Ship's Influence on Wind Measurements Determined from BOMEX Mast and Boom Data

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ABSTRACT

Comparison of wind speeds measured by ship mast and boom instrumentation during the Barbados Oceanographic and Meteorological Experiment (BOMEX) are presented. It was found that the mast wind measurements are strongly affected by the ship's superstructure when the ship is lying broadside to the wind.

1. Introduction

The bulk aerodynamic technique is used as the practical basis for obtaining estimates of air-sea fluxes of momentum, heat and moisture from shipboard measurements of wind, temperature and moisture (Roll, 1965). However, surface wind measurements collected at sea may be influenced by the ship's superstructure. During the Barbados Oceanographic and Meteorological Experiment (BOMEX), wind sensors were installed

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at the end of a boom extending 10 m forward of the bow, 10 m above the sea surface, from each of the five BOMEX ships. This instrumentation, mounted in an attempt to reduce the effect of deflection, has been described in detail by Seguin and Garstang (1971). Surface wind data were also collected simultaneously with sensors located on the mast of each ship. The analysis presented here was made to determine the relative quality of these two data sets and to assess the adequacy of the exposure of the mast and boom sensors when the ship operated in its primary, drifting, mode.

2. Description of data

Data used in this study were collected from 22 June to 1 July, 1969, by the ships stationed at the four corners of the 500 km by 500 km BOMEX square array, the *Oceanographer*, *Rainier*, *Mt. Mitchell* and *Discoverer*. The 1026 observations selected were evenly scattered between nighttime and daytime measurements, eliminating much of the effect of diurnal variations. Ten minute averages were computed from boom data taken at 0.5 s intervals, while the corresponding mast winds were taken from strip-chart recordings. Ship motion was added to each of the 10 min averages, which were then classified in terms of whether the ship was heading into the wind (to within ±10°), or was drifting and thereby lying broadside to the wind (relative wind direction 110°±5°). As shown in Fig. 1, the percentage of cases when the ship was aligned with the mean wind compared with those when it was broadside to the wind was small, about 25%. The *Rainier* was represented by the least number of samples and hence shows no pronounced single orientation.

3. Results

The boom winds are plotted against the mast winds in Fig. 2 for the case when the ships were oriented into the wind. The mast wind values appear to be consistently higher than those for the boom. The wind instruments on the *Oceanographer* and *Discoverer* were mounted at a height of 27 m; those on the *Rainier* and *Mt. Mitchell* at 22 m. The dashed lines in Fig. 2 were constructed after correction for the difference between these heights and the 10 m boom level by logarithmic interpolation. This procedure requires a value of roughness length z_0, which can be specified by its equivalent, the drag coefficient C_D. A value of $C_D=1.5\times10^{-3}$ (Roll, 1965) was used, corresponding to $z_0=0.03$ cm. The resulting dashed lines seem to fit the data reasonably well.

The large solid dots in Fig. 2 indicate the mean mast and boom winds uncorrected for height differences, and the stars represent the average mast winds normalized to the 10 m boom level. The individual values are given under Case A in Table 1.

The results are quite different when the ship is oriented broadside to the wind, as shown in Fig. 3 and

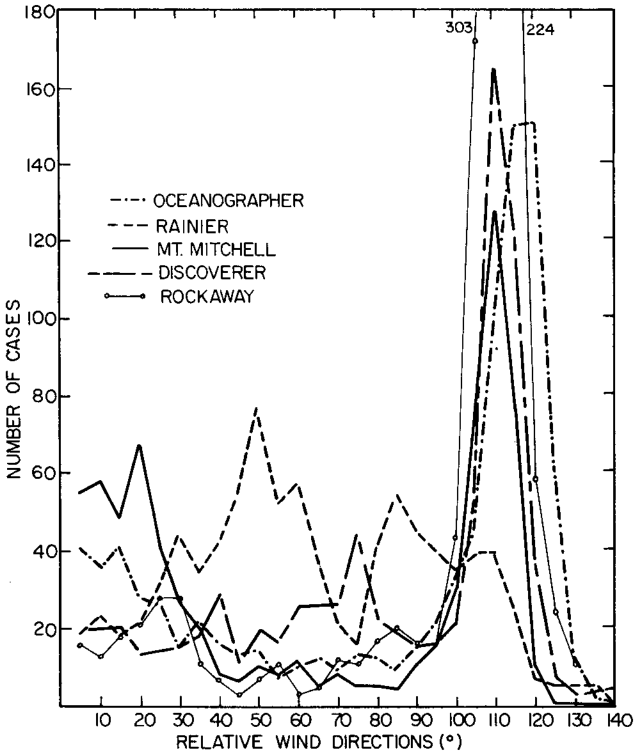

FIG. 1. Frequency distribution of 10 min averages for different relative wind directions, 22 June to 2 July, 1969.

listed under Case B in Table 1. The mast wind speeds are seen to be consistently lower than the boom values. These differences become even more pronounced when the boom and mast winds are made compatible in terms of height, as shown by the dashed lines. The largest differences are observed on the *Rainier* and the smallest on the *Mt. Mitchell*, a ship of the same class. The *Mt. Mitchell* differences are noted to decrease at high wind speeds. As in Fig. 2, the large solid dots indicate the mean winds uncorrected for height, and the stars represent the average mast winds normalized to 10 m.

We now need an indication of which wind system is least affected under different orientation of the ship with respect to the wind direction. Unfortunately, there is no direct information available during BOMEX to compare either system. However, it is not unreasonable to assume that the wind field is least disturbed upwind of the bow of the ship when the ship is directed into the wind. Support for this assumption is given by results of a wind tunnel test of the superstructure of the R/V *Flip* by Mollo-Christensen (1968) who concluded that the distortion of the air flow at the tip of a boom positioned directly into the wind was a minimum. Therefore the winds measured with instruments on the boom extending 10 m beyond the bow of the ship when the ship is heading into the wind are to be considered the best available shipboard measurements of the true wind during BOMEX. This data will hereafter be re-

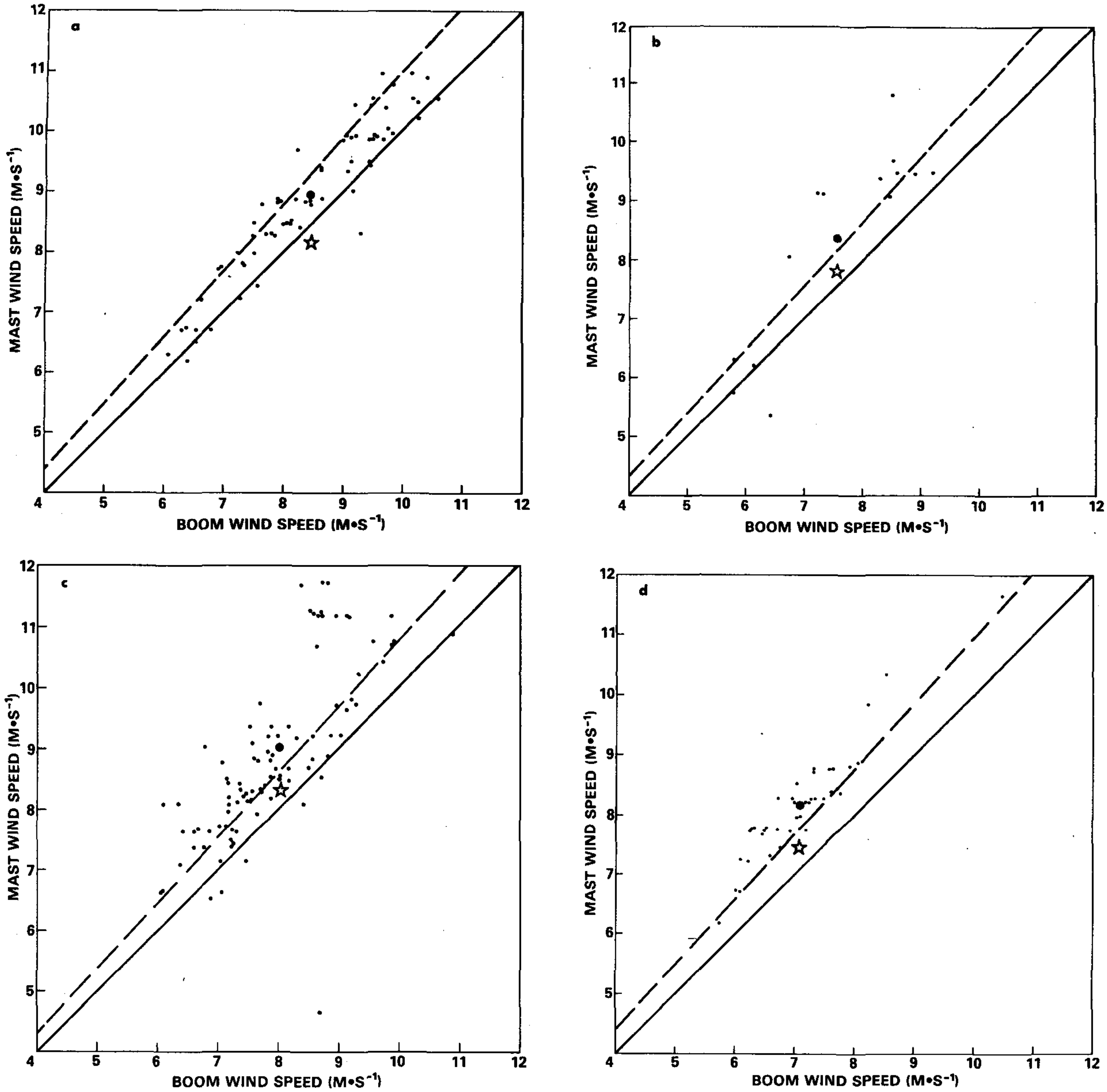

FIG. 2. Wind speeds measured on the boom and mast while the ship was headed into the wind: (a) *Oceanographer*, (b) *Rainier*, (c) *Mt. Mitchell*, (d) *Discoverer*. (See text for definitions of symbols.)

ferred to as the "control" set. The values of this data set minus those of the other data sets are shown in Table 2. The mast data have been normalized to the boom level and ship motion corrections have been incorporated. The *Discoverer* data are not included be-because poor navigation documentation resulted in unreliable ship motion corrections (N. Delver, personal communication, 1974).

With the ships oriented into the wind, the differences between the control and mast measurements are insignificant as already shown in Fig. 2. With the ship lying broadside to the wind, the differences between the control and boom data are also small, positive for the *Oceanographer* and negative for the *Rainier* and *Mt. Mitchell.* Part of the reason here probably lies in sampling errors (since the measurements were not simultaneous), in the limited accuracy of the ship motion corrections, and in the varying shapes and sizes of the ships. Thus it appears that the boom winds are not as seriously affected by changes in the orientation of the ship to the wind as are the changes observed in the mast data shown in columns 3 and 4 in Table 2. With the ships lying broadside to the wind, the differences between the control and the mast data are much larger and positive. The differences between mast into the wind and the mast broadside to the wind (column 4) are as large as those in column 3.

4. Discussion

The results of this study suggest that the winds measured on the mast are not seriously affected by the ship's superstructure when the orientation is into the wind. On the other hand, it appears that there is a large deflection of the wind at the mast when the ship is lying broadside to the mean flow. There is insufficient evidence to indicate consistent deflection of the wind at the boom when the ship is oriented broadside to the wind.

In another study, Augstein *et al.* (1974) demonstrate significant differences between winds measured concurrently on a tethered buoy upwind of the ship *Meteor* and those measured at a height of 25 m on the ship's mast. After normalizing to 10 m, they found that the difference, buoy minus ship, was positive and increased when ordered according to the buoy-measured speed, indicating that the ship's mast winds were too low. This difference, based both upon data taken in 1965 and during the Atlantic Tradewind Experiment (ATEX), was more pronounced when the ship's axis was normal than when it was parallel to the mean flow. The apparently lower wind speed at mast level on the *Meteor*

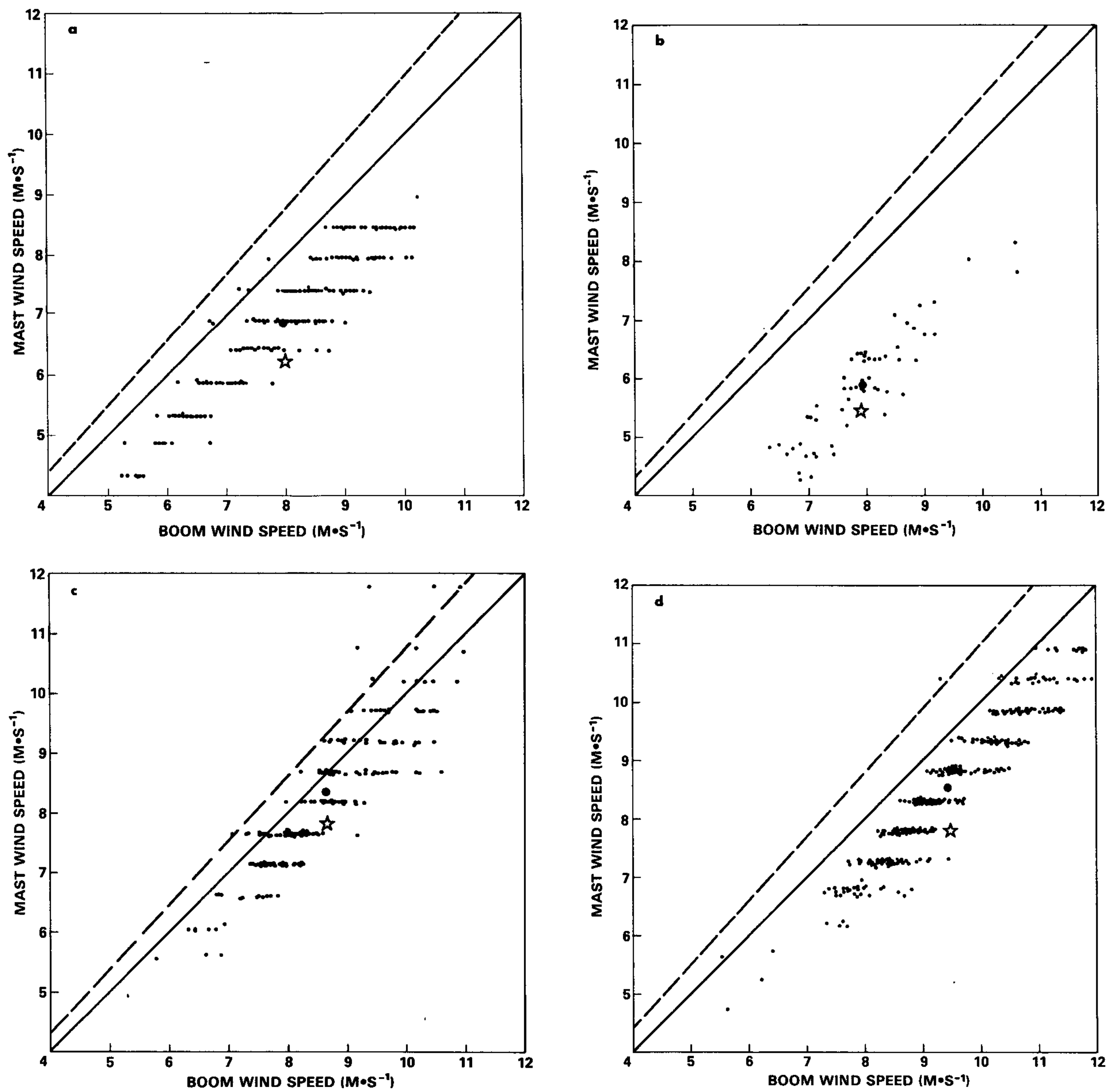

FIG. 3. As in Fig. 2 except for case when the ship was lying broadside to the wind.

TABLE 1. BOMEX mean winds (all values, m s^{-1}) measured on the ship boom and the yardarm of the mast. (Relative refers to winds uncorrected for ship motion, absolute to corrected winds.)

Ship	Boom		Mast		Mast (10 m)		Number of comparisons
	Relative	Absolute	Relative	Absolute	Relative	Absolute	
			Case A: Into-wind (control) mode				
Oceanographer	8.86	8.43	9.35	8.92	8.53	8.14	68
Mt. Mitchell	8.64	8.02	9.61	9.01	8.93	8.37	99
Rainier	7.45	7.57	8.28	8.37	7.69	7.78	14
Discoverer	8.68	7.09	9.77	8.17	8.91	7.45	38
			Case B: Broadside mode				
Oceanographer	7.75	7.96	6.66	6.88	6.08	6.28	222
Mt. Mitchell	8.20	8.64	7.92	8.36	7.36	7.77	207
Rainier	7.54	7.93	5.72	5.89	5.31	5.47	57
Discoverer	8.84	9.45	7.95	8.54	7.25	7.79	321

when operating in the drifting mode is in agreement with the BOMEX data, if the boom control data set can be likened to the buoy data in ATEX. To complicate matters, however, a study by Bogorodskiy (1966) using data taken aboard the R/V *Mikhail Lomonosov* indicated that the wind measurements taken on the windward side of the bridge were on the average 11.5% too high rather than too low as found in this study. Thus it can be concluded that the wind field in the proximity of ships masts and bridges are highly complex and any wind sensor, no matter how well calibrated, will not indicate the true wind.

TABLE 2. Differences (m s^{-1}) between the average boom winds when the ships are heading into the wind (control data set) and other wind speed measurements.

Ship	Control minus mast into the wind	Control minus boom broadside to the wind	Control minus mast broadside to the wind	Mast into minus mast broadside to the wind
Oceanographer	+0.29	+0.47	+2.15	+1.86
Mt. Mitchell	−0.35	−0.62	+0.25	+0.60
Rainier	−0.21	−0.36	+2.10	+2.31
Average	−0.09	−0.17	+1.50	+1.59

The evidence, then, is that serious errors can arise in bulk aerodynamic computations of momentum fluxes if one uses mast data for periods when the ship is drifting, lying broadside to the wind. This method of calculating the fluxes is quite sensitive to the accuracy of the wind measurements since the stress is proportional to the square of the wind speed. For example, if the deflection of the wind is of the order of 1 m s^{-1} in a mean wind of 8 m s^{-1}, the fluxes would be underestimated by about 25%.

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