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ABSTRACT

The variance, correlation and climatology parameterizations required in the optimum interpolation analysis of 1.5 m air temperature are given. Application of the ontimum interpolation method leads to horizontal temperature gradient estimates that correlate significantly, but poorly, with the difference between observed 1500 m wind and the surface geostrophic wind. From surface observations of pressure and air temperature a reliable estimate of upper winds (around heights of 1500 m) can be formed.

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THERMAL WIND ESTIMATES FROM SYNOPTIC AIR TEMPERATURE OBSERVATIONS

by

G.J. Cats

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I. INTRODUCTION

The estimation of wind speed and direction at heights around 1000 to 1500 m is often hindered by the rare availability in space and time of observations. Since at this height the geostrophic approximation is often valid (Holton, 1973), the wind may be estimated from the geostrophic wind, which is defined by

$$\underset{\sim}{u}_G\ (z) = \frac{1}{f\rho} \left(- \frac{\partial p}{\partial y} , \frac{\partial p}{\partial x} \right) \tag{1}$$

In here, p is the air pressure, x and y are the coordinates (east, north), f is the coriolis-parameter and ρ the air density. The pressure gradients can be analyzed from surface observations of air pressure (Cats, 1977), but the geostrophic wind then has to be corrected for the thermal wind

$$\underset{\sim}{u}_{th} = \frac{\partial \underset{\sim}{u}_G}{\partial z}$$

Using the hydrostatic relation $\frac{\partial p}{\partial z} = - \rho g$, the equation of state for a perfect gas $p = \rho RT$ and the approximation $\frac{g}{f} \frac{\partial T}{\partial x} >> \frac{\partial T}{\partial z} |\underset{\sim}{u}_G|$, the thermal wind is written as a horizontal temperature gradient:

$$\underset{\sim}{u}_{th} = \frac{g}{fT} \left(- \frac{\partial T}{\partial y} , \frac{\partial T}{\partial x} \right) \tag{2}$$

(The symbol T denotes the air temperature as observed at a height of, generally, 1.5 m, and g the acceleration of gravity).

In this report, the right hand side of (2) is estimated by using an optimum interpolation analysis of the 1.5 m air temperature observations. This estimate has been compared with the difference between the observed wind at about 1500 m and the surface geostrophic wind. If at 1500 m the geostrophic approximation holds, this difference is the integral of the thermal wind over the layer between 0 and 1500 m. From the comparison, therefore, a conclusion about the representativity of surface thermal wind for the integral thermal wind can be drawn.

II. TEMPERATURE ANALYSIS

The analysis of 1.5 m air temperature is based on the optimum interpolation method. In this method an interpolation of temperature variance, spatial correlation and long-term average temperature ("climatology") is required (Cats, 1978). From a data set, consisting of the hourly 1.5 m temperature observations at 15 stations in the Netherlands (fig. 1) during the years 1958 till 1967, the following parameterizations were derived:

(a) Variance:

$$\sigma_T^2 = 37.9 + 0.82\ x/\lambda - 0.38\ y/\lambda + 10.1\ \mathrm{tgh}(d/\lambda) \tag{3}$$

(explained variance: 95 %),

with λ = 20 km (which was chosen beforehand as a suitable scale for the distance to the coast d in the hyperbolic tangent tgh), and σ_T in K. The coordinate system (x,y) has its origin at $51^o58'$, $4^o56'$E. The diurnal variation has been included in (3). The variance over sea, therefore, is much smaller than over land.

(b) Correlation

$$\gamma = \gamma_o \exp(-(r/l)^2) \tag{4}$$

with r the mutual distance of the stations. Further,

$$\gamma_o = 0.978 \ ; \qquad l = 1135\ \mathrm{km} \tag{5}$$

The correlation length l is much larger than the one for surface wind (520 km; Cats, 1978), but agrees well with the synoptic scale (1250 km; Lorenc et al., 1977).

(c) Climatology

$$\langle T \rangle = 273.16 + 9.7 - 0.068\ x/\lambda - 0.053\ y/\lambda \tag{6}$$

(explained variance 85 %) $\quad$ ($\langle T \rangle$ in K).

In (6), tgh(d/λ) does not occur, because this term would not increase the explained variance significantly.

From (3) and (5) the root-mean-square observation error estimate

$$\sigma = (1/\gamma_o - 1)^{\frac{1}{2}}\,\sigma_T \tag{7}$$

turns out to be only 1 K. This observation error includes variations due to local phenomena.

At the lightvessel Noordhinder, some 50 km off the coast (see fig. 1), the values obtained by extrapolation of (3) and (6) agreed with observed values within 1.2 K^2 and 0.2 K respectively. This indicates that the parameterizations (3) and (6) may be extrapolated beyond the Netherlands coast.

The horizontal temperature gradient was determined from the 1.5 m air temperature observations by the same procedure as used to obtain the wind gradients (Cats, 1978).

Two examples of analyzed temperature fields are given in figures 2 and 3. As expected, the over land diurnal variation exceeds the over sea variation.

III. THERMAL WINDS

During the period 1-3-1977 till 1-3-1978 the thermal wind was estimated four times a day (1052 cases) according to (2) from the analyzed temperature gradient in the origin of the coordinate system. This estimate was compared with the difference between rawinsonde wind obsevations at De Bilt at heights varying between 1200 and 1600 m and the surface geostrophic wind, which had been obtained from synoptic pressure observations (Cats, 1977). The results of this comparison are:

1. The right hand side of (2) is significantly correlated with the wind difference. The correlation coefficient, however, is only 47 % for both wind components.
2. The right hand side of (2) overestimates the wind difference with a factor of 2.5 for both components.

The low correlation coefficient may be ascribed to the bad representativity of the surface temperature for the average temperature in the layer below 1500 m. Indeed, if only 1200 GMT (midday) situations are used, the correlation coefficient rises somewhat in the west-to-east component (namely, to 57 %). Yet, this correlation coefficient is still low. The main cause for the poor correlation is therefore the fact that two winds, that are of comparable order of magnitude, are subtracted. This leads to an increased influence of measuring errors, which, especially in the rawinsonde data, are not negligible. Further, in some cases the geostrophic approximation might be invalid.

The second result of the comparison, i.e. the systematic overestimation of the difference between the 1500 m wind and the surface geostrophic wind, is explained by the fact that near-surface temperature gradients tend to be higher than the average gradients over the layer between 0 and 1500 m.

From the low, but significant correlation coefficient (see result 1) it follows that it is - slightly - useful to estimate the winds at heights around 1500 m by augmenting the surface geostrophic wind by 40 % of the surface-derived thermal wind multiplied by the height at which the wind is estimated. On the same data set, this procedure led to correlation coefficients of 90 % between estimated and observed 1500 m wind components. If no thermal wind correction would have been applied, the correlation coefficient would have been 87 %.

The root-mean-square difference between estimated and observed 1500 m wind components amounts to 4.7 m/s with, and 4.9 m/s without thermal wind correction (averages for both components). Therefore, the thermal wind estimate from surface temperature observations makes up a small but nevertheless significant correction to the surface geostrophic wind for 1500 m wind estimates.

Scatter diagrams of estimated versus observed wind components around 1500 m are given in figures 4 and 5.

IV. CONCLUSIONS

The optimum interpolation method is suited for 1.5 m air temperature analysis from synoptic temperature observations. This method leads to horizontal temperature gradients that are significantly correlated with observed thermal winds, but they overestimate the thermal wind by a factor of 2.5.

From the surface geostrophic wind and the analyzed temperature gradients a reasonable estimate of winds at heights around 1500 m is obtained.

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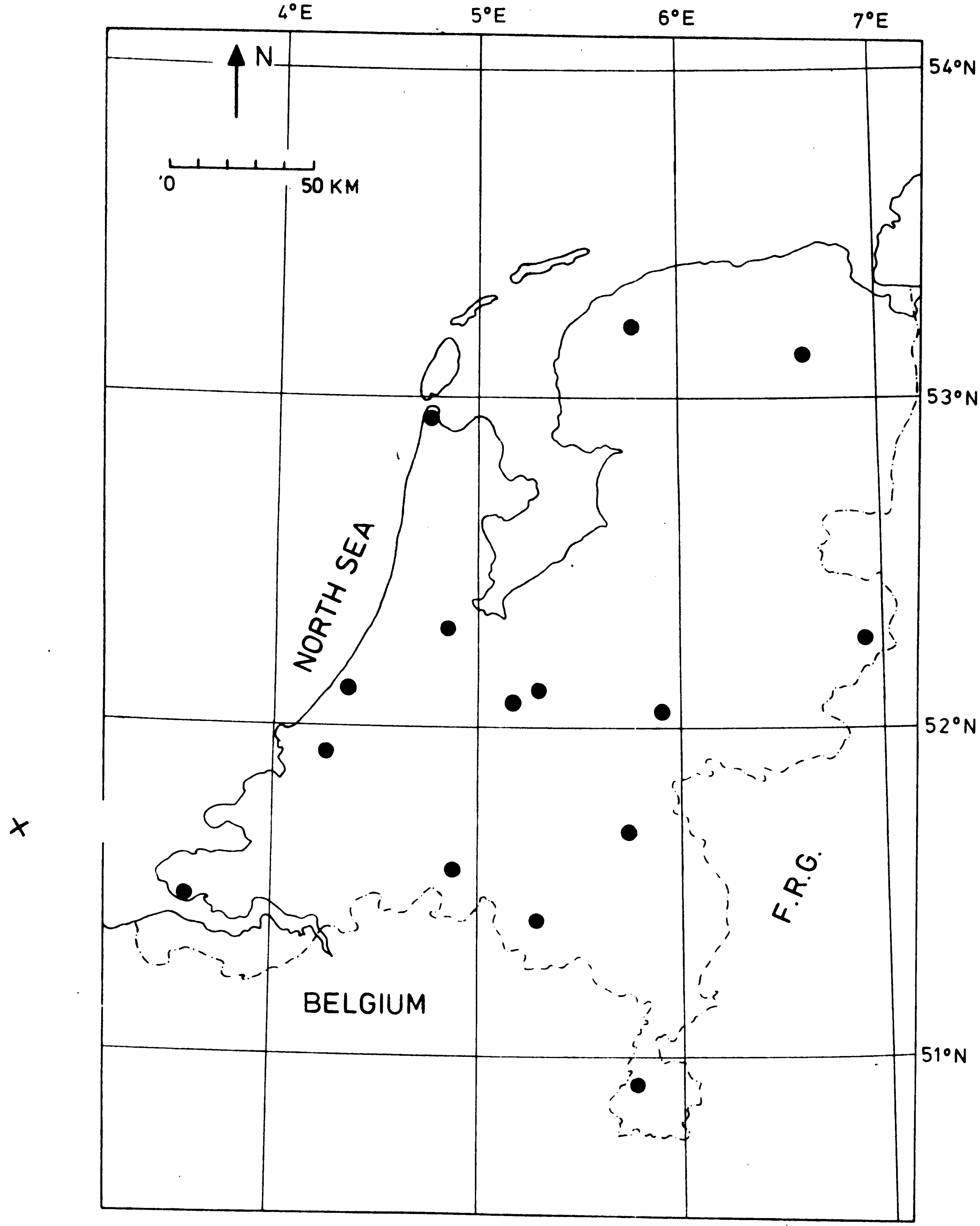

Fig. 1 Position of the 1.5 m temperature observation stations.
o : station used in the analyses
x : lightvessel Noordhinder (06300)

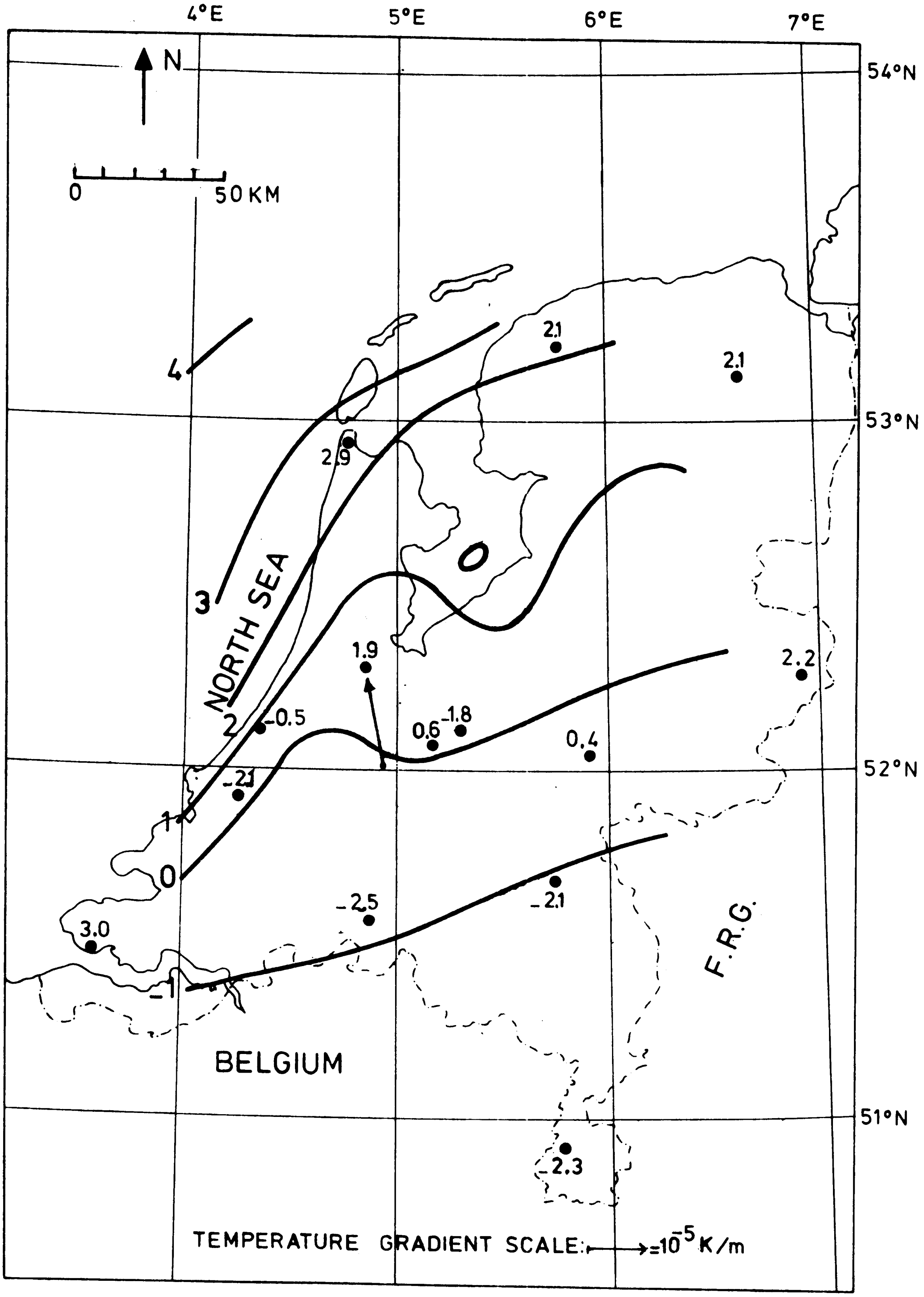

Fig. 2 Air temperature observations and analysis on 770301, 0000 GMT (midnight). Temperatures are given in centigrade. In the origin of the coordinate system the analyzed temperature gradient is indicated.

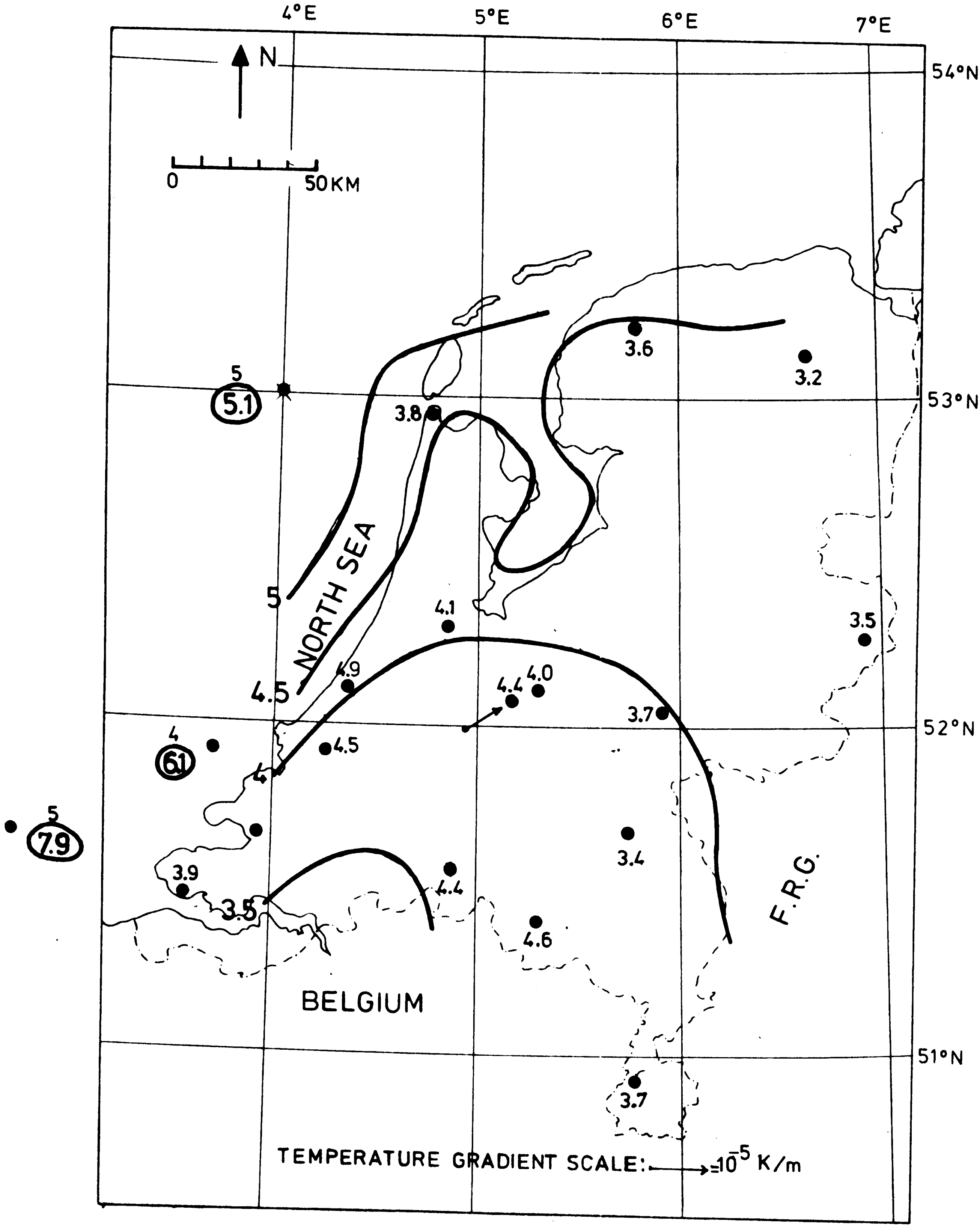

Fig. 3 As fig. 2, however at 1200 GMT (midday). Some temperature observations over sea are also shown (these are not used in the analysis). The figures in circles are observed sea water temperatures.

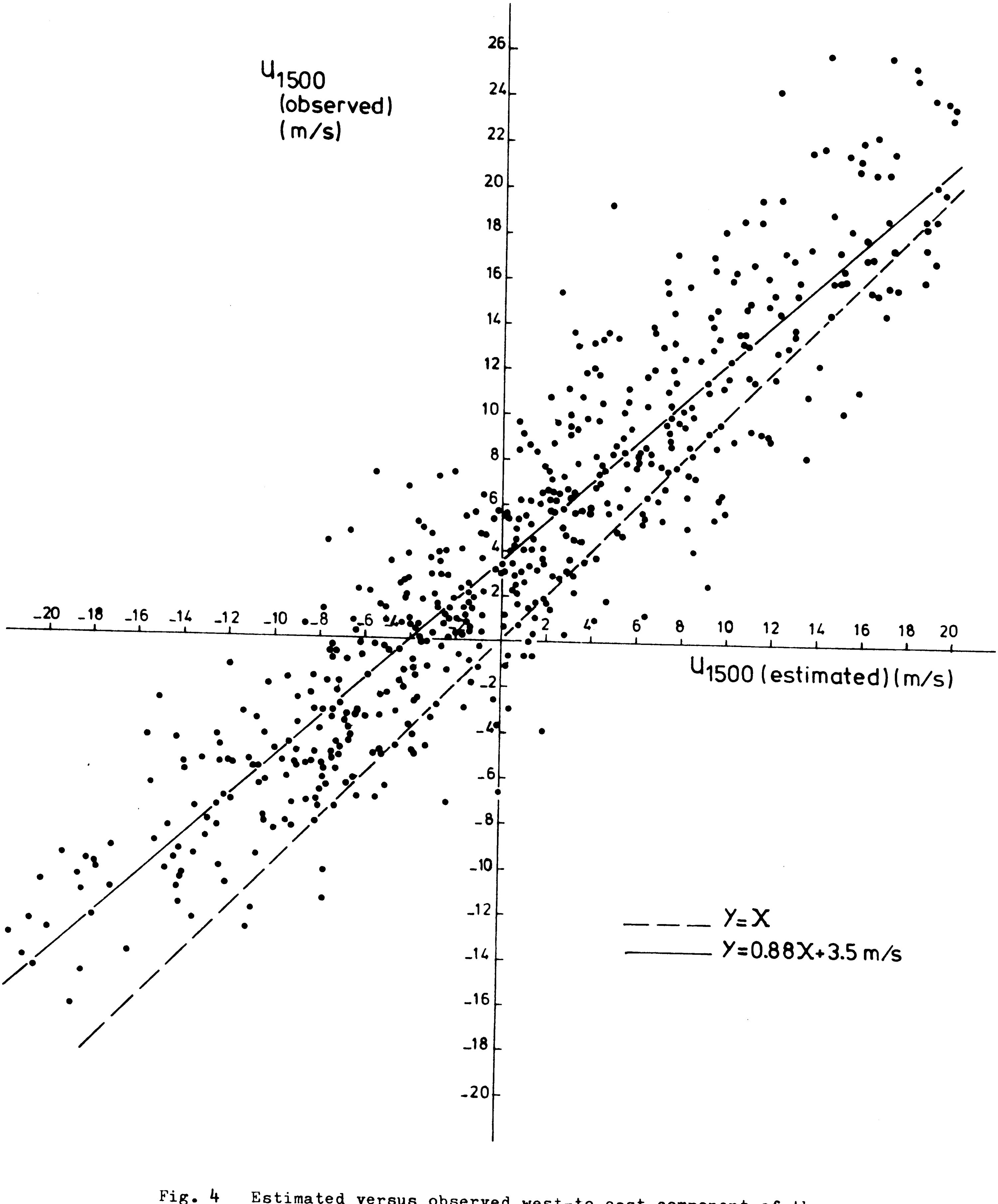

Fig. 4 Estimated versus observed west-to-east component of the wind around z = 1500 m.

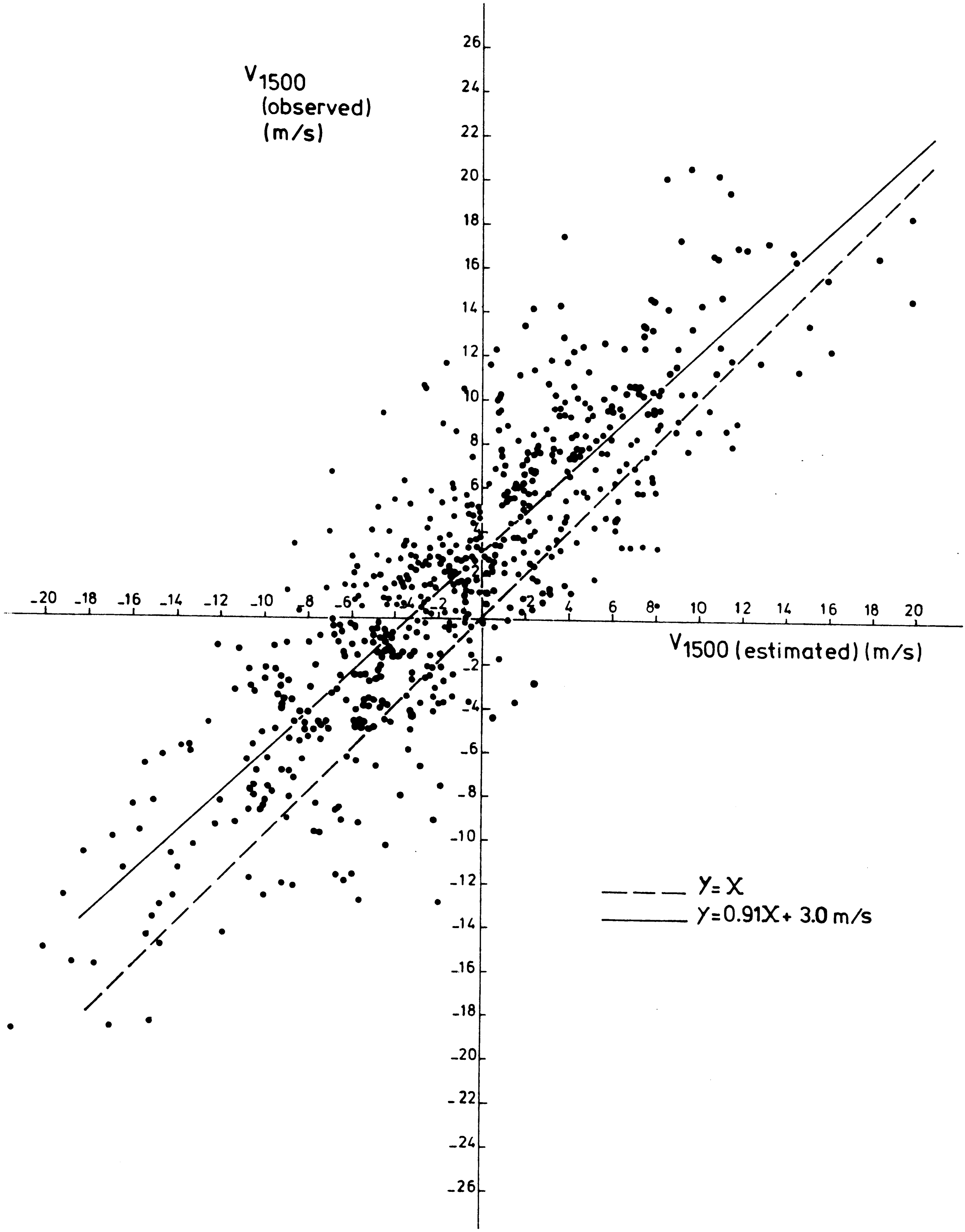

Fig. 5 Estimated versus observed south-to-north component of the wind around z = 1500 m.