An Analysis of Differences Between Ship and Buoy Observations

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1. Introduction

Advances in automation and satellite data transmission have produced a growing reliance on buoys for marine observations. Concurrently the differences between ship and moored buoys have been widely investigated (e.g. Augstein et al., 1974; Weller et al., 1983; Earle, 1985, 1987; Gilhousen, 1987). Most of these studies dealt with moderate data sets obtained in research settings. Exceptions are the extensive data of Earle (1985, 1987) who presented ship-buoy mean differences and standard deviations, grouped by buoy wind speed, regions, and seasons. His material was further analyzed by Wilkerson and Earle (1990). Their discussion has been expanded by us as a contribution to the problem of adjusting the Comprehensive Ocean-Atmosphere Data Set (COADS, Woodruff et al., 1987) for platform biases. The main results of our variance and covariance analyses are summarized in section 2; fuller details are given in an unpublished memorandum (Radok, 1989), available on request.

In the special context of wind speed differences, Earle’s ship-buoy differences, discussed in section 3, are grouped solely by buoy wind speeds; hence they do not permit an examination of the buoy-ship differences for grouped ship wind speeds. It has been suggested by Elms (1986) that these reversed wind speed differences will be of similar sign and magnitude not only in the low wind speed region, but also for the high wind speed groups. We have tested this possibility with a part of the COADS data used for data set comparisons by Woodruff et al (1991) and present the results in section 4, before drawing over-all conclusions in section 5.

2. Ship-buoy differences in Earle's (1985, 1987) data

Average ship-minus-buoy wind speeds, surface pressures, and air and sea surface temperatures are given for different regions and seasons in Table 1. The last column gives rms values derived from the between-regions and between-seasons shares of the total variances. When divided by the mean differences, these rms values become “coefficients of variation”. They show that in the regional grouping only the wind speed and SST differences vary significantly between regions; substantial seasonal differences are indicated for Pacific SST and for the air temperatures at the Gulf Stream buoy only. Surface pressure differences throughout are negative and probably reflect different barometer levels. Systematic differences between ship and buoy wind speeds pose special problems as further examined in the remaining sections.

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3. A detailed consideration of wind speed differences

Earle (1985) and Wilkerson and Earle (1990) found that the differences between ship and buoy wind speeds in general are positive and increase for smaller values of the buoy speeds that throughout served as reference. In his second report, Earle (1987) showed that vector averaging mitigated this effect (in part by increasing the variability). However, with that analysis he bypassed, rather than solved the problem, since the scalar average speed is required for transfer considerations and forms one of the basic COADS statistics.

Hinton and Wylie (1985) have demonstrated that an increasing bias for low wind speeds arises from the asymmetry of the distribution of negative differences which cannot decrease below the mean of the buoy speed group in that region. This effect is illustrated in Figure 1. We assume the truncated distribution of wind speed differences (represented by the broken curve in Figure 1) to arise from a Gaussian distribution (the solid curve); the normalized difference mean, $\bar{D} = D' rms(D)$, is then obtained as

$$\bar{D}' = \frac{\int_{-\bar{v}_b'}^{\infty} x e^{-x^2/2} dx}{\int_{-\bar{v}_b'}^{\infty} x e^{-x^2/2} dx} \qquad (1)$$

With the denominator equal to 1-A (see Figure 1), equation (1) becomes

$$\bar{D}' = \frac{e^{-\bar{v}_b'^2/2}}{(1-A)(2\pi)^{1/2}} \qquad (2)$$

This relation presumably was used by Hinton and Wylie (1985), but has been derived here because it was not explicitly stated by these authors. Its validity for wind speeds is somewhat restricted by the fact that their distribution is positively skewed. Without working out the exact consequences of truncation for such asymmetric distributions, it can readily be seen that somewhat larger difference means must be expected to result from their truncation than those suggested by equation (1).

As a test of the Hinton-Wylie hypothesis, values of $\bar{D} = D' rms(D)$ rms(*D*) are given in Table 2 for some of Earle's (1985) data. As expected, the Hinton-Wylie effect accounts for somewhat less than the observed positive speed bias at low wind speeds; moreover, distinct speed differences persist for higher buoy wind speeds. That leaves open the possibility that similar differences with the opposite sign might have resulted from applying the basic grouping to the ship winds rather than the buoy winds (Elms 1986). This possibility is examined in the next section.

4. Differences between ship and buoy wind speeds in a COADS sample

For a fuller analysis of sampling effects at both low and high wind speeds, the simultaneous ship and buoy observations listed in Table. 3 were extracted from the COADS observations for June 1988 and December 1986 which have been analyzed in great details by Woodruff et al (1991). Four of the six buoy anemometers operate at a height of 6 m above the sea surface, while one of them has its anemometer 13.8 m above the sea surface, and the remaining sixth anemometer operates at the 10 m level. Nevertheless, the mean and median speeds of the six buoys, also listed in Table 3, show no evidence of a height effect; this is in accordance with an earlier result reported by Woodruff et al. (1991), and also confirmed by the detailed speed frequency distributions for the different buoys.

A possibly more significant inhomogeneity may have been created by two contrasting averaging methods used by different buoys, viz. component averaging to form mean vectors at short intervals (denoted by *V* in Table 3), and “scalar” averaging of wind speeds over similar intervals (denoted by *S*). The vector averages would be systematically smaller than the scalar ones (which are akin to the wind speeds observed on ships) whenever the wind direction underwent appreciable short- term fluctuations. To explore this possibility, some of the speed differences will be considered also separately for the *V*- and *S*-buoys.

Figure 2 shows scatter diagrams of concurrent buoy speeds versus ship speeds separately for the two months and for the entire sample. The majority of points fall below the 45 degree line, suggesting a positive bias in the ship wind speeds (or a negative bias in the buoy wind speeds). Next, both the buoy wind speeds and ship wind speeds were subdivided into the following groups: 0 - 2.5 m/s, 2.6 - 5 m/s, 5.1 - 10 m/s, 10.1 - 15 m/s, 15.1 - 20 m/s, and compared with the concurrent ship and buoy wind speeds, respectively.

The resulting frequency histograms are given in Figures 3a-3d. While for the lowest speed range the two ways of grouping appear to give similar results, the differences increase as the grouping range moves up the speed scale. Table 4 compares the observed mean speed differences for all buoys with the Hinton-Wylie estimates calculated from equation (1); in the same way as for the Earle data in section 3, the group center speeds have been used. Again the calculated “expected” means of the truncated distributions are somewhat smaller than the observed means and vanish in the higher wind-speed groups. However, there the sign of the wind speed difference reverses with the change from grouped buoy speeds to grouped ship speeds, pointing to a definite upward bias in the ship winds. This is further confirmed by Table 5 which moreover shows, as might be expected, larger differences for the vector-averaged than for the scalar-averaged buoy winds.

5. Conclusions

The results presented thus suggest the existence of systematic ship-buoy wind speed differences which needs to be allowed for in COADS. More definite magnitudes for adjustments to wind speed means and perhaps to those of other elements will have to be established from a suitably selected and more extensive set of COADS observations. However, monthly and seasonal mean differences have rms values only one order of magnitude smaller (for samples of around 100) than the individual rms values shown in the tables; thus adjustments must be considered for longer-term averages, rather than for single months or seasons.

The speed bias in ship winds relative to buoy winds and its dependence on the absolute wind speed needs further explanation; for the time being a convergence of flowlines upstream of and over the ship structures seems a possible cause. If so, relative winds from different directions observed on a ship would be expected to differ from the same true wind by different amounts after the ship's velocity vector has been subtracted. An experiment exploring that possibility has been reported by Radok and Steiner (1984) and is described in Figure 4; a number of different anemometer positions could be tested simultaneously in this manner.

Acknowledgement

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Table 1. Regional and seasonal mean differences, $\overline{D}$, of wind speed (kts.), surface pressure (hPa), air temperature (AT, °C, and sea surface temperature (SST, °C).

1) 4-region averages (Atlantic-Pacific-Gulf of Mexico-Great Lakes)

Variable	Number of Observations	Mean D	RMS D	RMS of 4 (weighted group means)
Wind Speed	62898	3.48	7.68	1.37
Pressure	44477	-0.51	4.17	0.14
AT	61625	1.07	4.33	0.30
SST	54172	0.14	3.48	0.42

2a) 4-seasons aerates (Atlantic buoys)

Variable	Number of Observations	Mean D	RMS D	RMS of 4 (weighted group means)
Wind Speed	11887	3.18	8.74	0.21
Pressure	12353	-0.44	4.51	0.22
AT	12057	1.01	2.81	0.29
SST	9766	0.85	3.65	0.41

2b) 4-seasons averages (Pacific buoys)

Variable	Number of Observations	Mean D	RMS D	RMS of 4 (weighted group means)
Wind Speed	25273	2.74	8.79	0.05
Pressure	24131	-0.46	4.31	0.14
AT	24991	1.33	5.91	0.21
SST	23013	0.18	2.68	0.22

2c) 4-season averages (Gulf of Mexico buoys)

Variable	Number of Observations	Mean D	RMS D	RMS of 4 (weighted group means)
Wind Speed	6617	1.42	6.23	0.19
Pressure	7155	-0.55	2.75	0.11
AT	7084	1.28	1.95	0.16
SST	6610	-0.25	2.85	0.08

Table 2. Ship-buoy wind speed difference dependence on (buoy) wind speed. The expected mean differences have been calculated with equation (1) from text. All buoy and ship wind speed values are in knots.

1) All ships and buoys (Earle, 1985)

Description	2.5	7.5	15.0	25.0	35.0	45.0
Mean Difference	6.4	3.7	2.0	1.2	0.1	0.8
RMS*	8.5	8.4	8.5	9.3	9.4	11.1
Mean expected	5.3	2.6	0.7	0.1	0.004	0.001

2) Buoy #41002 (Gulf Stream)

Description	2.5	7.5	15.0	25.0	35.0	45.0
Mean Difference	6.0	3.3	2.2	0.6	-1.7	-
RMS*	8.7	5.6	6.8	7.9	12.9	-
Mean expected	5.4	1.0	0.2	0.02	0.13	-

3) Buoy #41002, ship winds adjusted to buoy anemometer level

Description	2.5	7.5	15.0	25.0	35.0	45.0
Mean Difference	3.0	3.1	2.6	0.8	-	-
RMS*	2.1	4.9	3.9	5.5	-	-
Mean expected	0.47	0.65	0.001	<<	-	-

* RMS of wind speed differences; valid for speeds themselves when the ship and buoy speeds correlation = 0.5.

Table 3. COADS data for December 1986 and June 1988 (Woodruff et al 1991) used for the truncation tests of section 4 (results in Table 4). Scalar averaging is denoted by *S*, and vector averaging by *V*.

2° box number	4287	4467	4468	4646	4981	5184
Buoy number	44007	44008	44011	44004	46011	41002
Anemometer height (m)	6.0	13.8	6.0	6.0	10.0	6.0
Averaging method	S	S	V	V	S	V
December 1986:						
Mean wind speed (m/s)	8.09	8.03	7.64	7.90	5.98	7.53
Median wind speed (m/s)	8.20	7.20	8.20	7.20	6.10	6.20
June 1988:						
Mean wind speed (m/s)	6.65	6.24	4.99	6.51	6.77	5.77
Median wind speed (m/s)	5.70	6.20	4.20	6.10	6.20	6.20

Table 4. Wind speed differences for all buoys in Table 3. Ile expected mean is calculated using equation (1) from text.

(a) Mean ship minus buoy wind speed difference dependence on buoy wind speed.

	Center of buoy wind speed group (m/s)				
	1.25	3.8	7.55	12.55	17.55
Mean Difference	2.46	1.57	1.66	2.03	-
RMS	2.50	2.90	4.50	4.18	-
Mean expected	1.27	0.51	0.46	0.02	-

(b) Mean buoy minus ship wind speed difference dependence on ship wind speed.

	Center of buoy wind speed group (m/s)				
	1.25	3.8	7.55	12.55	17.55
Mean Difference	2.51	0.78	-1.09	-3.34	-4.95
RMS	2.33	2.19	2.33	2.30	3.15
Mean expected	1.00	0.20	0.01	<0.01	<0.01

Table 5. Wind speed differences for select buoys grouped by scalar- and vector-averaging.

(1) scalar-averaging, buoys #44007, #44008, #46011.

(a) Mean ship minus buoy wind speed difference dependence on buoy wind speed.

	Center of buoy wind speed group (m/s)				
	1.25	3.8	7.55	12.55	17.55
Mean Difference	2.26	1.29	0.94	0.98	-
RMS	2.88	2.67	3.87	3.84	-

(b) Mean buoy minus ship wind speed difference dependence on ship wind speed.

	Center of buoy wind speed group (m/s)				
	1.25	3.8	7.55	12.55	17.55
Mean Difference	2.71	1.21	-0.80	-3.17	-4.10
RMS	2.48	2.14	2.37	2.62	3.34

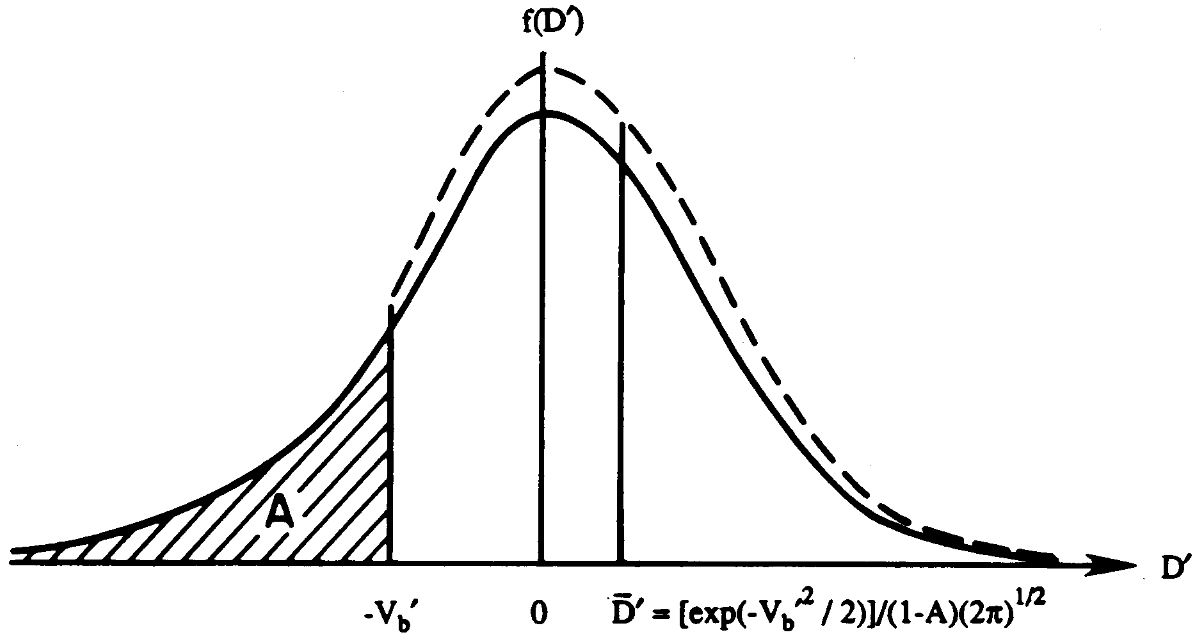
(2) Vector averaging, buoys #44011, $44004, #41002

(a) Mean ship minus buoy wind speed difference dependence on buoy wind speed.

	Center of ship wind speed group (m/s)				
	1.25	3.8	7.55	12.55	17.55
Mean Difference	-	1.95	2.58	3.50	-
RMS	-	3.16	5.07	4.25	-

(b) Mean buoy minus ship wind speed difference dependence on ship wind speed.

	Center of ship wind speed group (m/s)				
	1.25	3.8	7.55	12.55	17.55
Mean Difference	1.89	0.13	-1.46	-3.50	-6.55
RMS	1.72	2.12	2.23	1.96	1.95



V_s, V_b ship, buoy wind speeds

$D = V_s - V_b$

$V' = V/rms(D)$ $\quad$ $D' = D/rms(D)$

Assumed distribution:

$(1\text{-}A)f(D') = N(0,1)$ $\quad$ for $D' \geq -V_b'$

$= 0$ $\quad$ for $D' < -V_b'$

This distribution is shown as a broken line; A is the area under the standard normal curve between $-V_b'$ and $-\infty$.

Figure 1. Truncation of difference frequency distribution at low buoy wind speeds V_b (after Hinton and Wylie, 1985).

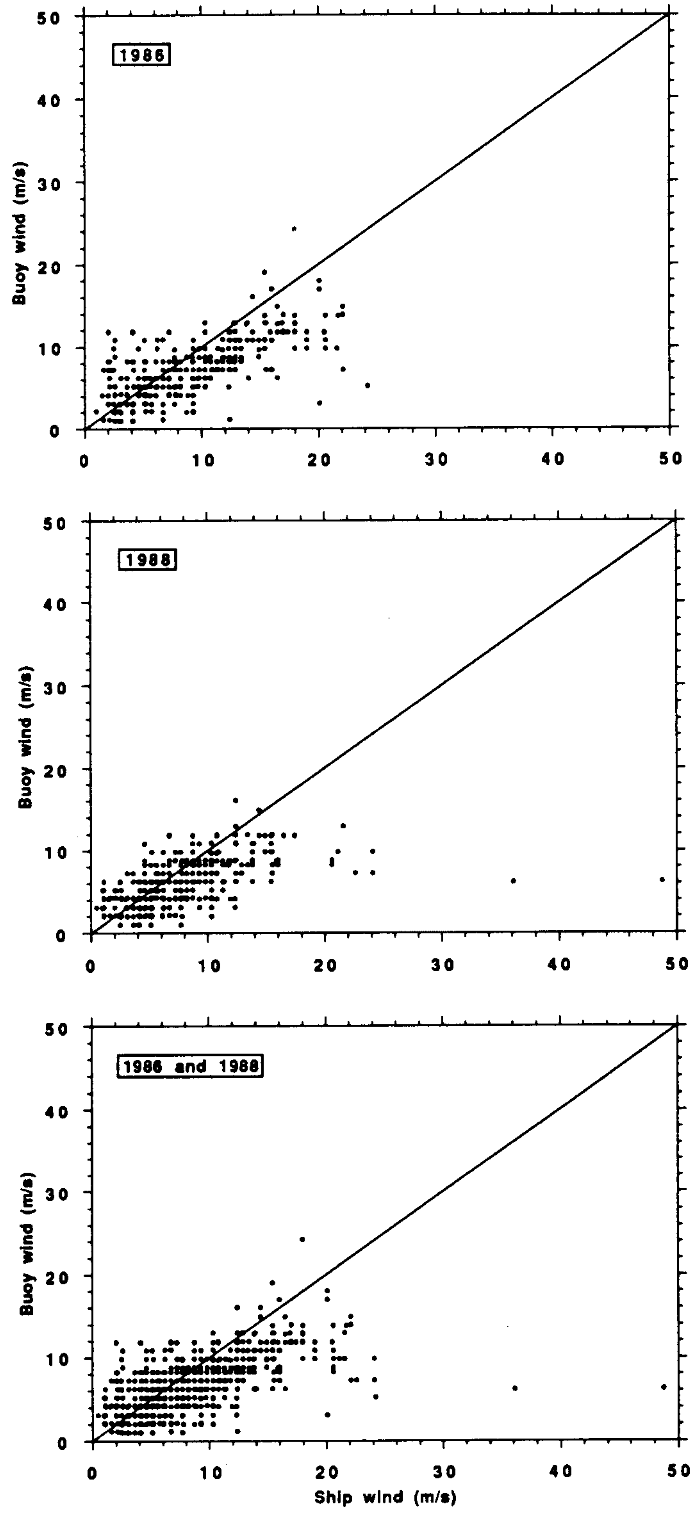


Figure 2. Scatter plots of concurrent buoy wind speeds (ordinate) and ship wind speeds (abscissa) in COADS sample.

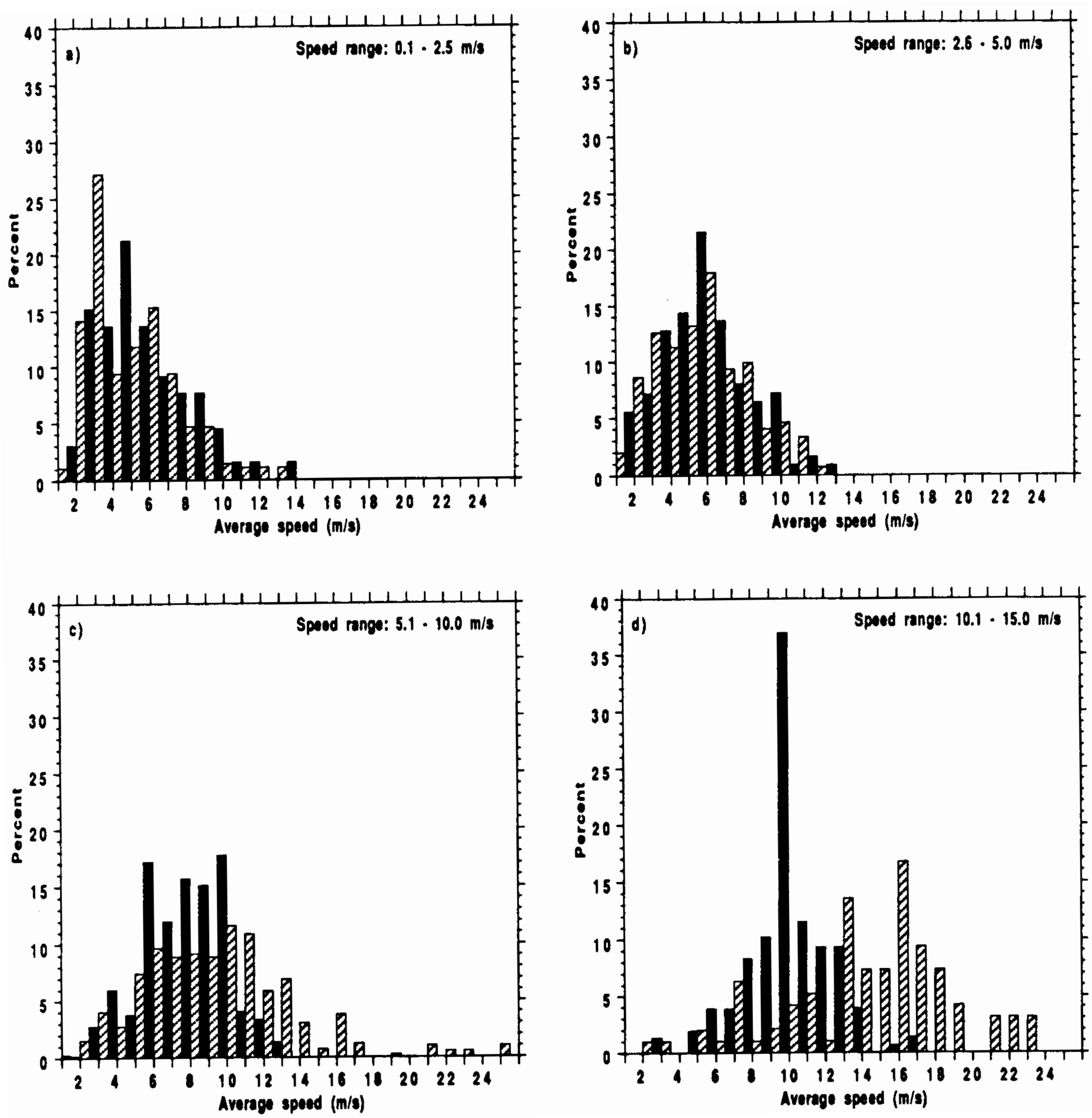
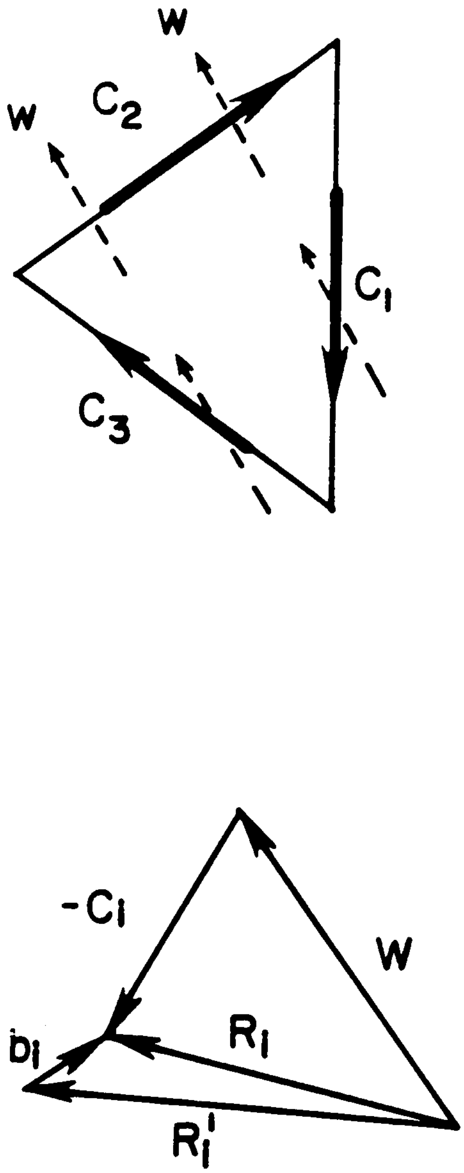


Figure 3a-3d. Frequency histograms (%) of concurrent ship and buoy wind speeds. Hatched bars: ship wind speeds when the buoy wind speeds fell into the speed ranges indicated. Dark bars: buoy wind speeds when the ship wind speeds fell into the speed ranges indicated.



a) Ship track with speeds C_i through a uniform wind field W

b) Wind speed bias estimation (schematic)

W = wind
$-C_i$ = ship "draft"
R_i = true resultant
R_i' = observed relative wind
b_i = bias

$R_i' = W + b_i + C_i$

$\bar{R}_i' = W + \bar{b}_i \; ; \; \bar{C}_i = 0$

$\therefore \; b_i - \bar{b}_i = R_i - \bar{R}_i' - C_i$ = deviation from average bias

Figure 4. Wind estimation from a moving ship (Radok and Steiner, 1984).