Estimates of Wind Stress and Heat Fluxes with Bias Corrections

Arlindo M. da Silva, Christine C. Young
Department of Geosciences, University of Wisconsin-Milwaukee
and
Sydney Levitus
National Oceanographic Data Center/NOAA

Abstract

We investigate the effect of the scientific Beaufort equivalent scale on the mean wind speed and standard deviations over the global oceans. Using the COADS Compressed Marine Reports 5, we correct each observation with Kaufeld’s scientific Beaufort equivalent scale and convert the wind speeds to a common 10 m reference level according to the stability of the surface layer.

Our detailed calculations partially validate the statistical approach of previous authors who corrected winds based on monthly mean data. However, the effects of the corrections on nonlinear quantities such as wind stress are subtle and require the consideration of the individual ship observations.

1. Introduction

Most of the available ocean surface data sets are derived from observations by ships of the Voluntary Observing Fleet (VOF) (e.g., Bunker 1976, Slutz et al., 1985, Esbensen and Kushnir 1981, Goldenberg and O’Brien 1981, Harrison 1989, Hastenrath and Lamb 1978, Hellerman and Rosenstein 1983, Hsiung 1986, Isemer and Hasse 1987, Oberhuber 1988, Picaut et al., 1985). Since the beginning of this century there has been growing concern about the quality of this data, and many authors have cast some doubts on the usefulness of ship data for identifying climatic trends (Cardone et al., 1990, Isemer and Hasse 1987, Ramage 1984, 1987 and references within.)

Because wind is a key parameter for the determination of the air-sea fluxes at the ocean surface, a great deal of effort has been devoted to sort out the problems with ship winds. Wind speeds reported by VOF’s are either directly *measured* with anemometers or *estimated* from sea state. Instrumentation problems with anemometers are believed (or better, assumed) to be non-systematic and hopefully cancel out when spatial/ temporal averages are taken. Estimated winds are somewhat subjective and depend on the skill of the observer. But even when a correct identification of the sea state is made, it still needs to be converted to wind speed through a Beaufort equivalent scale. Since 1946 a Beaufort scale developed by Simpson (1906) combined with a well-defined description of sea state due to Petersen (1927) has been used for meteorological weather services (Isemer and Hasse, 1991). It is now widely accepted that this old WMO Beaufort scale contains systematic errors. Several alternative scales exist (WMO 1970, Cardone 1969, Kaufeld 1981)

In a recent paper, Isemer and Hasse, 1991, (hereafter referred to as IH91) examine the effect of using a scientific Beaufort scale on wind statistics and climatological air-sea fluxes in the North

Atlantic Ocean. They suggest that systematic errors in the scientific Beaufort scale cause climatological wind speeds to be underestimated, and wind speed standard deviation to be overestimated in the North Atlantic ocean. Cardone et al. (1990) show that Beaufort scale correction, ship height adjustment, and stability correction strongly reduce artificial trends in wind speed, and drastically increase the agreement between measured and estimated winds.

In this paper we further document the effect of a Beaufort scale correction on wind speed and fluxes at the air-sea interface. Contrary to IH91, we utilize individual ship observations, perform a more detailed ship anemometer height correction based on the stability of the surface layer, and extend our analysis to the global oceans. In section 2 we describe our data set and methods of correction. In section 3 we compare our results in the North Atlantic with Isemer and Hasse's. The following section shows results for wind stress and heat fluxes for selected regions of the North Atlantic. Concluding remarks appear in section 5.

2. Data and procedures

Data set

All the calculations are based on the *Compressed Marine Reports* (CMR-5), Product 10 of the COADS data set (Slutz et al., 1985). Release I of this data set covers the period 1854-1979, and recently these observations have been extended to the end of 1989 (the so called *interim product).* For this study we only use data for the post World War II period (1945-1989).

The CMR-5 data base consists of ship reports of zonal and meridional wind components, air temperature, sea surface temperature, sea level pressure, dew point depression and cloudiness. Also available are quality control indicators and flags identifying the measurement procedure (estimated vs. measured winds, bucket vs. intake SST measurements, etc.) We only keep individual observations of a particular parameter that passed the *trimming* test as outlined in Slutz et al. (1985). Except for the wind speed correction described below, the other parameters are not corrected at this time[1].

All estimated wind speeds in CMR-5 had been converted to m/s using the *old* WMO Beaufort equivalent scale (WMO 1970). We used flag WI in this data set to distinguish estimated from measured winds. It should be noted that this flag takes only two values: 1 for measured winds and 0 for estimated or unknown. It is conceivable that some of the observations flagged as *estimated* could in fact be *measured.* We have compared the number of measured/estimated winds in CMR-5 with similar estimates by Cardone et al. (1990) who used a better quality controlled data set. The ratio of estimated/measured winds in CMR-5 agrees extremely well with the results of Cardone et al. (1990).

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[1] The reader is referred to Isemer and Hasse (1987) and references within for a discussion of measurement problems with SST, surface air and dew point temperatures.

Bias Corrections

For this study we use primarily Kaufeld's scientific Beaufort scale. Conversion factors as in Isemer and Hasse (1991) are derived for each of these scales and applied to the estimated CMR5 winds. Several alternatives exists to the old WMO scientific Beaufort scale (e.g., Cardone 1969, WMO 1970, Kaufeld 1981). In order to test the sensitivity of the bias corrections we have also performed calculations using Cardone's (1969) scientific Beaufort scale. The results of such comparison are summarized in section 5. For additional details the reader is referred to da Silva et al. (1992).

Following Cardone et al. (1990) we take the average ship height to be 20 m and correct all measured winds to a standard 10 m reference level using standard surface layer similarity theory. This procedure, which closely follows Large and Pond (1981, 1982), takes full consideration of the stability of the surface layer. All transfer coefficients needed to estimate the surface fluxes are taken from Large and Pond (1981, 1982), with a light wind correction as in Trenberth et al. (1990). Estimated winds corrected with Kaufeld's (1981) scale are converted from 25 m, apparently the average anemometer height of Kaufeld's ocean weather ships. Winds estimated with Cardone's scale are converted from a height of 20 m (Cardone et al., 1990), the average anemometer height in the ships used by Cardone to derive his scale.

3. Effect on Climatological Wind Speed

The effect of the above corrections on the climatological January wind speed and standard deviation has been investigated by da Silva et al. (1992) (hereafter referred to as dSYL). Figure 1 shows the difference between *corrected* minus *uncorrected* wind speed (a) and standard deviation (b) for the North Atlantic ocean. The main effect on wind speed is to increase magnitudes for most of the North Atlantic, except for a small region south of Greenland. The standard deviation decreases throughout the North Atlantic with a small increase off equatorial Africa. These results agree qualitatively with the findings of Isemer and Hasse (1991) but the magnitude of the correction is somewhat dependent on the statistical properties of the data set (dSYL use COADS, IH91 use Bunker) and to a lesser extent on the method of correction (dSYL make corrections on the individual observations while IH91 correct the monthly climatology).

4. Effect on Wind Stress and Heat Fluxes

Based on the results of the previous section, IH91 used the increase in wind speed to derive a correction factor for wind stress and heat fluxes. Simply put, IH91 assume that the increase in wind speed leads to an increase in wind stress proportional to the wind speed squared[2].

[2] Their procedure also includes a nonlinear correction factor and the wind steadiness parameter but this technical detail is irrelevant for the discussion here.

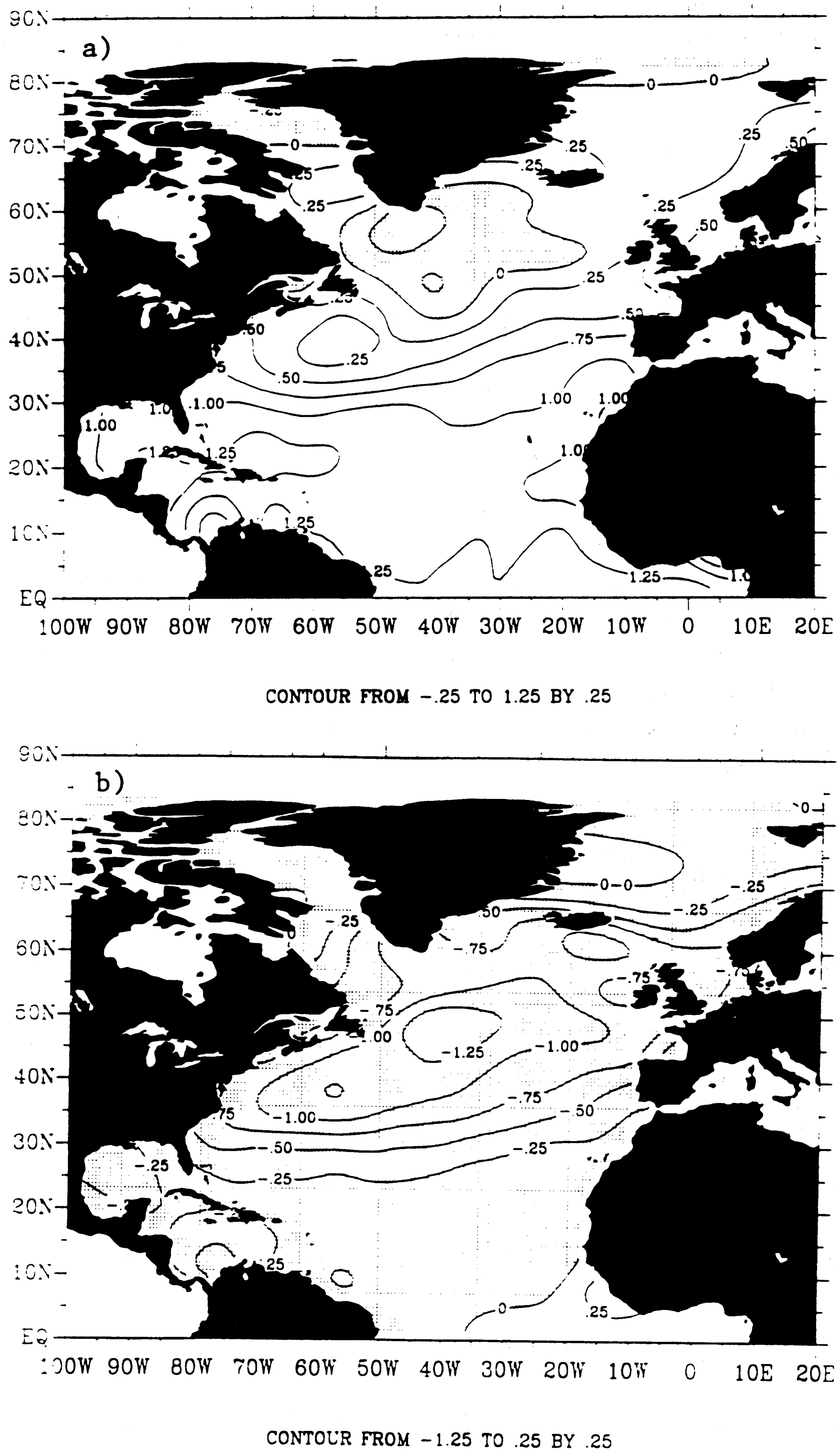

Figure 1. Corrected minus uncorrected a) wind speed and b) standard deviations. The climatology is for the period 1945-1972, approximately the same period as in Isemer and Hasse (1991). Contour interval is 0.25 ms^{-1}.

A serious difficulty with IH91 approach can be more easily demonstrated for the particular case of directionally steady winds, which are typical of the trade wind region. Let us assume that winds in this region can be written as

$$(u, v) = W(t)(\bar{C}, \bar{S}) \quad (1)$$

where $\bar{C}$ and $\bar{S}$ are constants satisfying $\bar{C}^2 + \bar{S}^2 = 1$. For this idealized case the magnitude of the average pseudo-wind stress reads

$$|\bar{P}| = \bar{W}^2 + \sigma_w{}^2 \quad (2)$$

where the bar means time average and σ_w is the wind standard deviation. It is clear that the magnitude of the average stress depend on both average wind speed and standard deviation. For the Beaufort wind speed corrections discussed above, W increases but σw decreases so that conceivably they could cancel out. IH91, by ignoring the σw contribution, overestimate the wind stress correction for most of the North Atlantic. The above results can be generalized for the full wind stress and the directional steadiness assumption can be removed if additional wind statistics are included.

In order to further establish this result we have computed wind stress and heat fluxes as described in section 2 for selected regions of the North Atlantic, using CMR5 100 box files. The selected regions are:

> Box 212: 10°W-20°W, 30°N-40°N, west of the Mediterranean, a region where the corrected wind is about 1 m/s larger than the uncorrected wind, and
> Box 174: 30°W-40°W, 40°N-50°N, south of Greenland, a region where the corrected wind is smaller than the uncorrected wind.

Figure 2 depicts the magnitude of the monthly climatological wind stress and latent heat flux corrected by the procedure described in section 2 (full line) and uncorrected (dashed line). Recall that this uncorrected wind assumes that the wind observations are at 10 in and uses the old WMO Beaufort scale. For Box 212 (Fig. 2.a) there is a strong seasonal dependence of the correction, with larger corrections in June, but very little change in January. Based on wind speed considerations alone one would riot expect such a small correction for January. In the region of Box 174 (Fig. 2.b) the corrected stress magnitude is smaller than the uncorrected version in January, but only marginally larger in July. These corrected wind stress magnitudes are quite different from the climatology based corrections of IH91. The change in latent heat flux depicted in figure 2.c for Box 212 is also smaller than IH91's, but it is consistent with the changes in average wind speed. This can be understood in terms of the small covariance between W and Δq (Esbensen and Reynolds, 1931).

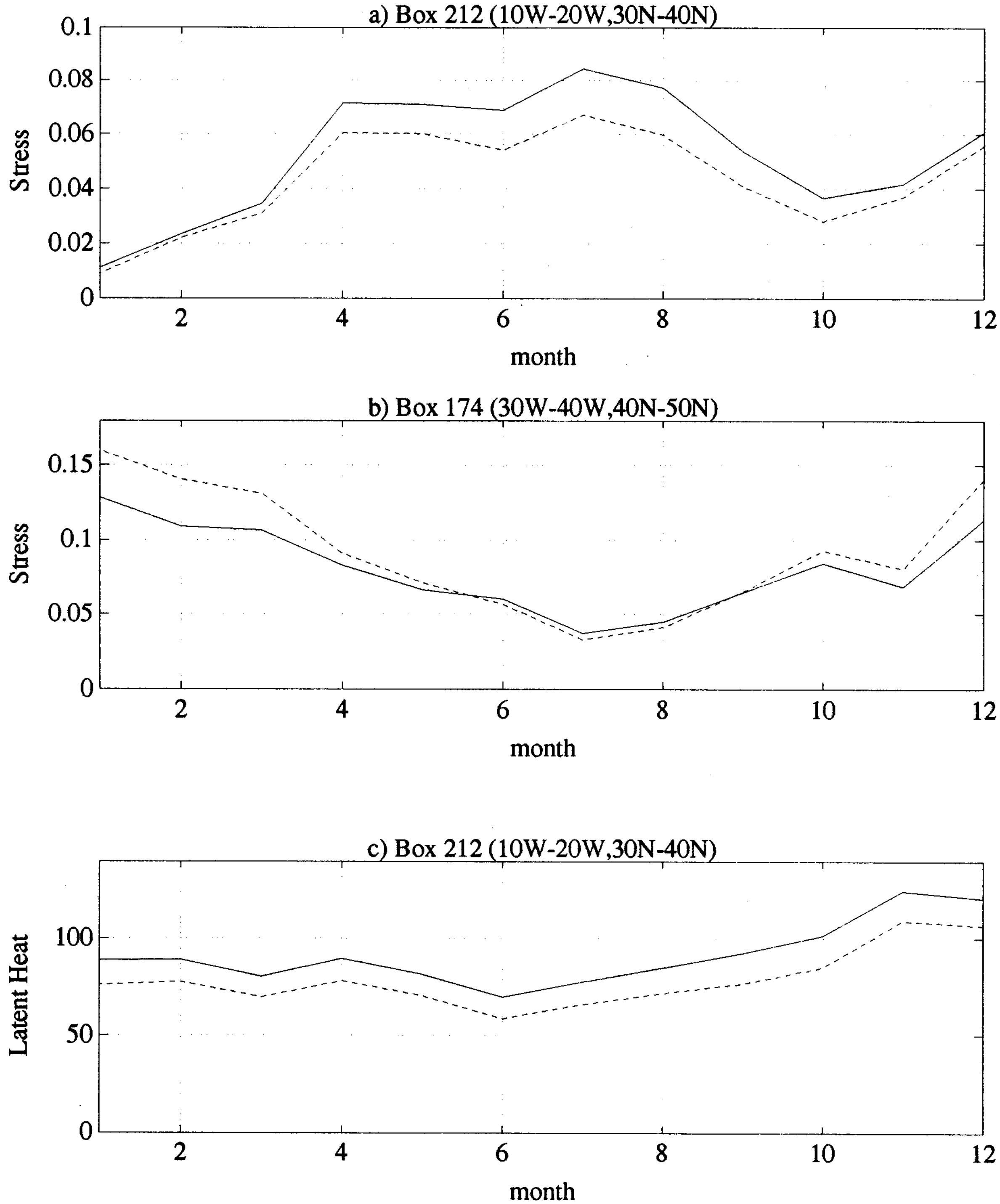

Figure 2. Corrected (full line) and uncorrected (dashed line) estimates of a) wind stress (units: Nm^{-2}), box, box 212, b) wind stress (units: Nm^{-2}), box 174, and c) latent heat flux (units: Wm^{-2}), box 212. The climatology corresponds to the period 1945-1969.

5. Concluding remarks

We have analyzed individual ship measurements from the COADS Compressed Marine Reports 5 to produce climatology of wind speed and other surface fluxes. Our primary concern was to further document the effect of bias corrections such as the scientific Beaufort scale and anemometer height corrections on these quantities, and the need for a detailed computation from the individual observations. The main points emerging from this study are:

- Our detailed calculations validate the statistical approach of Isemer and Hasse (1991) in the extratropics; some discrepancies are found in the tropics. However, our more extensive COADS data set produces corrected wind speeds that are about 1 m/s smaller than Isemer and Hasse's. These discrepancies are attributed to the difference in the standard deviation of the two data sets (tropics and extratropics) and correction procedure (tropics).
- We have tested the sensitivity of the wind speed correction on two different scientific Beaufort scales: Kaufeld (1981) and Cardone (1969). For certain parts of the North Atlantic ocean Cardone's scale produces a correction that is about half the correction based on Kaufeld's scale. The corrected wind speeds, however, do not differ by more than 0.5 m/s (da Silva et al., 1992).
- The scientific Beaufort scale correction affects the January mean wind speed and standard deviations on a global scale. The general effect is to increase wind speeds in the tropics and subtropics and to decrease wind magnitudes north of 45°N. Standard deviations are generally decreased except in some regions of the tropics (da Silva et al., 1992).
- Our preliminary results indicate that accurate Beaufort scale and anemometer height correction musts be based on the individual ship observations. Both wind stress and heat fluxes show considerable differences from correction procedures based on climatological data.

The wind speed correction described here significantly impacts fluxes of heat and momentum at the ocean surface. We are in the process of producing global, high resolution (1° x 1°) climatology and anomalies for the period 1945-89 of several quantities, including surface wind stress, latent and sensible heat fluxes, short and long wave radiation, etc.

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