab. 1 and estimated every three hours during the regular weather observations.

During the measurements the temperature data were frequently controlled with reference instruments. The accuracy of the data acquisition system was controlled by signal simulators. The errors due to the measuring inaccuracy of the data acquisition system can be neglected compared to the instrument errors. The error of the temperature data was 0.1 K. Since a calibration of the cup-anemometers was impossible in Antarctica it was carried out in Germany one year after being set into operation. The deviations from the manufacturer's specifications did not exceed 2%. Under calibration conditions the cup-anemometers can be regarded as free of errors within these range. In the field the accuarcy is probably less because of overspeeding, snowdrift, and temperature effects.

During the overwintering period from March 13, 1982 to February 18, 1983 about 50.000 profiles were measured. In this paper only 85 days including the polar night from May 12, 1982 to August 4, 1982 are taken into consideration since, during this time, there were no significant changes in the macro- or microstructures of the surface due to snowfall, snow accumulation, sastrugie modulation or sun radiation.

All profiles with obvious errors due to interference with the local radiostation or malfunction of instruments as well as profiles with wind speed not exceeding 2 m/s are excluded.

BROCKS et al. (1970) pointed out that any buoyancy effect will strongly influence the wind profile and,

Class	Strength of the drift snow
0	No drift snow
1	Drift snow close to the ground (up to 0.2 m)
2	Drift snow close to the ground (0.2 —1.5 m)
3	Drift snow, slight or moderate
4	Drift snow, moderate or heavy
5	Violent drift snow

Tab. 1: Classification of the snowdrift.

Tab. 1: Klassifikation der Schneedrift.

therefore, will result in incorrect z_0 values. To avoid this, only profiles with an absolute value of the Richardson number less than 0.0001 are considered. Only 20% of the profiles fulfill this condition.

The profiles cannot be classified with regard to different wind directions because more than 90% belong to easterly winds. To avoid a possible dependance on the wind direction, as mentioned by JACKSON et al. (1978) only the data which do not differ more than 30 degrees from the main wind direction are regarded.

1888 profiles correspond to all to the above restrictions. They represent the data base for this paper. Because of a temporary malfunction of one of the cup-anemometers each profile is computed by using five data points at heights 0.30, 0.95, 2.15, 4.55, 14.35 m, respectively.

With the aid of the visual drift observations each profile is classified with regard to a certain strength of drift. The drift classification is rather rough (see Tab. 1) and the time resolution of the drift observations is quite low, but nevertheless it offers the possibility to analyse the profiles with respect to the drifting snow.

PROFILE ANALYSIS

The 1888 profiles show only minor deviations from the logarithmic profile

$$u(z) = \frac{u^*}{\varkappa} \ln \left(\frac{z-d}{z_0}\right) \tag{1}$$

with u = wind velocity, z = height above ground, d = zero point displacement, u* = friction velocity, $\varkappa$ = von Karman constant, z_0 = roughness length. The zero point displacement d is regarded to be zero, which is a good approximation for a plain iceshelf. Fig. 2 gives some examples. With a least squares fit, it is possible to determine the profile parameters u* and z_0 from a u-ln(z)-plot. The roughness length z_0 is normally used to characterize the surface roughness and u* is a measure of the vertical momentum flux in the Prandtl layer.

The regression coefficient for each profile is greater than 0.95, mostly about 0.99. Systematic deviations from the logarithmic profile law due to blowing snow as mentioned by SOMMERFELD et al. (1965) were not observed.

Averaged over all 1888 profiles the magnitude of z_0 is about $1*10^{-4}$ m (Fig. 3). The variance of z_0 may partly be due to the observational methods, partly to real changes of the surface roughness with respect to drifting snow or wind velocity.

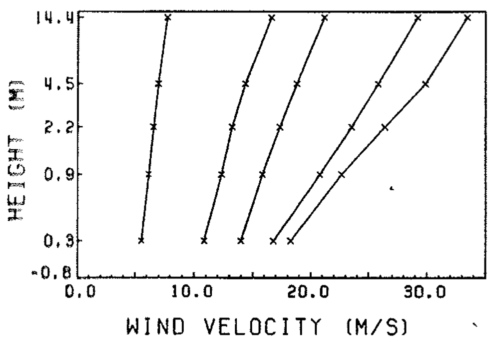

Fig. 2: Semilogarithmic presentation of some examples of windprofiles under neutral conditions. Crosses are datapoints

Abb. 2: Halblogarthmische Darstellung einiger Windprofilbeispiele bei adiabatischer Schichtung. Kreuze sind Meßwerte

Class	z_o*10+4 m	CDN10*1000	Profiles	$\bar{U}$ m/s
0	0.56	1.104	11	8
1	0.58	1.116	94	13
2	0.88	1.193	18	12
3	0.93	1.214	321	16
4	0.96	1.231	673	18
5	2.16	1.462	771	22

Tab. 2: Dependence of the roughness length z_o and the drag coefficient C_{DN10} on the snow drift. $\bar{U}$ is the averaged wind velocity 10 m above ground.

Tab. 2: Abhängigkeit der Rauhigkeitslänge z_o und des Widerstandsbeiwertes C_{DN10} von der Schneedrift. $\bar{U}$ ist die mittlere Windgeschwindigkeit in 10 m Höhe.

Tab. 2 shows the averaged z_o for each class of snow drift according to Tab. 1. The roughness length increases monotonously with the strength of snow drift.

Because of the strong correlation between the classes of drift snow and the wind speed (see Tab. 2) it cannot be proven whether the drag coefficient depends on drift snow, wind speed or both. Better drift measurements could help to answer this question.

Frequently the drag coefficient C_{DN10} — defined as $C_{DN10} = (u^*/u_{10})^2$ — is used instead of the roughness length z_o. For neutral conditions, the relation between C_{DN10} and z_o is given by:

$$C_{DN10} = \left(\frac{\varkappa}{\ln\left(\frac{10}{z_o}\right)}\right)^2 \qquad (2)$$

It is found that C_{DN10} depends on wind speed. Fig. 4 shows the result from the Ekström Ice Shelf. All 1888 profiles are grouped into 10 classes of different wind speed. The class with the lowest wind speed contains only 11 cases. The mean of the following class is slightly smaller, but in general C_{DN10} increases with increasing u.

HOLMGREN (1971) and other authors who dealt with C_{DN10} over snow surfaces found a remarkable increase of C_{DN10} with decreasing u for low wind speed. In order to avoid buoyancy effects Holmgren accepted only a certain deviation from the near-neutral stratification. The adopted limits, given by the difference in potential temperature between the 0.14 and 4.50 m levels of his mast, have been taken as +/—0.15 K. This corresponds to a Richardson number of about +/—0.01 which is 100 times larger than the limit applied in this paper. Taking HOLMGREN's (1971) limits, the same remarkable increase of C_{DN10} with decreasing wind speed results from the data of the Ekström Ice Shelf. It seems that the limits used by HOLMGREN (1971) do not sufficently exclude buoyancy effects.

Fig. 4 shows that C_{DN10} increases remarkably at about 25 m/s. For lower and also for higher wind velocities the dependence of the drag coefficient on wind speed is rather small. Some data derived over sea show a similar behaviour at about 15 m/s. Follwing WU (1969) this results from the phase velocity of the short gravity waves which are responsible for the sea surface roughness. The shape of the surface of an

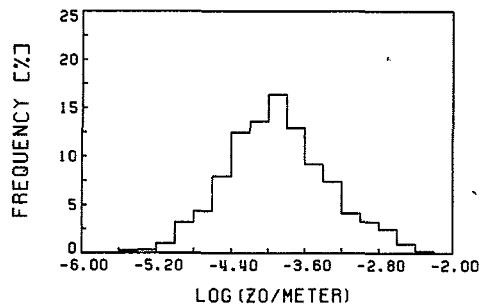

Fig. 3: Relative frequency distribution of the Brigg's logarithm of the roughness length z_o in meters

Abb. 3: Relative Häufigkeitsverteilung des dekadischen Logarithmus der Rauhigkeitslänge z_o in Metern

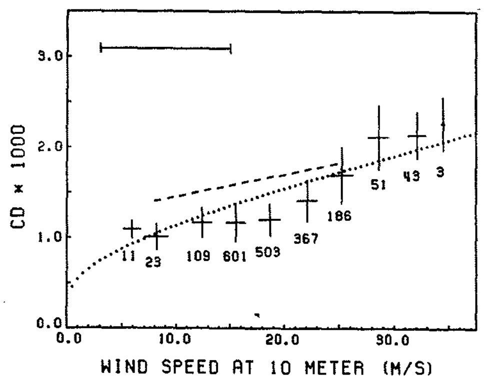

Fig. 4: Dependence of the drag coefficient C_{DN10} on wind speed. The number of 10-minute profiles is plotted under the 1-sigma-bars. The straight line after MACKLIN (1983) is derived from data over sea ice, the broken line after KONDO (1975) is derived from data over sea, the dotted line is the Charnock relation with a = 0.006

Abb. 4: Abhängigkeit des Widerstandsbeiwertes C_{DN10} von der Windgeschwindigkeit u. Die Anzahl der jeweils berücksichtigten 10-Minuten Profile ist unter dem 1-Sigma-Fehlerbalken vermerkt. Die durchgezogene Linie sind Meßdaten von MACKLIN (1983) über Meereis, die gestrichelte Linie sind Meßdaten von KONDO (1975) über See, die gepunktete Linie ist die Charnock Beziehung mit a = 0.006

ice shelf is rather independent of the wind velocity and cannot explain the sudden increase of C_{DN10}. Probably the drift particle itself causes this effect.

CHAMBERLAIN (1983) suggested that the roughness created by modification of a mobile surface is numerically similar regardless of the surface being water, sand or snow and that the roughness of mobile surfaces can be described by the Charnock relation

$$z_o = a \frac{u^{*2}}{g} \qquad (3)$$

with g = 9.81 m/s and a = constant. The dotted line in Fig. 4 is the Charnock relation. It fits best with a = 0.006. The relation shows a decreasing slope of the drag coefficient with increasing wind speed and does not describe the sudden increase of C_{DN10} at about 25 m/s. Nevertheless it may be used to describe the conditions over the Ekström Ice Shelf within the range of data scattering.

For comparable wind velocities KONDO (1975) provides an empirical relation for C_{DN10} derived from measurements over sea under near neutral conditions:

$$C_{DN10} * 1000 = 1.2 + 0.025 * u \qquad \text{for } 8 < u < 25 \text{ m/s} \qquad (4)$$

Over sea ice the drag coefficient can be much larger. MACKLIN (1983) found from data derived over heavily fractured sea ice in the Bering sea that

$$C_{DN10} * 1000 = 3.09 \qquad \text{for } 3 < u < 15 \text{ m/s} \qquad (5)$$

with no dependence on wind within the indicated range. Except for very strong winds the drag coefficient over the Ekström Ice Shelf is smaller than over sea and far smaller than over fractured sea ice.

ACKNOWLEDGEMENTS

The data for this paper are a result of the entire overwintering crew of 1982. The author thanks everyone who helped to make the overwintering as enjoyable and succesful as it was, and H. Hoeber who contributed many helpful suggestions in rewiewing the manuscript.

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