Comparison of Estimated and Measured Marine Surface Wind Speed

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1. Introduction

A large portion of marine surface wind data is based on Beaufort estimates made subjectively from the visual appearance of the sea surface. At the time being, beaufort number from several decades are converted to wind speed by *one* equivalent scale. Application of a revised scientific equivalent scale (Kaufeld, 1981) to wind estimates of the period after World War II eliminates a considerable mean bias in existing wind statistics and estimates of air-sea fluxes (Isemer and Hasse, 1991).

However, estimating Beaufort numbers from the appearance of the sea state is a highly subjective technique, which is supposed to be influenced by a number of different factors. These factors may be divided into (1) the condition of the individual observer and his ship, and (2) the physical conditions of the marine boundary layer and the sea surface. In order to detect and quantify biases in marine wind statistics, which are produced by these factors, wind estimates from ships of the voluntary observing fleet are compared to wind measurements made on ocean weather ships. It is expected that wind measurements on ocean weather ships are much more reliable than estimates from other ships. Hence, the derivation of Beaufort equivalent scales are an “a-posteriori” calibration of the estimation techniques of observers on ships. Equivalent scales for different conditions are constructed and compared. Essentially the same technique is used for the construction of equivalent scales as was applied by Kaufeld (1981).

2. Data and Method

Individual meteorological reports from seven ocean weather ships (OWS) in the North Atlantic Ocean (Table 1), and ships of the voluntary observing fleet (VOF) passing nearby one of the OWSs were obtained from the archives of the German Weather Service (DWD). The reports contain a flag which is supposed to indicate whether wind speed was estimated or measured. Nearly all OWS-reports are based on measurements, while the percentage of measurements on voluntary observing ships (VOS) increases from near zero before 1960 to 30% to 60% after 1980. Only estimates from VOF-ships and measurements from OWS are used in this study. Individual pairs of OWS-VOS meteorological reports were formed if VOS-estimate and OWS-measurement i) are neighbouring (distance less than 150 nm), ii) were taken simultaneously (time difference less, equal than 1 hour), and iii) differ by no more than 30 degrees in wind direction. 274935 pairs could be extracted from the period 1951 to 1989 (Table 1). Condition iii) is applied in order to eliminate synoptic situations with different meteorological conditions at the VOS and the OWS, respectively (e.g. a front between VOS and OWS). However, the number of pairs extracted by iii) is considerably high (Table 1), indicating that also pairs with a bad agreement in the estimation of wind direction are eliminated. This is likely to introduce a bias towards “good” VOS wind estimates compared to OWS- measurements.

Equivalent scales are established by comparing the cumulative frequency distributions of the VOS-estimates versus those of the OWS-measurements (for details see Kaufeld, 1981). Equivalent wind speeds calculated from the whole sample (fig. 1) are nearly identical to those of Kaufeld (1981) below Beaufort number (Bft.) 8, while for Bft. 8 and above Kaufeld’s study results in lower equivalent wind speeds. Differences at Bft. 10 are about 1.5 kn. One reason for that may be seen in the larger data base used here.

The total sample is divided into subsamples according to one of the different factors. Differences of equivalent scales among subsamples and also differences between the subsample and the total sample are discussed. Error estimates of equivalent wind speeds are calculated by performing the analysis with 50 bootstrap samples created from the original sample or subsample (see Efron, 1982).

Overlap of error bars indicate random differences of equivalent wind speeds. Additionally, differences of equivalent wind speeds less than 0.8 kn (= 0.4 ms^{-1}) are considered insignificant even if the error estimates do not overlap. This threshold should hold at least for monthly means of wind speed. The latter must differ by at least 0.4 ms^{-1} in the extratropics, to be considered as significantly different from each other (according to the x^2-test at the 5% error level, see Isemer and Hasse, 1991).

3. Results

a) Observations from different nations

Although the equivalent scale of the World Meteorological Organisation (WMO) should have been used worldwide at least since 1946, the rules for observers concerning estimation and coding of Beaufort numbers may be different among different countries. Most of the VOS-reports contain a flag indicating the nationality of the VOS. Hence, division into subsamples of different nations is easily possible. Here, equivalent scales of ships of the United States of America (US) and of Germany (GER) are compared (figs. 2 to 4). Equivalent wind speeds from US-ships are significantly lower for Bft. 2 to 5 (about 2 kn, see fig. 2) as compared to all other ships. That means, that US observers estimate higher than other observers especially at Bft. 2 to 5. Or, in other words, applying one equivalent scale, that has been calibrated from estimates of all nations, to estimates from US ships leads to too high wind speeds. Inspection of fig. 2 (bottom) indicates that the equivalent wind speeds at Bft. 8 and above are insignificantly higher and can only in part compensate for the bias at Bft. 2 to 5. So, mean monthly wind speed calculated from US estimates will be higher compared to those calculated from all (or all other) estimates, if the same equivalent scale without any correction is used.

German observers behave conversely (fig. 3). Equivalent wind speeds at Bft. 2 to 5 are significantly higher than those calculated from all other nations. At Bft. 9 to 11, however, equivalent wind speeds are lower. fig. 4 shows the remarkable difference in the estimation practice of these two nations. German observers estimated significantly lower (up to 2.5 kn) at Bft. 2 to 5 (and higher at Bft. 9 and 10) as compared to their colleagues from the US.

For this pilot study only subsamples of US - and German ships are investigated to prove that significant differences between nations exist. Investigation must be extended to other nations that contribute a considerable amount of observations to the data archives. The fraction of reports from different nations in the archives depend strongly on region (Table 1). It is concluded that equivalent scales for different nations should be calibrated and applied to the respective VOS-estimates. Otherwise, parts of the differences in wind statistics tend to document just the variation of the composition of nationalities in the archive.

b) Artificial trends in VOS wind samples

In the past a number of studies identified interdecadal changes of marine wind speed as an indicator for climate change. Most often, uncorrected VOS-wind reports are used. Here, we check the reliability of VOS-estimates against OWS-measurements. Linear trends are calculated for different periods at different OWSs (Table 2). The linear regression line is fitted to the monthly anomalies, weighted by their standard errors. While VOS-estimates indicate a significant (according to the t-test with 5% error level) positive linear trend (except at OWS C and J) for all periods, trends based on OWS measurements are negative (except at OWS K), but are not significantly different from zero. It has been argued in the literature that an artificial trend in VOS-wind reports is caused by the increasing amount of measurements in these data. The results presented here indicate that artificial positive trends are also within the data set of wind estimates. One reason for this artificial trend may be seen in the increase of number of US reports with time. In the DWD archives almost no US reports are found before 1960, their number increases afterwards and varies considerably with region (Table 1). However, to make things even worse, wind trends based on estimates of single nations show significant trends, but with different signs for the same region and period (Table 2). The reason for this is unclear. This suggests the establishment of time-dependent corrections of the national Beaufort equivalent scales proposed in the preceding chapter.

c) Ahead-winds versus stern-winds.

Information necessary to calculate the wind direction relative to the ship is available from about one third of all individual VOS observations in the DWD files. The total sample was divided into i) wind from stern (wind direction between 135 and 225 degrees relative to the ship) and ii) wind from ahead (between 325 and 45 degrees). Equivalent wind speeds for ahead-wind situations are remarkably lower than those for stern-wind situations (fig. 5). The bias increases with Bft. number reaching 4 kn at Bft. 8 to 10. Obviously, as might be expected, observers overestimated with, “the wind in their face”, while they underestimated wind speed when travelling with the wind. However, the differences against all observations (fig. 5, bottom) are fairly symmetrical. So, if both situations i) and ii) are equally represented in a sample, biases according to i) may compensate those according to ii) to a certain degree. However, variances of wind speed are overestimated if one equivalent scale is used.

d) Daytime - versus nighttime observations

The observation time and the ship's position is used to calculate the solar elevation angle h for each observation. Daytime (nighttime) observations are defined for h > 5 degrees (h < 5 degrees). Figure 6 indicates that observers estimate higher Bft. numbers during the day. Differences are significant for Bft. 4 and higher, they reach 1 kn for Bft. 4 to 9 and are even higher for storm conditions. Again, this will effect mean wind speed only for samples with a considerable imbalance between day- and night estimates. It might influence the annual cycle of wind speed at high latitudes with almost all observations during day (night) in summer (winter). Variances of wind speed may be artificially increased.

e) Stability of the planetary boundary layer

The sea surface at different Beaufort numbers is characterized in terms of wave development, foam and white caps. Hence, it is closely connected to the wind stress, i.e. the vertical flux of momentum. However, the stress depends on the stability of the planetary boundary layer. Hence, different equivalent wind speeds should be expected for equal sea surface characteristics (i.e. Bft. numbers) but different stabilities.

As a first approach the uncorrected air minus sea surface temperature difference T_a-SST of the VOF-ships was used as a criterion. The total sample is divided into VOS-estimates made under stable (T_a-SST > 0.5 K) and unstable (T_a-SST < -0.5 K) boundary layer stratification. Up to Bft. 8 equivalent wind speeds for unstable stratification are higher than those for stable stratification (fig. 7). However, differences are less than 1 kn. Hence, effects on mean wind speed should only be remarkable under extreme stability conditions (e.g. in upwelling regions or the core region of the Gulf stream area). But, with these conditions, effects *on* estimates of turbulent air-sea fluxes may be even more important if stability-dependent coefficients are used.

4. Conclusions and Recommendations

This investigation has the character of a pilot study. The data set used here is dominated by German VOS-observations, at least before 1960. In order to circumvent this limitation the same type of study will be extended to individual observations from the COADS in the near future. Data from other OWSs, also in the Pacific Ocean, will be included. Results of this future study may help to find strategies and procedures to be applied for Release 2 of the COADS. The following conclusions and recommendations may be drawn from the present study:

1) National equivalent scales, at least for those countries with a considerable contribution to international data archives, should be established and applied.

2) Time dependent corrections to the national scales have to be investigated and applied. Otherwise, interdecadal changes of wind speed cannot be deduced from uncorrected wind estimates.

3) The ratios of a) ahead-wind versus astern-wind observations and b) daytime versus nighttime observations should be investigated in a number of key regions of the World Ocean. If a

considerable variation, both in time and/or in space, of these ratios is found, corrections have to be established and applied.

4) More insight is needed in the dependence of Beaufort estimates on stability. Effects on mean wind speeds should be remarkable only in regions with a strong deviation from neutral conditions in the mean. The results presented here suggest that estimates already contain the information about stability. If so, calculation of turbulent air-sea fluxes should not be performed with stability-dependent bulk coefficients, as is done mostly today. However, this holds only for wind estimates, not for wind measurements.

5) In future, estimates and measurements should be processed separately and in a different way (see e.g. Cardone et al., 1990). Statistics based on estimates should be stored separately from those based on measurements.

6) Finally, additional checks for homogeneity of wind data against independent data should be performed. Lindau et al. (1990) proposed a method which calibrates historical wind data against air pressure differences measured on VOF-ships. Essentially, *individual* wind observations are related to *individual* pressure differences between single ships. The comparison is not based on pressure gradients from averaged pressure fields, which might be misleading. Although this method has some limitations (e.g. it may not be applied near the equator), it is a powerful tool to homogenize wind data from the last 150 years and to eliminate artificial trends.

5. Acknowledgements

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Table 1. Statistics of ship reports at different ocean weather stations in the North Atlantic Ocean. NoP(150nm): Number of OWS-VOS pairs with a distance of not more than 150 miles. NoP(DD): As NoP(150nm), but additionally reporting a wind direction difference between OWS and VOS of less than 30 degrees. Red(DD): Reduction of OWS-VOS pairs according to the wind direction criterion (%). US/GER: Percentage of United States and German VOS (%).

OWS	Position	Period	NoP (150nm)	NoP(DD)	Red(DD)	US/GER
C	53°N/35°W	1950-89	51662	36444	29	10/27
D	44°N/41°W	1950-70	55481	37961	31	34/32
E	36°N/48°W	1950-70	37827	25095	33	36/30
I	59°N/18°W	1950-71	69755	49241	29	4/52
J	53°N/19°W	1950-71	54379	40747	25	12/23
K	44°N/16°W	1950-68	64255	46739	27	16/42
R	47°N/17°W	1975-89	51284	38708	24	17/42
Total			384643	274935	29	16/32

Table 2. Linear trends of wind speed ($ms^{-1}/10y$) measured at ocean weather ships (OWS) and estimated on VOS nearby the OWS. VOF(G) and VOF(US) indicates German- and US-VOS only, respectively. A indicates trends significantly different from zero at the 5% error level.

	1950-1970		1975-89			
	OWS	VOF	OWS	VOF	VOF(G)	VOF(US)
D	-0.06	+0.25*				
E	-0.02	+0.17*				
I	-0.12	+0.26*				
J	-0,08	+0.10				
K	+0.01	+0.22*				
C	-0.11	+0.03	+0.15	+0.28*	+0.59*	-0.68*
R			-0.03	+0.27*	+0.41*	+0.15

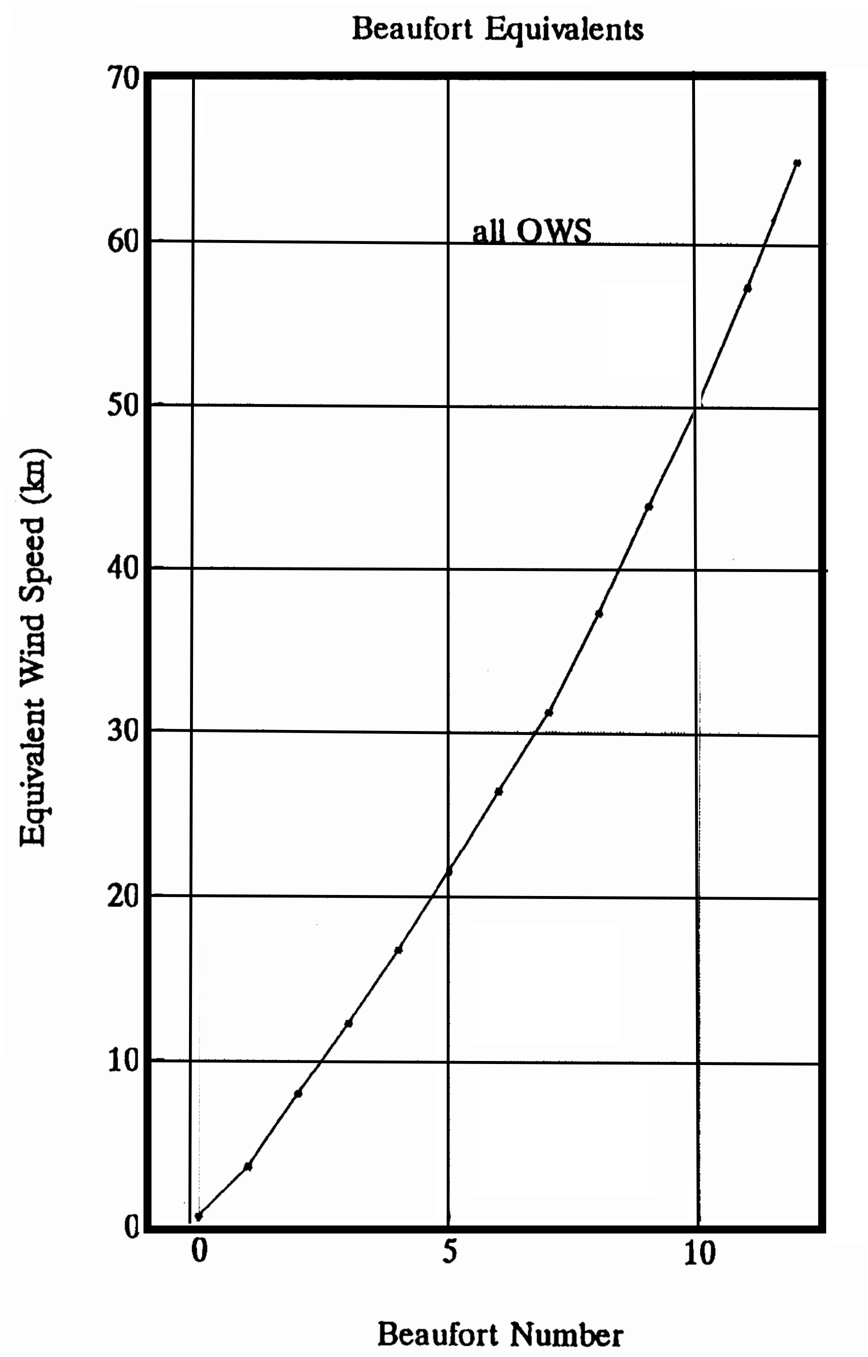

Figure 1. Equivalent wind speeds (kn) calculated from the total data sample (274935 VOS-OWS pairs) as a function of Beaufort numbers.

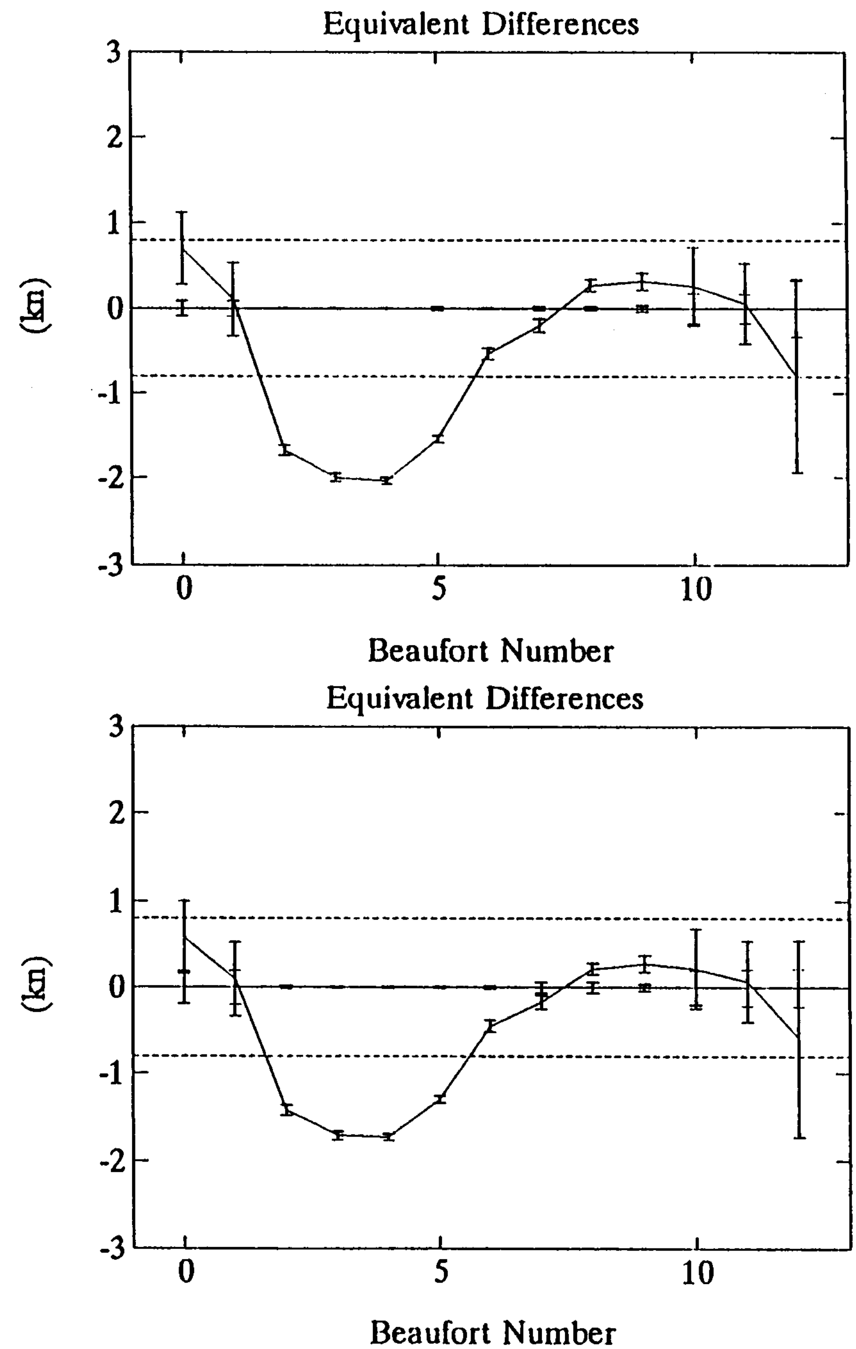

Figure 2. Differences of equivalent wind speeds (kn) as a function of Beaufort number. Error bars are calculated from 50 bootstrap samples of the relevant original subsample. Top: Equivalent wind speeds of United States (US) ships minus those of other ships. Bottom: US ships minus all (including US) ships.

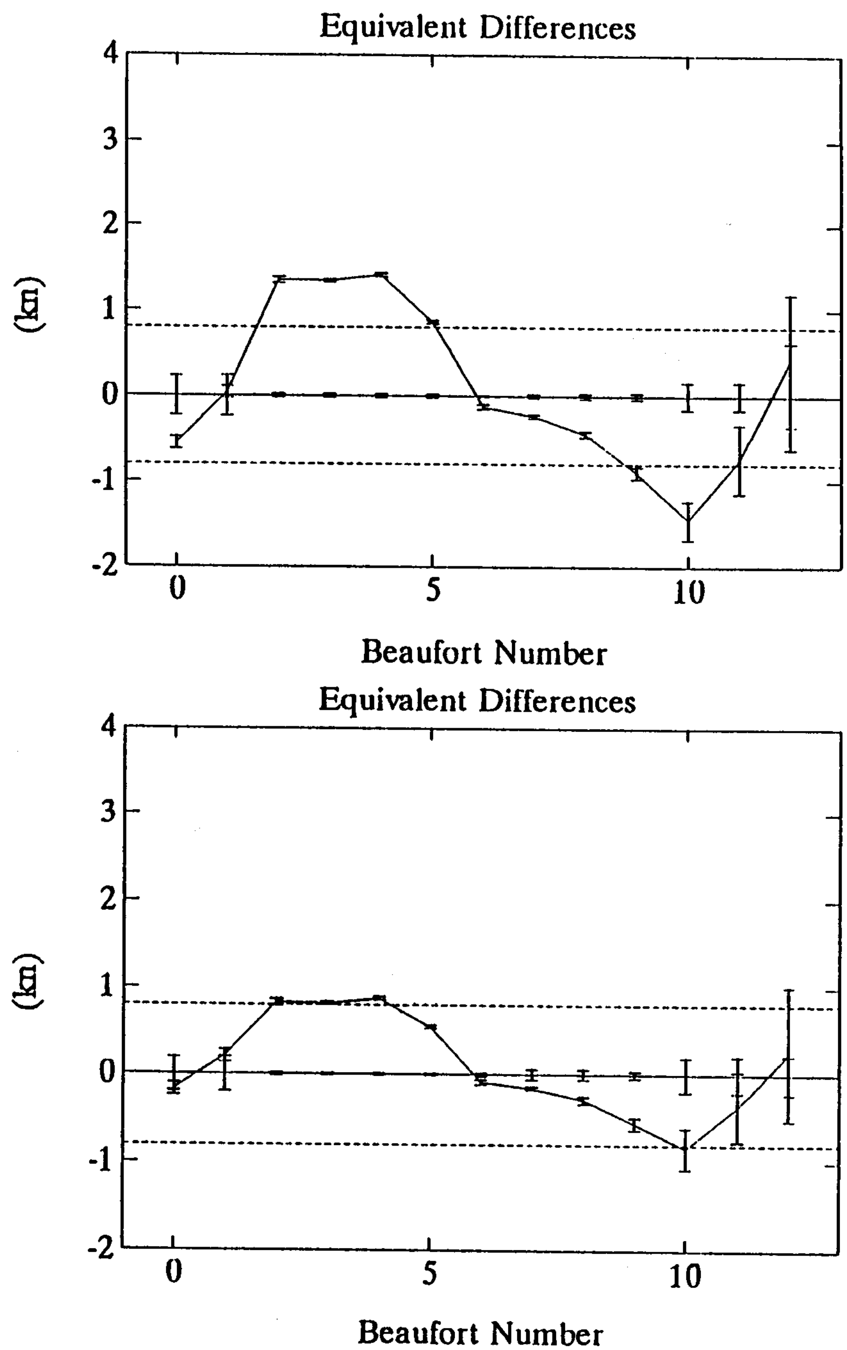

Figure 3. As Fig. 2, but for German Ships

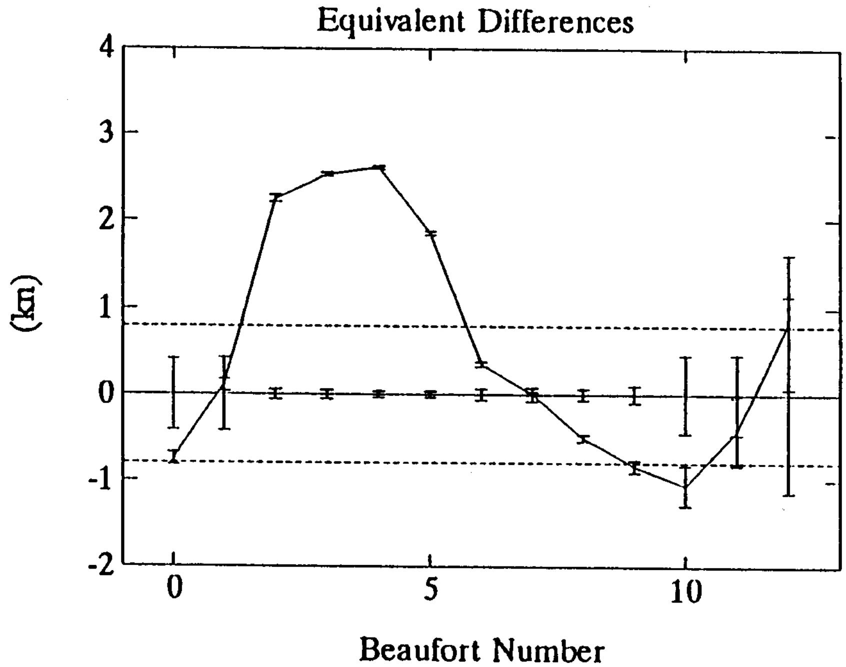

Figure 4. As Fig. 2, but equivalent wind speeds of German ships minus those of US ships.

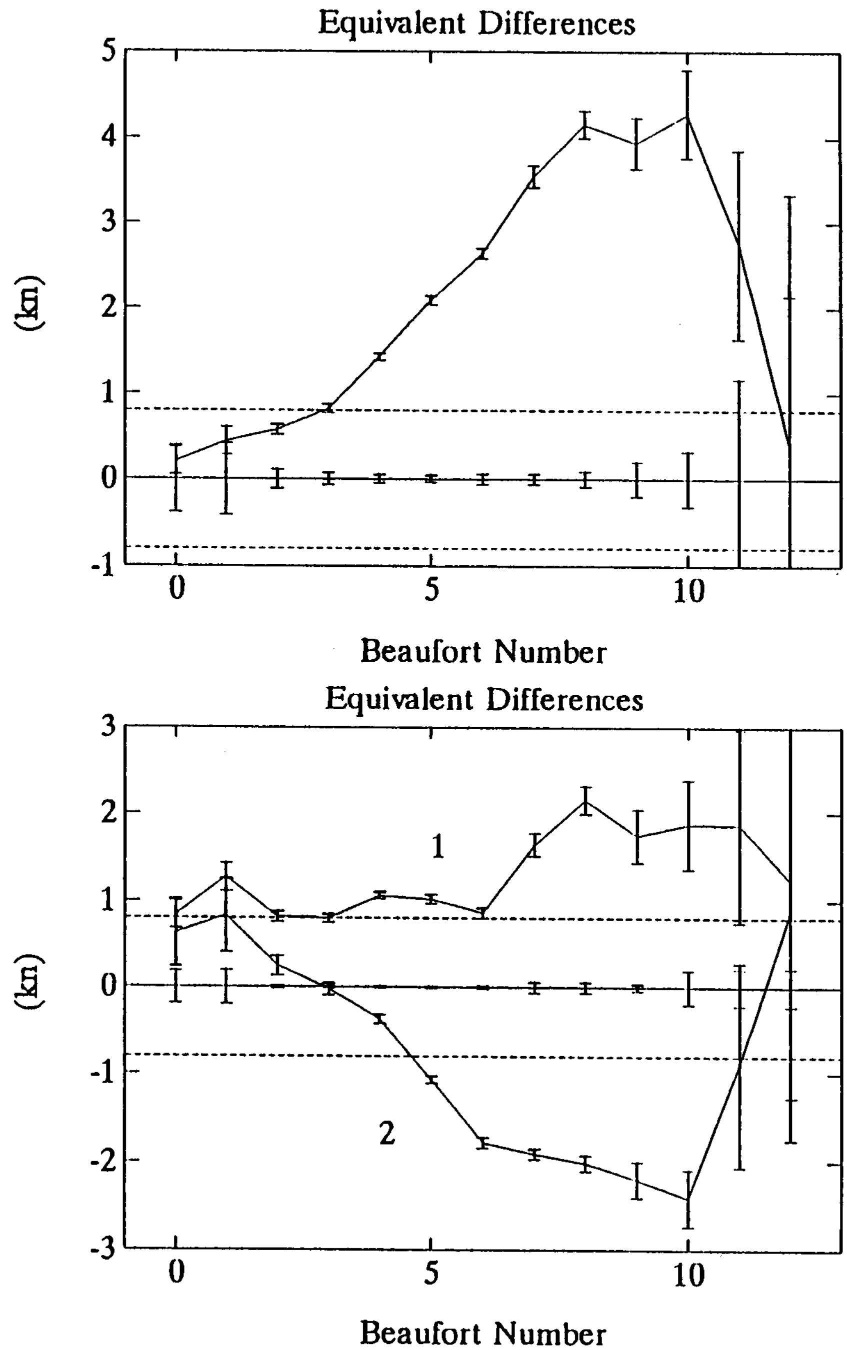

Figure 5. As Fig. 2, but equivalent wind speed differences of ahead wind (relative to the observing ship) situations versus those of situations with wind from stern. Top: Stern wind - minus all observations (curve 1) and ahead wind - minus all observations (curve 2).

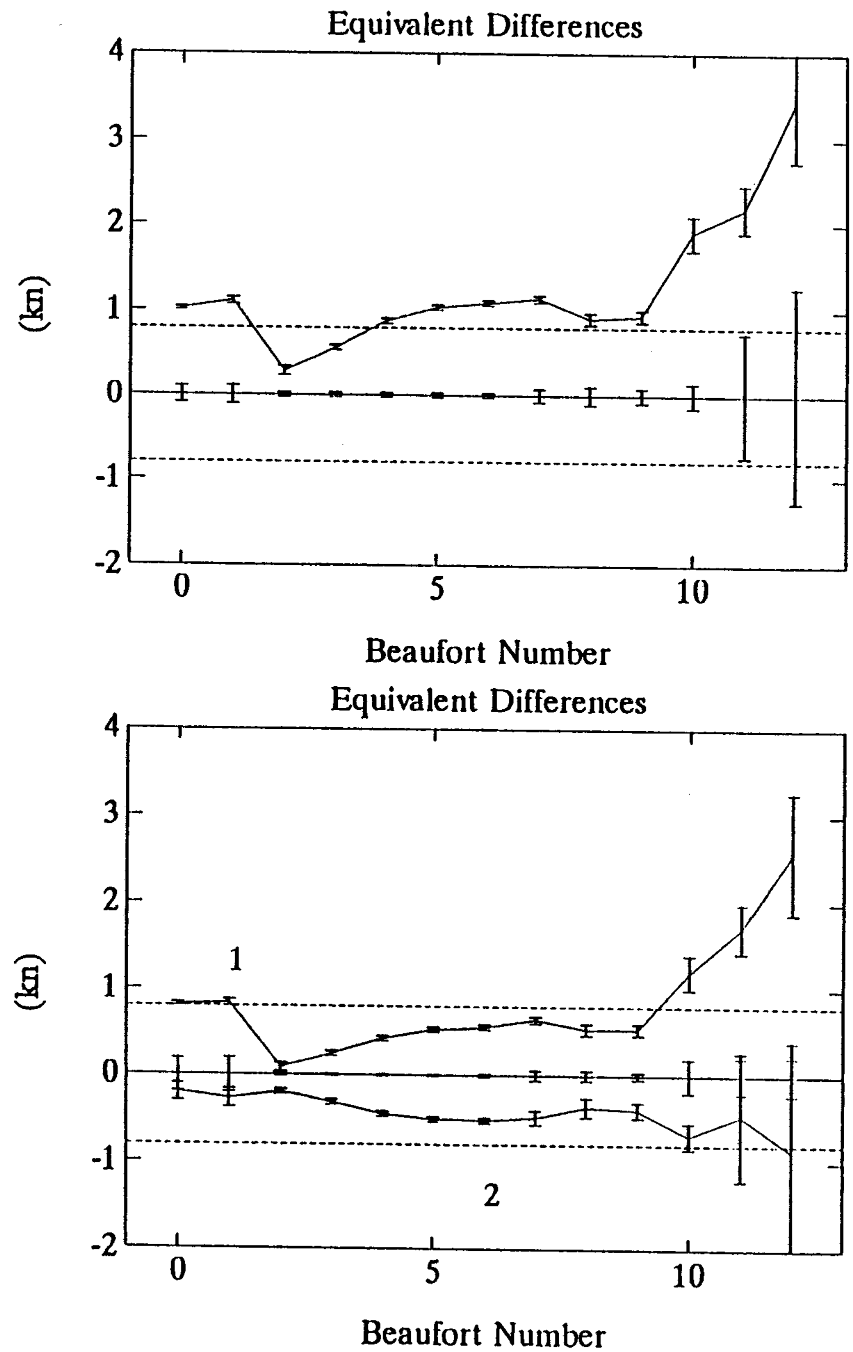

Figure 6. As Fig. 2, but equivalent wind speed differences of nighttime - versus daytime observations. Top: Nighttime - minus daytime observations. bottom: Nighttime - minus all observations (curve 1) and daytime - minus all observations (curve 2).

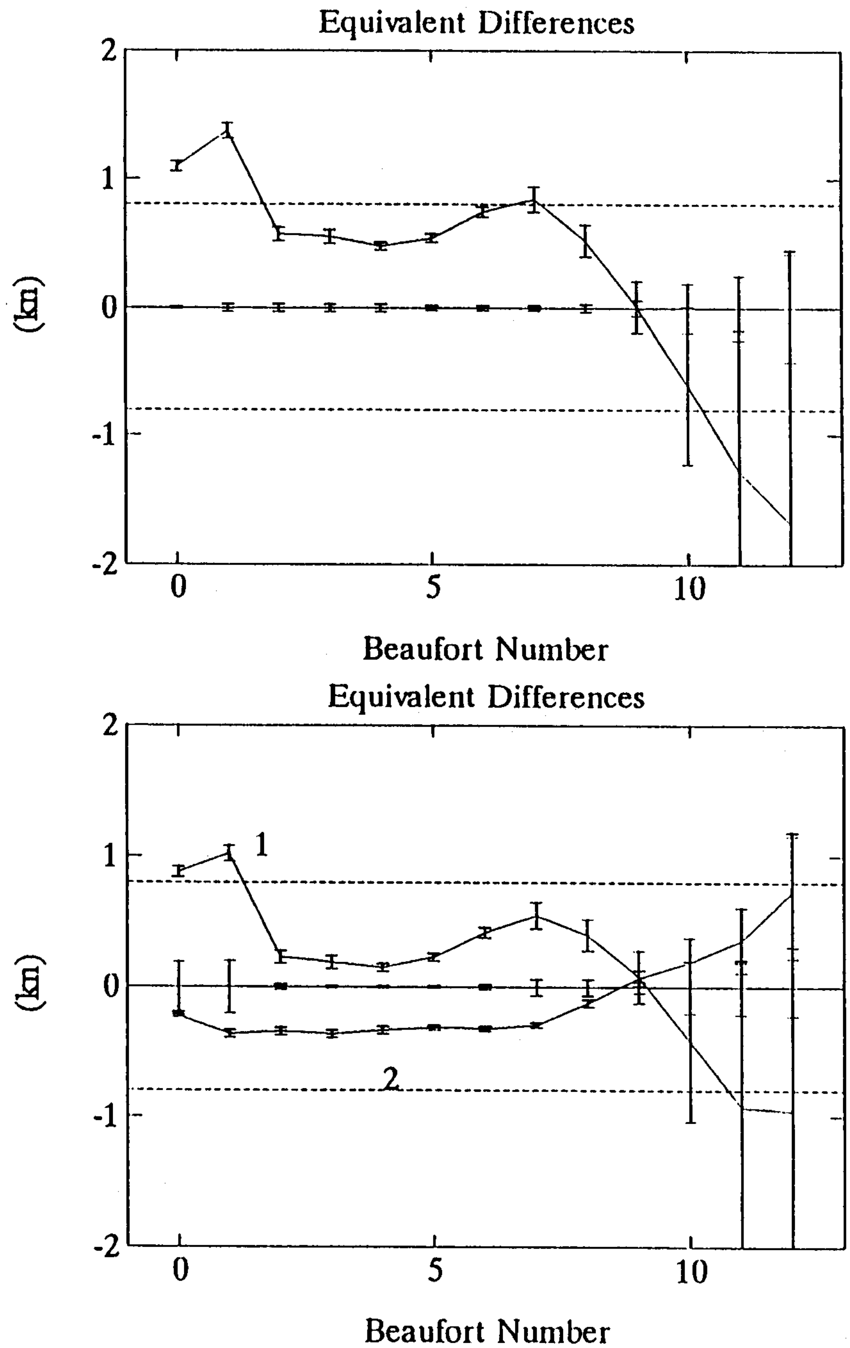

Figure 7. As Fig 2, but equivalent wind speed differences of estimates with stable versus those with unstable density stratification. Top: Stable stratification minus unstable stratification. Bottom: Stable stratification minus all (curve 1) and unstable stratification minus all (curve 2).