KATABATIC WIND PROFILES OVER THE GREENLAND ICE SHEET: 
OBSERVATION AND MODELLING 

A. G. C. A. MEESTERS, N. J. BINK, E. A. C. HENNEKEN, H. F. VUGTS and 
F. CANNEMEIJER 
Institute of Earth Sciences, Vrije Universiteit Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, 
The Netherlands 

(Received in final form 24 July, 1997) 

Abstract. Profiles of wind and temperature have been observed above the Greenland ice sheet, 90 km 
from its western margin, in July 1991. The terrain slopes downward to the west. Measurements 
were performed with instruments on a 30 m mast, combined with a Doppler SODAR and a RASS. 
Whereas the surface is usually at the melting point, the temperatures in the free atmosphere are above 
freezing. The depth of the boundary layer, in which the wind turns to the free atmosphere direction, 
is not much more than 100 m. The surface wind is always about from the southeast (hence with a 
downslope component), whereas winds from the southwest (with an upslope component) often occur 
at the 100 m level. 
Mixing length profiles for momentum were estimated by comparison of calculated and observed 
wind profiles. A good accordance between calculated and observed wind speed was obtained. The 
neutral mixing length had a maximum of only a few metres, which was approached already at low 
height. The limiting value is proportional to the 0.7-th power of the Froude number times a length 
scale obtained from the temperature profile. 

Key words: Katabatic wind, Greenland ice sheet, SODAR measurements, Mixing length 

1. Introduction 

The katabatic wind over the slopes of the Greenland ice sheet has some interesting 
features. Far from the ice margin, the katabatic wind is a typical slope wind not 
perturbed by terrain inhomogeneity, which makes its investigation attractive from a 
micro-meteorological point of view. Further, the energy balance during the melting 
season is directly related to the mass balance and hence to sea level change, and 
for this reason the atmospheric circulation above Greenland has become a field 
of much research (Meesters, 1994; Gallée et al., 1995; Van den Broeke, 1997; 
Van den Broeke and Gallée, 1996). Reliable parameterization of the boundary 
layer is of great importance for this work. However, much is unclear concerning 
the outer region of the boundary layer under katabatic conditions. This is the 
principal reason why the prediction of turbulent surface fluxes for Greenland is 
a major problem for numerical models of the atmosphere (Ohmura et al., 1994). 
Useful meteorological observations from Greenland are notoriously scarce, since 
measurements with masts in general are insufficiently high, whilst radiosonde 
observations have insufficient resolution. 
In this paper, a dynamic model is discussed in which the turbulent diffusion 
of momentum is expressed in terms of wind shear, neutral mixing length, and a
stability factor. The mixing length is tuned by comparing calculated and observed wind profiles. Wind and temperature profiles were observed in July 1991 as a part of the Greenland Ice Margin Experiment (GIMEX, see Oerlemans and Vugts, 1993). The wind above mast height (30 m) was observed by acoustic sounding up to 90 m, whereas temperature data above mast height were gathered with a RASS. In Meesters et al. (1997a) these measurements are described more elaborately, and compared to results for other sites. Exchange at the surface is dealt with in Meesters et al. (1997b).

2. Theory

2.1. General Description of the Model

A dynamic model has been developed to produce stationary wind profiles from a limited number of assumptions. The results will be compared with observed wind profiles. The employed temperature profiles are prescribed as such, and remain unchanged during the computations.

The model is one-dimensional, with integer-numbered \( z \)-levels from 0 m to 80 m with steps of 10 m, but with the 70 m level left out and with a level at 5 m added. The kinematic momentum flux \( \mathbf{\tau} = (\tau_x, \tau_y) \) is attached to these levels, whereas the wind speed \( \mathbf{v} = (u, v) \) and the potential temperature \( \theta \) are attached to the half-numbered levels in between and to the top level \( H = 90 \) m. The dynamic equations are written as

\[
\frac{\partial u}{\partial t} = f(v - v_g) - \frac{\partial \tau_x}{\partial z} + bn_x, \tag{1}
\]

\[
\frac{\partial v}{\partial t} = -f(u - u_g) - \frac{\partial \tau_y}{\partial z} + bn_y. \tag{2}
\]

Herein, \( f = 1.16 \times 10^{-4} \) s\(^{-1}\) is the Coriolis parameter, \( \mathbf{v}_g = (u_g, v_g) \) is the geostrophic wind at the model top, \( \mathbf{n} = (n_x, n_y) \) is the horizontal unit vector pointing in the downslope direction (see Section 3.1), and

\[
b(z) = g \frac{\theta(H) - \theta(z)}{\theta_0} \sin \alpha, \tag{3}
\]

in which \( g = 9.8 \) m s\(^{-2}\), \( \theta_0 = 273 \) K, and \( \alpha \) is the slope angle (see Section 3.1). For the derivation of Equations (1) to (3) we refer to Mahrt (1982). However, in (1) and (2), the ‘thermal wind term’, which contains the spatial derivative of \( \theta \) in the flow direction, has been omitted, as has the advection term. Both were shown to be negligible, for the present case, by Van den Broeke et al. (1994).

For \( \mathbf{\tau} \) we have

\[
\tau_x = -K \frac{\partial u}{\partial z}; \quad \tau_y = -K \frac{\partial v}{\partial z} \tag{4}
\]