Time Dependent Calibration of Marine Beaufort Estimates Using Individual Pressure Differences

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Abstract

COADS contains wind estimates from the last 130 years. They indicate a considerable negative trend until World War II, after that an often discussed increase of the wind force. Whether these trends are a true climate signal is questionable because the observing practices have changed during the last century which probably introduced an artificial interdecadal trend into the wind series.

In order to examine this question, Beaufort estimates from COADS are compared to individual pressure differences between two ships. In this way the geostrophic wind component perpendicular to the function line of the ships is obtained. Assuming a constant geostrophic angle this component depends on the wind direction relative to the function line and a sinusoidal fit over all relative wind directions leads to the geostrophic wind speed, when effects of observation inaccuracies in the wind direction are eliminated.

According to this method mean geostrophic wind speeds are computed for each month of an individual year, separately for the four 10° latitude zones between 20°N and 60°N in the North Atlantic. With an orthogonal regression the relationship between wind force and geostrophic wind is determined for each year, based on the 12 monthly values. It is assumed that this relationship has to be constant through the years and each deviation is referred to a temporal drift of the Beaufort scale. In this way a time-dependent equivalent scale is evaluated, using the scale for the period 1960-1971 (see Lindau: "A New Beaufort Equivalent Scale", this volume).

If Beaufort estimates of COADS are converted with the time dependent equivalent scale the negative trend in the period before 1945 is converted into a positive trend of the same magnitude. The mean historical wind speed is increased and becomes equal to the mean wind speed since the year 1945. In the modem period the positive trend vanishes.

Introduction

Meteorological observations on board Voluntary Observing Ships (VOS) are an important data source for climatological studies. They date back to the middle of the last century. Even today, the wind observations of VOS are based mostly on Beaufort estimates. The reports indicate a significant decrease of the wind speed up to 1945, after this a considerable increase is registered (Peterson and Hasse, 1987). Whether these trends are a true climate signal is questionable because the observing practices have changed during the last century which probably introduces an artificial interdecadal trend into the wind series. In earlier times, when sailing ships were dominant, the Beaufort wind force was defined by the amount of sail a special type of ship were able to carry (Kinsman, 1969). With the introduction of steamships the Beaufort scale had to be redefined and the wind force has been estimated by the sea state (Petersen, 1927). Since the sixties more and more merchant ships have been equipped with anemometers and wind estimates have been partly substituted by measurements.

For this reason the unreliable wind trends deduced from ship reports have to be verified by objective criteria, e.g. by comparing to mean air pressure gradients (Ramage 1987). However, his method requires extremely high directional steadiness of the wind. Consequently, it is applicable in only some regions of the world ocean. Therefore, in this study *individual* pressure differences are used.

A necessary condition of the purposed absolute interdecadal calibration of the Beaufort estimates, is the availability of an equivalent scale valid for a fixed period. This is accomplished by the “New Beaufort” equivalent scale derived in the North Atlantic for the period 1960 to 1971 (Lindau, 1994). Whether this scale is valid also for other decades or whether a time dependent scale is necessary will be examined in the following by a calibration against pressure differences.

Data

Individual wind and pressure reports of the North Atlantic between 20°N and 60°N dating from the period 1890 to 1990 are taken from COADS. Only Beaufort estimates are considered, in order to exclude the well known artificial increase of the wind speed due to measurements (Cardone et al., 1990). Measurements are separated according to a flag given in COADS, indicating whether the wind was measured, or whether the observation practice is unknown. The latter are here considered to be Beaufort estimates.

In COADS direct information about the Beaufort force is available only in some data sets. The standard information concerning the force is given in knots, even if the wind was originally estimated. Obviously, the wind speed was obtained by converting the estimates with the old WMO scale Code 1100. In following computations the original knot-values are first changed into Beaufort (with the old WMO scale) and then reconverted into knots with the *new* equivalent scale (Lindau, 1994) valid for the period 1960 to 1971.

The resulting wind speeds are shown in Figure 1. Anomalies with respect to monthly means of the respective $1° \times 1°$ box indicate a significant negative trend of more than 1 cm/s/year for the period 1890 to 1945, and even stronger but positive trend of 1.5 cm/s/year since 1946.

Method

Outline

Individual ship reports are used, if they contain the air pressure and the wind strength and direction. Pairs of simultaneously observing ships are formed, provided that the distance between them is larger than 200 km and less than 500 km. Their pressure difference yields the momentum geostrophic wind component perpendicular to the junction line between the two ships. The magnitude of this component depends not only on the wind strength but also on the wind direction relative to the junction line, if a constant but unknown geostrophic angle is assumed (Fig. 2). Therefore, the geostrophic wind component is averaged separately for 36 classes of relative wind direction. A sinusoidal fit over all relative wind directions leads to a function which provides the requested parameters: The amplitude of the resulting sine curve represents the magnitude of geostrophic wind, its phase shift defines the mean geostrophic angle (Fig. 3).

Effects of observation errors

Inaccuracies in estimating the wind direction may falsify the results as follows: The pressure differences may be sorted into wrong classes of relative wind direction, which effects a diminished amplitude of the fitted sine curve. If Δd denotes the mean observation error of the wind direction, the amplitude decreases with the factor $\cos\Delta d$.

The mean error of wind direction is evaluated by computing differences in the reported wind direction $D_1–D_2$ between two simultaneously observing ships, which are separated by a certain distance. A linear fit for values of $\cos(D_1–D_2)$ with respect to ships' distance allows to extrapolate to the distance $\Delta x=0$, where only observation errors are responsible for a value less than 1. If the errors are random the mean value of $\cos(D_1–D_2)$ at the distance $\Delta x=0$ is equal to $\cos^2\Delta d$, representing the squared mean observation error of the wind direction. Figure 4 illustrates the evaluations. At the distance $\Delta x=0$ a value of 0. 804 remains for the mean cosine of $D_1–D_2$, which is equivalent to observation error of 26.3°

Time Dependent Calibration

According to the method introduced above monthly magnitudes of the geostrophic wind are computed firstly for the standard period 1960 to 1971, separately for the four 10°-latitude zones between 20°N and 60°N in the North Atlantic. Figure 3 shows the result for the month of January in the zone between 40°N and 50°N. Based on more than 1 million pairs of observation a mean geostrophic wind of 13.3 m/s is found, together with an geostrophic angle of 17.6°. However, because of the large observation errors in estimating the wind direction (Δd=26.3°, see Fig. 4), the amplitude of the computed sine curve is diminished by the factor $\cos\Delta d$. Hence, the computed raw value has to be enlarged by the factor $\cos^{-1}\Delta d$, in order to get the true magnitude of the geostrophic wind. A value of 14.8 ms^{-1} results. The magnitude of the simultaneously observed wind speed, according to the New Beaufort scale, amounts to 10.2 ms^{-1} (Fig. 5).

For the standard period 1960 to 1971, the procedure is carried out for each month and each 10° zone, so that 48 pairs of geostrophic wind "G" and observed wind "U" are available.

A linear and orthogonal regression provides the relationship between both parameters, according to:

$$G = A_1 U + A_0$$

Figure 6 shows the result, which yields the following values for the constants A_0 and A_1:

$$A_0 = -3.7\ ms^{-1}$$

$$A_1 = 1.81$$

This relationship between G and U is considered to be highly reliable, since it is derived within the standard period, when the New Beaufort scale used is valid. It is further assumed, that this relationship has to be constant through the years. Each deviation is referred to a temporal drift of the Beaufort scale.

Then, relationships between G and U are analogously computed for other periods. The evaluations are carried out for each individual year, if at least 40,000 pairs of observations are available per 10° zone, otherwise observations of surrounding years are included. Figure 7 illustrates the results for some selected years.

In general, the constants a_o and a_1, defining the relationship. between G and U in a certain year differ from the constants A_0 and A_1, which are derived for the standard period. a_0 and a_1 are considered to be falsified, because a non-time-dependent scale has been used.

True relationship (1960-71): $G = A_1U+A_0$ (1)

Potentially falsified relationship for a certain year: $G = a_1(t)u+ a_0(t)$ (2)

In order to obtain the true relationship for each year, the equivalent scale has to be transformed according to: $U = c_1(t)u+c_o(t)$ (3)

$$c_1(t) = a_1(t)/A_1$$
$$c_o(t) = (a_0(t)-A_0)/A_1$$

Hence, the intended calibration of the new equivalent scale is reduced to the two time dependent coefficients $c_1(t)$ and $c_o(t)$. Their application on all years yields the time dependent equivalent scale showed in Fig 8.

Results

If Beaufort estimates of COADS are converted with the time dependent equivalent scale, the negative trend in the period before 1945 is reversed into a positive trend of the same magnitude (Fig. 9). However, the mean historical wind speed is raised and becomes equal to the mean wind speed since the year 1945. In this modem period the positive trend vanishes. The increasing wind speed of the uncorrected COADS is obviously due changing observational practices.

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Figure 1: Wind anomalies of the period 1890 to 1990 in the North Atlantic between 20° N and 60°N. The values are based on Beaufort estimates converted by the New Beaufort scale. Anomalies are computed against monthly 1° x 1° box averages. One year running means of these anomalies are plotted. A linear regression yields for the period 1890-1945: -1.03 ±0.21 cm/s/year. For the period 1946-1990 results a linear trend of +1.48 ±0.20 cm/s/year.

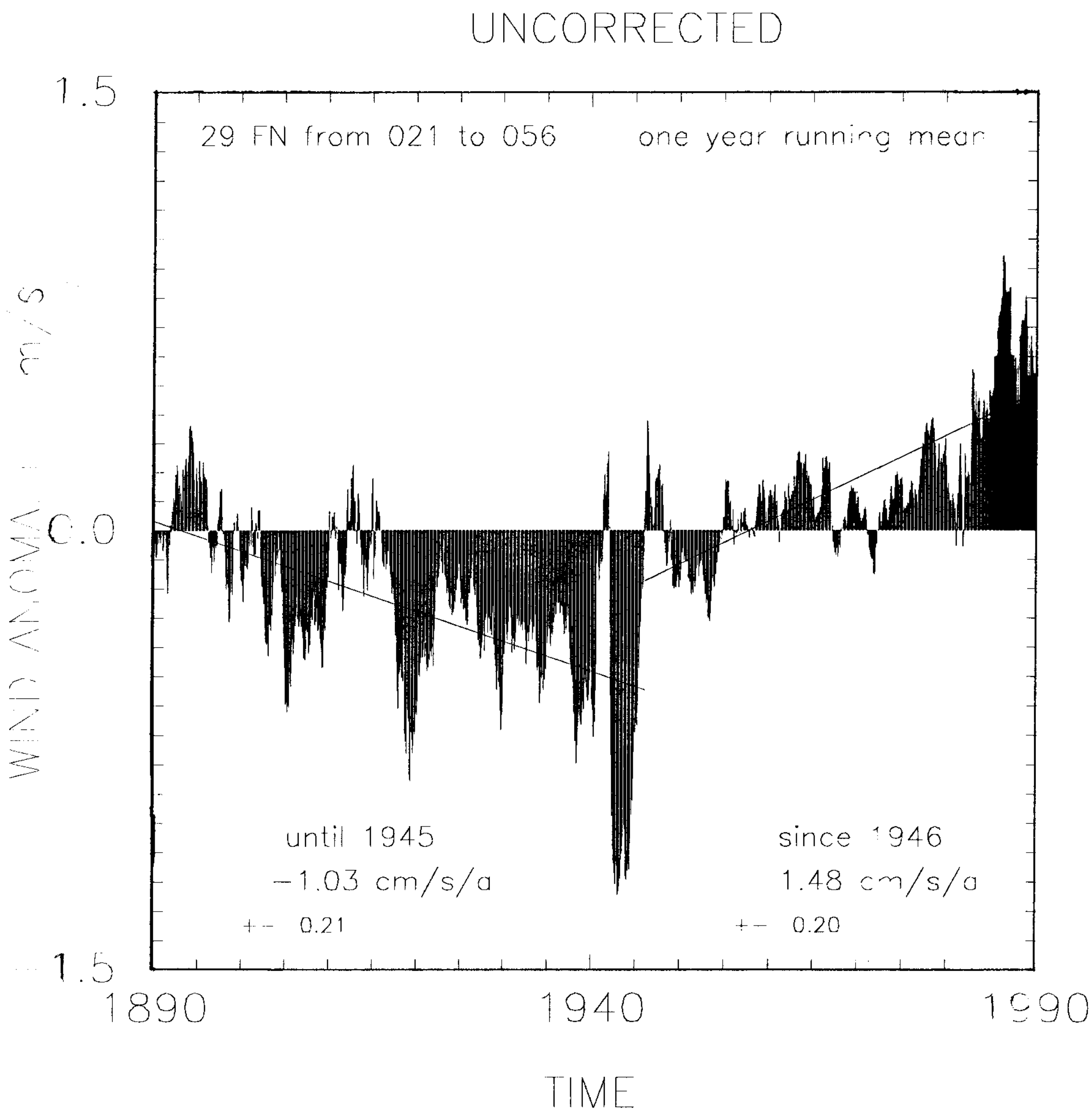

Figure 2: Wind direction *Drel* relative to the junction line between two individual ships. The value is based on the mean observed wind direction. The figured example shows *Drel* = 290 .

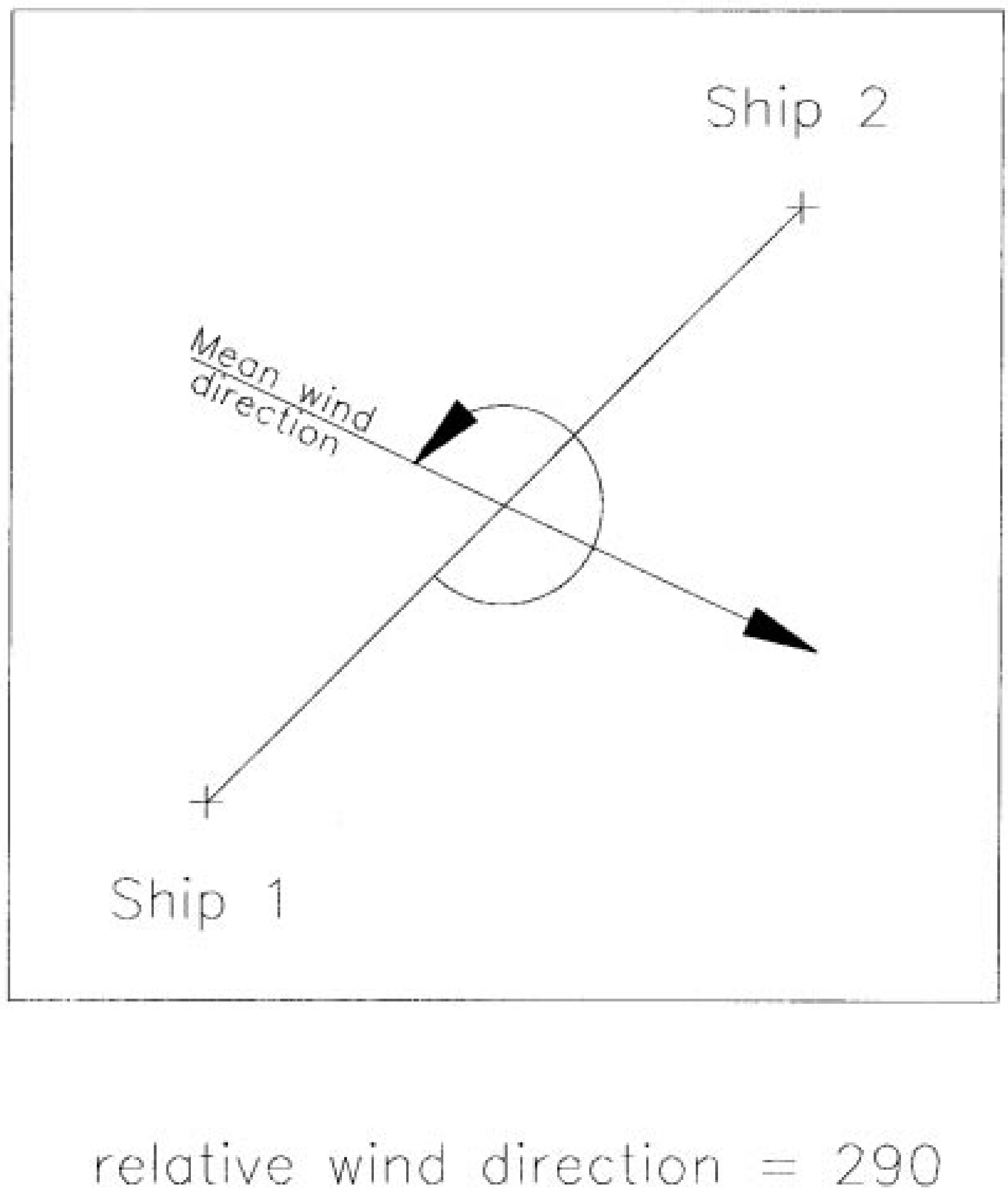

Figure 3: Magnitude of the geostrophic wind for the month of January in the standard period 1960 to 1971 and in the North Atlantic between 40°N and 50°N. The computed sine curve is based on mean geostrophic wind components for 36 classes of relative wind direction. The evaluations yield a geostrophic wind of 13.3 ms^{-1} and an geostrophic angle of 17.6 .

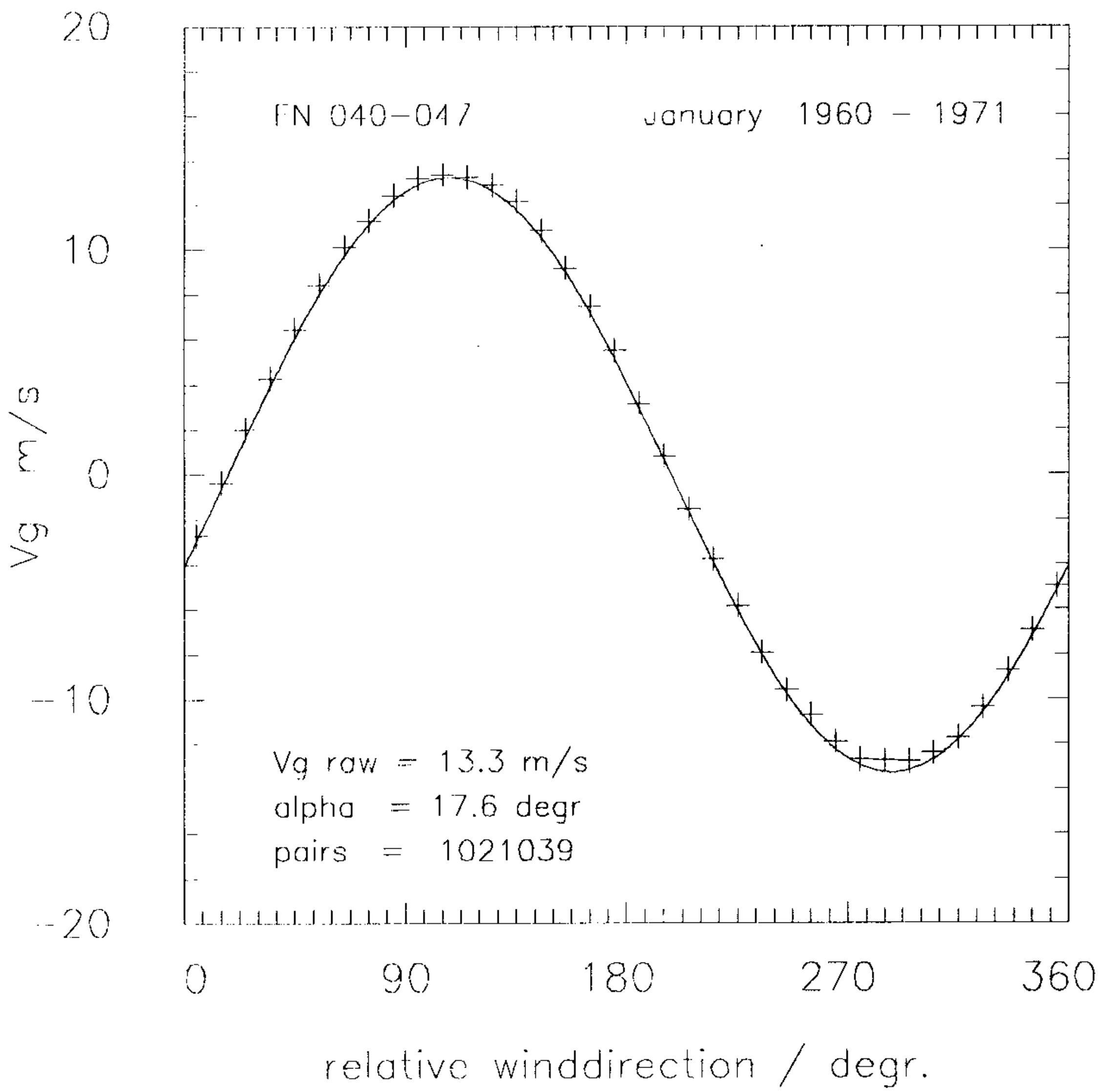

Figure 4: Example for the evaluation of the mean observation error in estimating the VOS wind direction. The mean cosine of the differences between two ship reports are figured as a function of distance. The value at the distance Δ=0 represents the mean observation error. The results are referred to the same region, period and month as in figure 3.

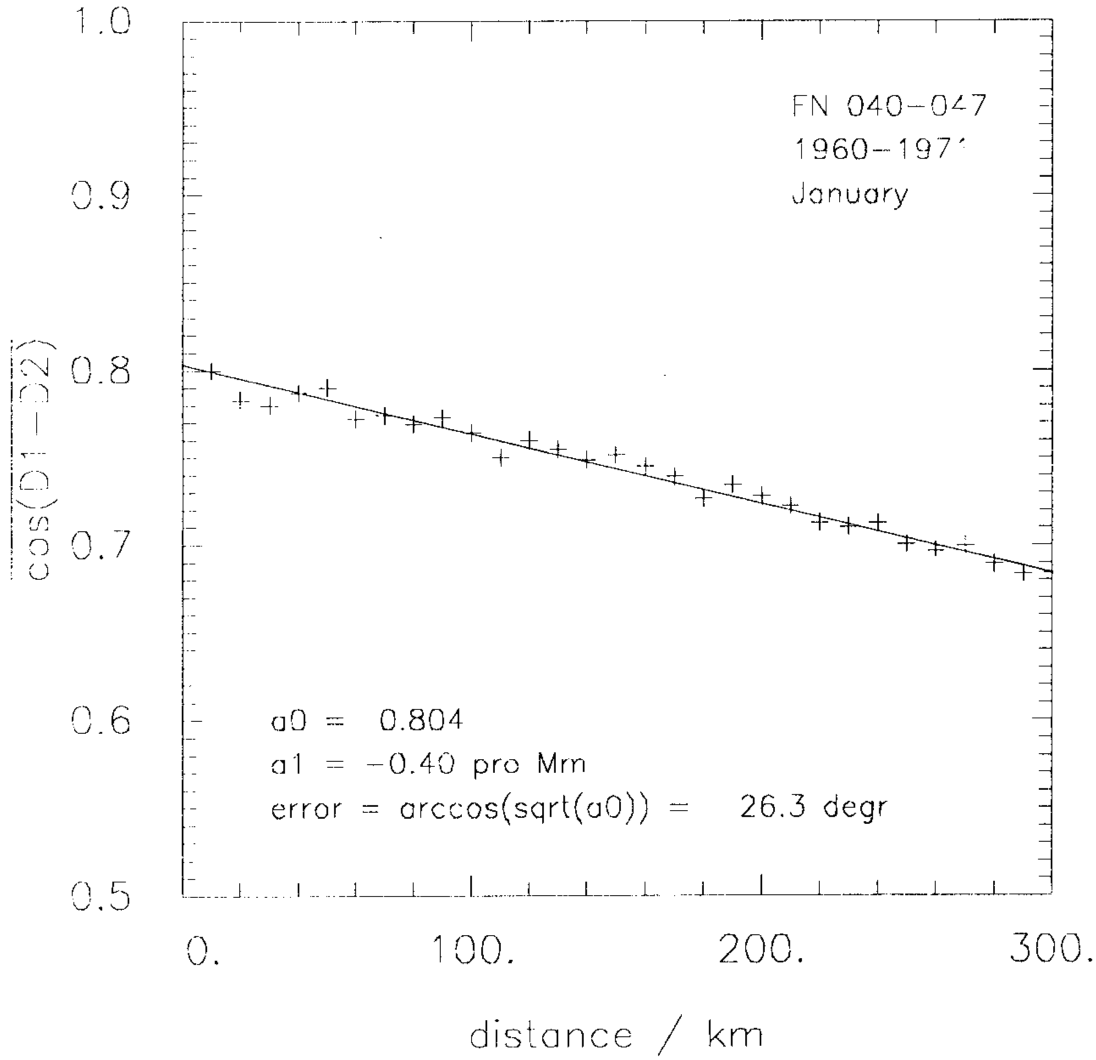

Figure 5: As figure 3, but including the true geostrophic wind figured as dashed line after the correction with $\cos^{-1} \Delta d$. The correction compensates the effects of observation errors in the wind direction. The resulting geostrophic wind of 14.8 ms^{-1} will be compared to the simultaneously observed wind speed of 10.2 ms^{-1}.

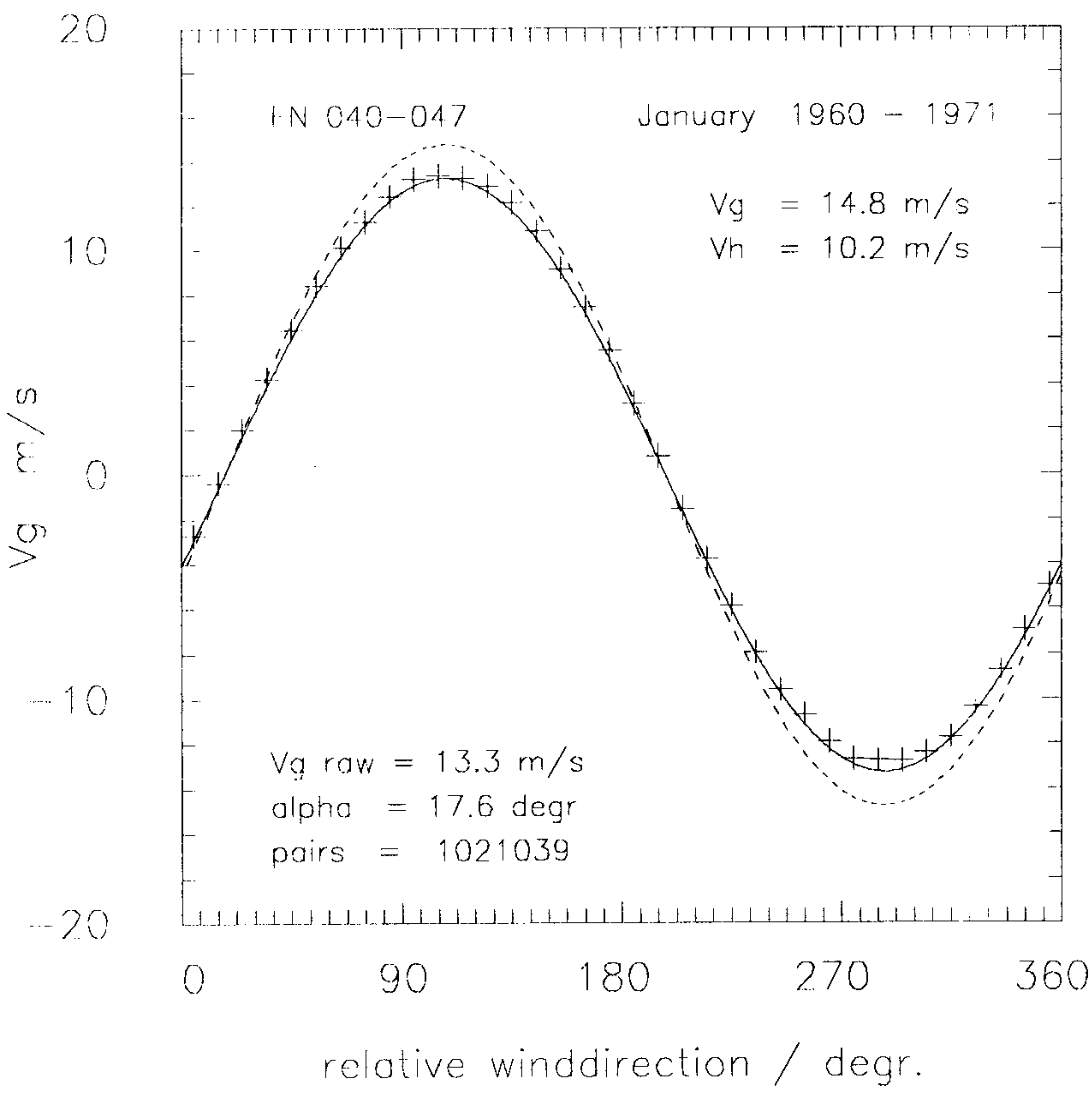

Figure 6: Determination of the relationship between geostrophic wind G and observed wind U for the standard period 1960 to 1971. The evaluations are basing on 48 G vs. U pairs derived for 12 month and four 10° zones. The linear and orthogonal regression yields G = 1.81*U - 3.7 ms^{-1}.

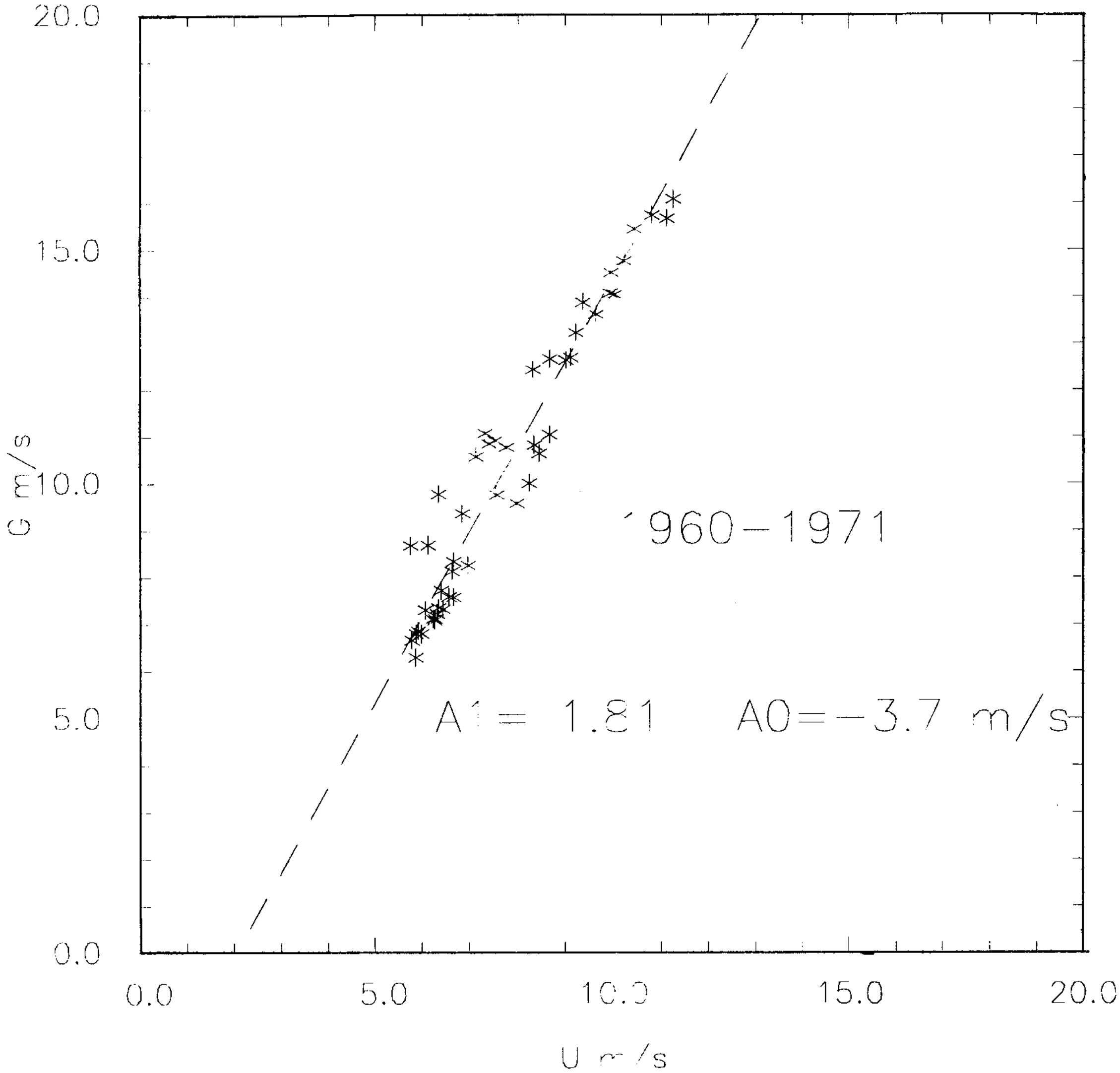

Figure 7a: Relationship between G and U for the year 1895. Additionally, the relationship for the standard period 1960 to 1971, which is regarded to be valid, is pictured as dashed line. The comparison of both relationships provides coefficients of correction for the respective year. For the year 1895 the following values result: reg. coeff$^{(1895)}$ = 1.043 and constant$^{(1895)}$ = -0.55 ms-1.

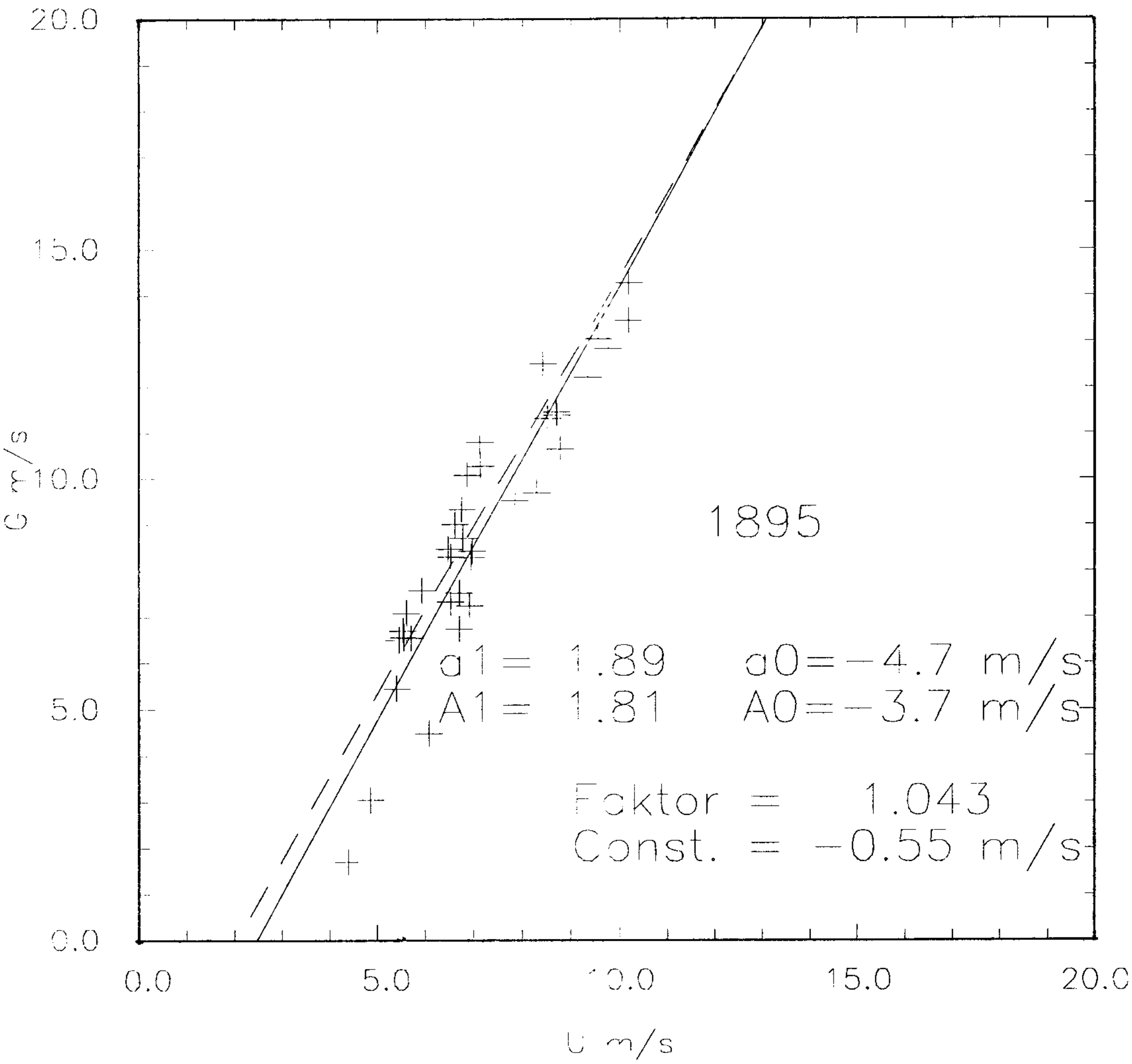

Figure 7b: As figure 7a, but for the year 1935.

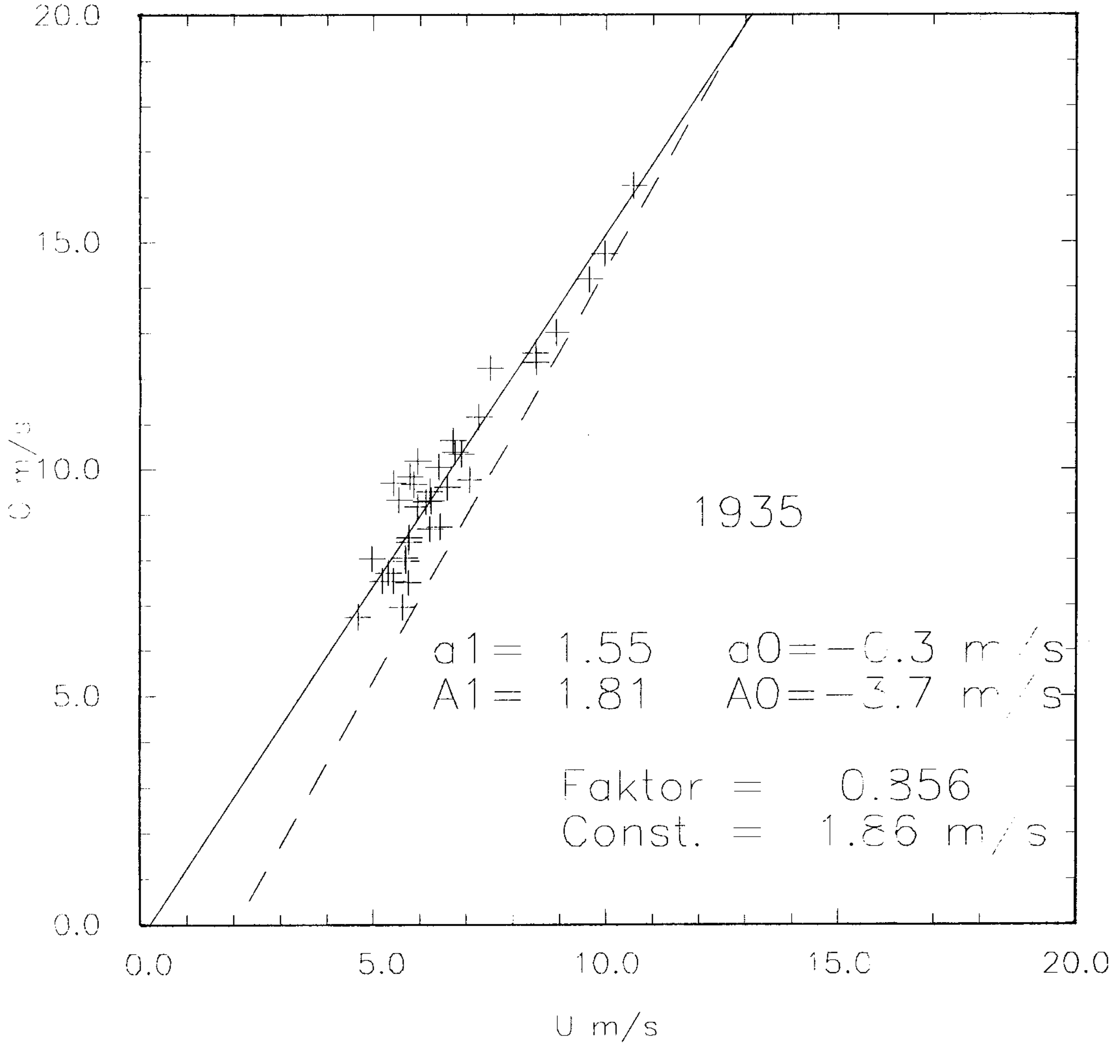

Figure 7c: As figure 7a, but for the year 1955.

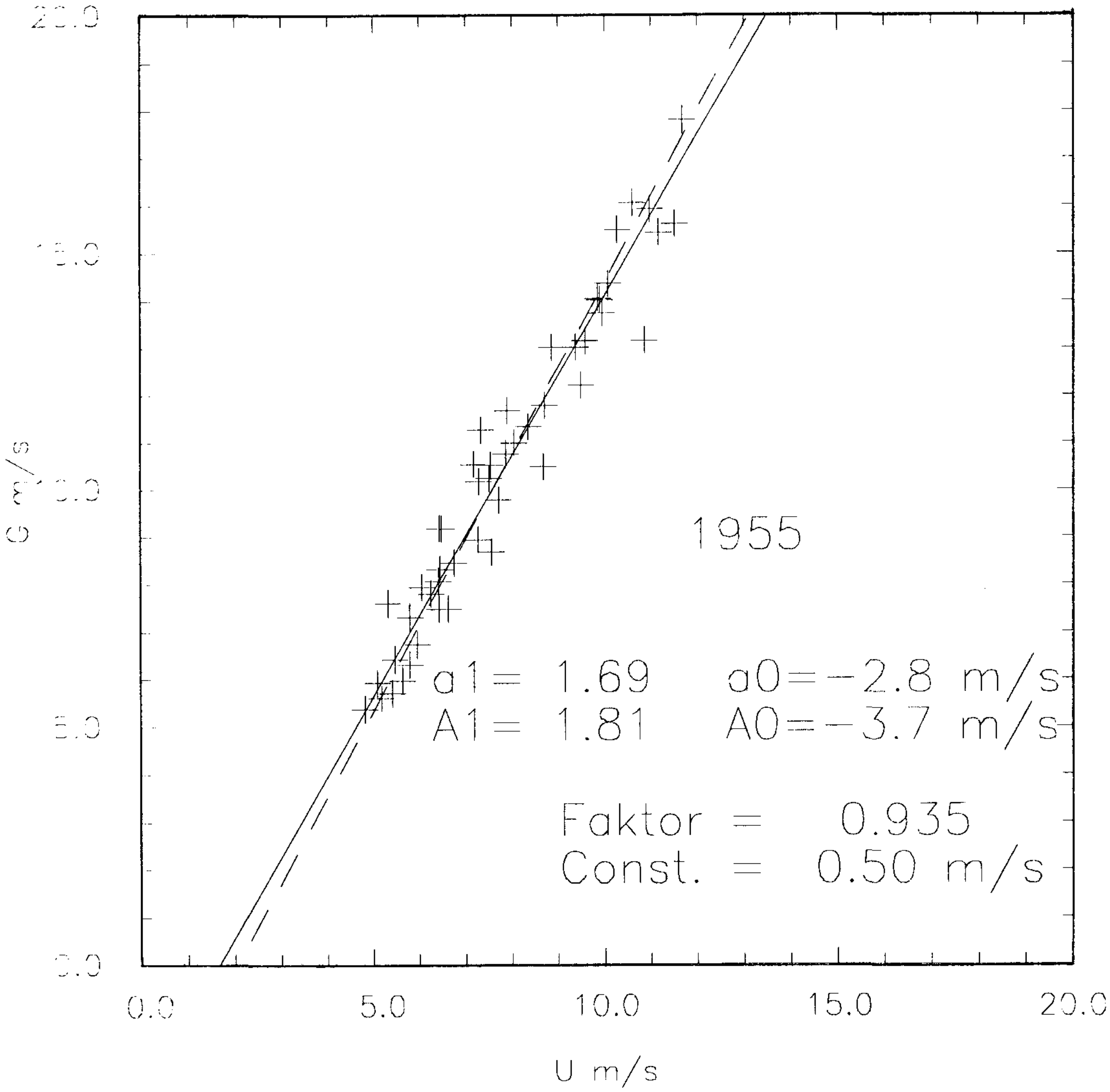

Figure 7d: As figure 7a, but for the year 1985.

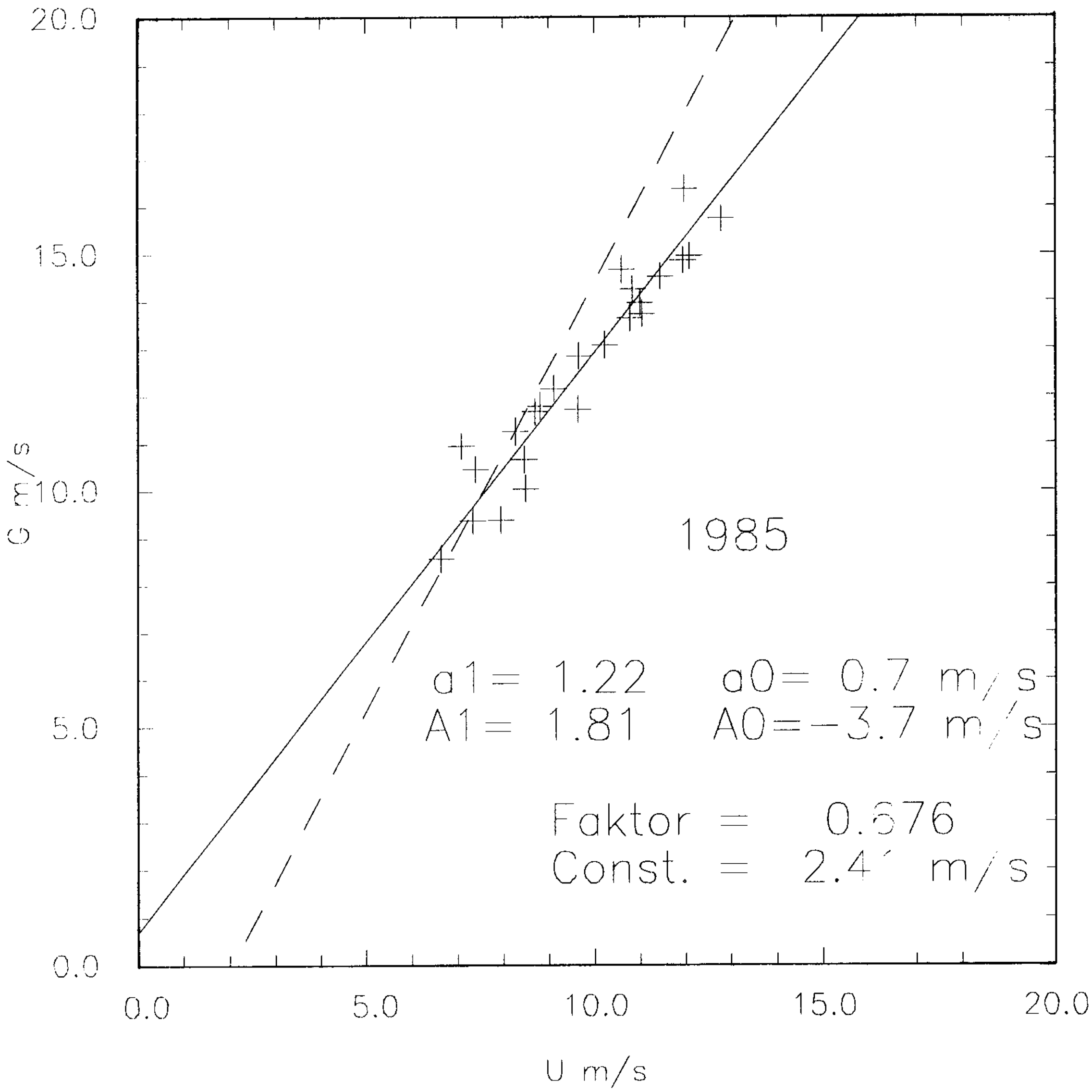

Figure 8: Time dependent Beaufort scale. The equivalent values for Beaufort 2 to 7 are figured as deviations to the equivalent scale (Lindau, 1994) valid for the standard period 1960 to 1971.

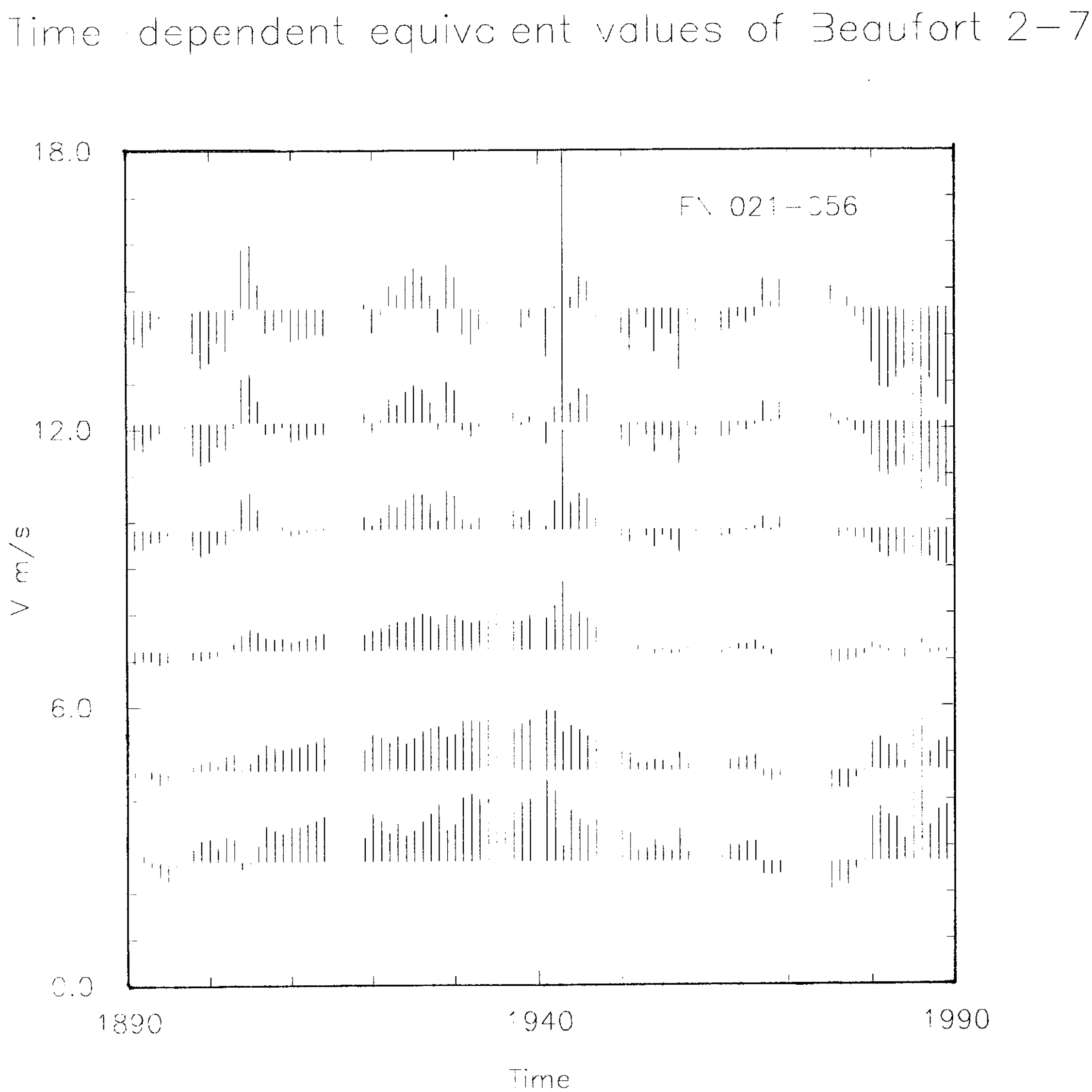

Figure 9: As figure 1, but representing the time series for Beaufort estimates converted by the time dependent scale. A positive trend of 1.02 ±0.20 cm/s/a is found for the historical period and a not significant trend of -0.11 ±0.23 cm/s/a remains for the modern period.