Did the Beaufort Scale or the Wind Climate Change?

E. W. PETERSON* AND L. HASSE

Institut für Meereskunde Kiel, D-2300 Kiel, Bundesrepublik Deutschland

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ABSTRACT

Possible long-term variations of the Beaufort scale of wind speeds are investigated from frequency distributions of about 300 000 ship observations. Records from the western entrance to the English Channel are taken as representative for observing and coding practices of voluntary weather observing ships. There is some indication that a change of either the Beaufort scale or of the wind climate occurred at the turn of the century. There is also a significant bias of the Beaufort estimates from those ships that carry anemometers.

The determination of the climate over the sea depends on the availability of a continuous and consistent record of the various weather variables. Aside from the general difficulties of obtaining representative meteorological measurements from ships, special problems exist with the determination of wind speeds (e.g., see Dobson, 1981). In addition, the methods of wind determination have changed over the years. In order to assess the occurrence of climate variations over the past century (since weather records have been kept) it is necessary to reconcile the changes that have happened in the measurement and estimation of the wind.

Winds at sea most often have been reported in terms of Beaufort force. The definition of Beaufort force may have changed, however, as sailing ships have changed, and as sailing ships have been replaced by motorized vessels (e.g., Ramage, 1982). At least three types of scales have been used over the period:

1) The force of the wind has been related to the amount of sail a ship could carry under various conditions (e.g., see Kinsman, 1969).

2) The Beaufort force has been related to local sea state (Petersen, 1927).

3) Measurement of wind speed by shipboard anemometers is substituted for estimation of Beaufort forces.

Another systematic influence on Beaufort estimates might arise from the repeated attempts to determine wind speed equivalents of Beaufort grades. Originally, the Beaufort scale was designed to aid ship operations. Yet soon, however, an academic and practical interest to relate Beaufort grades to wind speeds arose (for a detailed historical review of major international endeavors see WMO, 1970). Apparently, early attempts did not influence the definition of Beaufort grades. For this reason, it seems unlikely that the discussion between scientists on Beaufort-equivalents had influenced observing ship officers. In 1927, a redefinition of Beaufort scale from sail carrying capacity to appearance of sea state was advised (Petersen, 1927). This transition appears to have been fairly smooth, at least as evidenced by the frequency distribution before and after World War I.

The original motivation for this study was to ascertain the variation in the winds that could be ascribed to variations in reporting methods; specifically, variations in the manner in which the Beaufort force is determined. Since it is possible that there has been a change in the wind climate over the last 100 or so years, we propose to use the geostrophic wind as obtained from surface pressure observations as a standard of comparison. A suitable site for this purpose would be the entrance to the English Channel (Fig. 1). There are synoptic stations on both sides, the area is wide enough to be representative of open sea meteorological conditions (influence of tides could be investigated separately if necessary), and the ships passing through the area are probably a representative sample of weather reporting ships from industrialized nations.

Approximately 300,000 ship reports of winds and weather for the period 1850–1980 from the western entrance to the English Channel are contained in the archives of the Deutscher Wetterdienst; Seewetteramt Hamburg. A description of the data is contained in Meißner and Gloeden (1985). Understandably, there is an uneven distribution of the reports over the period. Prior to 1900, there were few reports (total of 14 330); from 1900 through 1913, there were as many as 2000 reports each month. In the 1920s and 1930s there were several hundred per month, but after 1950, there were usually less than 100 per month. For periods during

* Current address: 1410 SW 53rd St, Corvallis, OR97333.

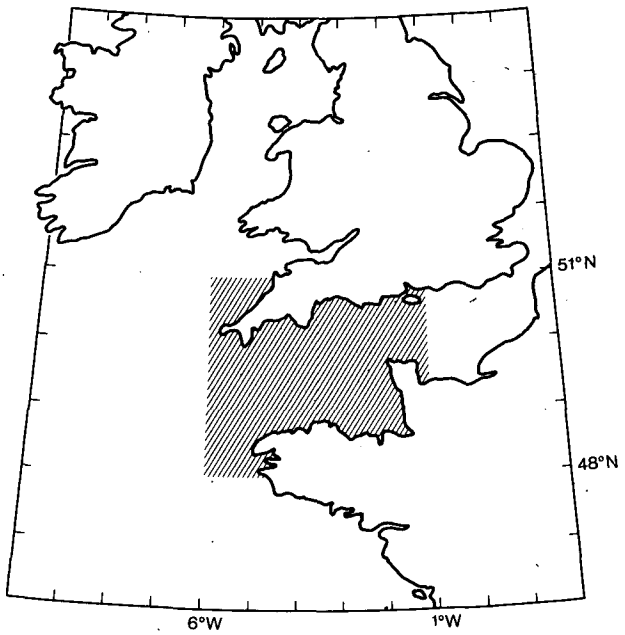

FIG. 1. Observations for this study are taken from the area 48°–51°N, 6°–1°W at the western entrance to the English Channel.

and shortly after the two world wars, there are no data. The amount of earlier data is increasing due to working up old records.

Sufficient pressure observations are not readily available at present, however, though they may exist in old files. Calibration of observed surface wind by geostrophic wind therefore was not possible at this stage. In order to see whether an extraction of pressure from old files for this investigation would be useful, we checked the available ship Beaufort estimates by simple statistics. The results are presented in the following.

Figure 2 shows the temporal variation of the frequency distribution of the reports of Beaufort-force number (Bft) for four periods: 1857–99, 1900–15, 1919–39, and 1949–79. While the three distributions after 1900 appear to coincide reasonably well, the frequency distribution of estimates prior to 1900 appears to deviate significantly; there were more observations of Bft 5 and 6, and less at Bft 2 and 3. The average Bft force changed from 4.0 (before 1900) to 3.8 (after 1900). This coincides with an increasing use of steam ships, and a decline in the relative number of sailing vessels. This change, if it is not just due to the natural year-to-year or decade-to-decade variability, could be ascribed to changes in observing practices of Beaufort estimates, but a shift in wind climate or simply an effect of climate variability cannot be discounted at this stage. One may speculate that there are other reasons for an apparent change: e.g., changing habits of weather reporting ships, different shipping routes, variation of the ratio of day-to-night observations, etc. Since smaller ships were more at the mercy of weather, there even might be a tendency to take more weather observations under bad weather conditions. This tendency is counteracted by the fact that weather log books call for regular entries. Figure 2 also shows that the largest deviations between frequency distributions are found at moderate

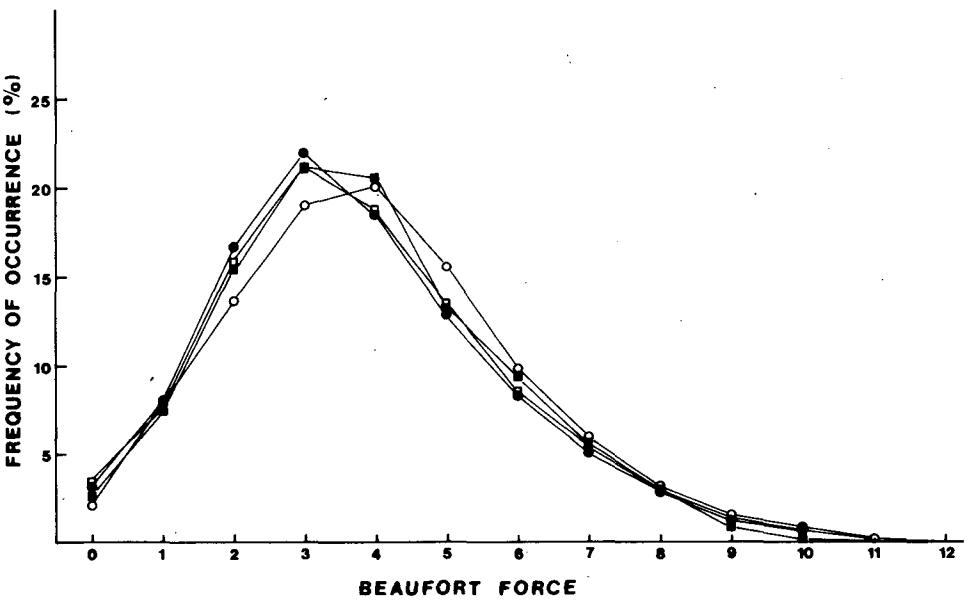

FIG. 2. Frequency distribution of Beaufort-force from ship reports of observations taken at western entrance to the English Channel: ○ 1857–1899, 14 330 observations; □ 1900–1915, 184 827 observations; ● 1918–1939, 76 588 observations; and ■ 1949–1979, 24 442 observations.

wind force; i.e., Beaufort 3 to 5. Regardless of speculations about the reasons, Fig. 2 documents that there is, indeed, a definite change in reported wind force.

The result seems to be significant in the sense that it is not due merely to random observational error. Note that even before 1900, the number of reports for the area was 14 330. In the wind force range 2 through 6 Bft, where there are 1000 to 3000 observations per Bft grade, if we assume a random observational error of ±1 Bft grade, the confidence intervals would be fairly small. Since the study has also been made regardless of seasons, one might suspect a bias in the distribution of observations over seasons. There is, in fact, some systematic effect: before 1900, there were slightly fewer observations in winter and correspondingly more in summer than after 1900. As winds are notably higher in winter, however, this type of bias would tend to lower wind speeds before 1900 compared to thereafter. Since higher Bft grades were reported before 1900, the apparent change should be more pronounced if corrected for seasonal biases.

In statistical terms, taking into account the large number of observations, almost any deviation between frequency distributions would be significant, since the number of observations is fairly large. Obviously, however, data from the same day and even from consecutive days do not provide independent information. Assuming data from 5 days to be coherent, an effective degree of freedom was calculated based on the number of years and 73 degrees of freedom per year. Using these with the Kolmogoroff-Smirnov test, it shows that the Beaufort estimates of 1919–39 are not significantly different (at the 0.1% level) from the 1900–1915 period. In contrast, the Beaufort estimates of the period from 1859–99 are significantly different (at the 0.1% level) from the ones of period 1900–1915, as well as from 1919 to 1939, or the combined period 1900–1939. These conclusions show little dependency on the assumption made for the degrees of freedom per year. For the period 1949–1979, no firm conclusion can be drawn (i.e., assuming 73 degrees of freedom per year, the distribution of 1949–1979 is not significantly different at the 20% level from the ones of 1900–15, 1919–39 or 1900–1939).

There is another significant change evident in the data. Beginning in 1957, the WMO coding format was changed so that measured *or* estimated winds were transmitted. The meteorological log books provide for records of both estimated force and measured wind. On investigating reports of Beaufort estimates of those ships that also record anemometer measurements, a drastic change in the Beaufort frequency distribution is found (Fig. 3), indicating that having a measured wind speed available somehow influences the determination of Beaufort force. It was at first assumed that when the wind speed was measured, the Beaufort force was computed by some scheme. However, further investigation gives no evidence that a definite scheme was used; on the contrary, if any scheme for converting wind speed to Beaufort force was used it was done on board ship and judging from the reported observations there was considerable variation in the methods used.

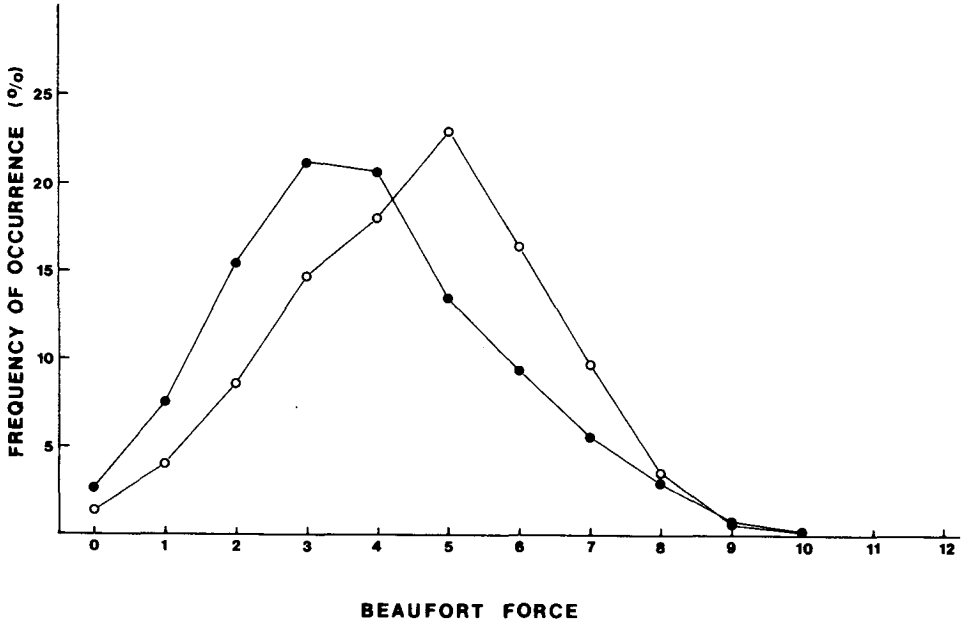

FIG. 3. Frequency distribution of Beaufort-force from ship reports of observations taken at the western entrance of the English Channel. Open circles: measured wind speed reported together with Beaufort estimates (981 observations since 1963). Full dots: Beaufort estimates only reported (24 442 observations since 1949).

For comparison, for the same period (though not for the same days and hours) the Beaufort reports of ships without anemometer measurements were analyzed, too, and plotted in Fig. 3. As can be seen from Fig. 2, the latter distribution has not changed much compared to the preceeding 50 years. However, the difference between Beaufort force reports from ships with an anemometer on board and those with no device for measuring wind speed is distinct (significant at the 0.1% level).

The reason for different Beaufort estimates of ships with and without anemometer records is not really known. A possible explanation is that anemometer outputs at ships often use simple dial displays showing instantaneous wind speed. On viewing the instruments, one tends to be more impressed by gusts instead of lulls. The knowledge of gust speed may then inadvertently influence the estimation of Beaufort force. We do not known whether this happens or not; in any case, the data shows that for ships carrying anemometers, a more detailed analysis is necessary.

The present note may appear to shed some doubt on the usefulness of Beaufort estimates of wind speeds. This is not the intention of the paper. Wind speed measurements at ships are certainly difficult (e.g., Dobson 1981), especially because of flow distortion and the need to correct readings for course and speed of ship. Consequently, most marine meteorological services perfer Beaufort estimates. We also did not deal with the question of how to translate Beaufort estimates into speeds (see WMO 1970). We have ascertained, however, that for climate studies, one has to include the Beaufort scale changes (and we have suggested how a relative calibration might be done).

Summary

There is some evidence for either a change of climate or a change in wind reports due to changes in Beaufort force definitions or observing methods. The introduction of shipboard anemometers appears to have had a drastic effect on the estimation of the wind using the Beaufort scale.

Although our results are preliminary, they are of some bearing since the relevant WMO (1970) report on the Beaufort scale stated that "no systematic differences are detectable which would indicate changes in time."

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