Use of COADS Wind Data in Wave Hindcasting and Statistical Analysis

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Introduction

Wind observations from the Comprehensive Ocean Atmosphere Data Set (COADS) are used for two primary applications by Environment Canada: (1) the production of various wind statistics for design and operational planning, and (2) hindcasting of ocean waves, particularly in severe storms.

For wind statistics, the wind data are used directly in the Marine Statistics (MAST) interactive statistical analysis suite of programs (Swail et al., 1983), which produce both point statistics and contour analyses for marine climate atlases. Although problems relating to consistency in shipboard wind observations have been well documented (Dobson, 1981; Pierson, 1990), no modification is made to the wind observations in COADS for these analysis. It is generally considered that for these purposes that differences in measurement or observation methods are unimportant (e.g. Ramage, 1987). However, when these wind observations are used as input to wave hindcasting (or forecasting), or for other applications such as flux calculations, or for climate change detection, errors in wind observations become very important.

Wave Hindcasting using COADS Winds

It is well-documented that wind field errors are the single largest source of error in spectral wave modeling. Winds produced directly from numerical weather prediction models do not provide the same degree of accuracy for wave modeling as winds produced by kinematic analysis of wind fields from surface wind observations from ships and buoys (e.g. Khandekar et al., 1994). However, since the wave models are very sensitive to the wind input, it is very important to remove as many of the sources of error as possible from the data.

Wind observations from COADS may be either anemometer measurements or estimated by an observer, either from the state of the sea, or from the effect of the wind upon the ship (or the observer). There is no way to determine which method of estimation was used for a report. In order to carry out an accurate wave hindcast the surface winds must be adjusted to provide a consistent set of values. The following paragraphs briefly describe the corrections applied to both measurements and estimates to arrive at a consistent wind field. The method is described in detail by Cardone et al. (1990).

Wind speed reports based on Beaufort estimates are adjusted to 20 m using the Beaufort equivalent scale developed by Cardone (1969). This scale was derived from paired estimates from British and Canadian weather ships in the open ocean, and related the Beaufort number to a 20 m level. The official WMO (1946) scale relates to 10 m level winds, while Kaufeld's (1981) scale presumably relates to the 25 m level, the average height of the shipboard anemometers in his study; no reference level is specified for the WMO (1970) scientific scale. Cardone's and Kaufeld's scales diverge at Beaufort 12, likely due to the limited sample in Cardone's study at that wind speed class (9 occurrences). Otherwise, for neutral stability, the differences between Cardone's and Kaufeld's estimates due to reference level is about 3%. The Cardone scale (and the other newer scales) show that the operational WMO scale under light winds and over estimates strong winds. To correct, the reported wind speed, presumably derived from the operational scale, is related to the Beaufort force number. This is converted to a 20 m wind speed using Cardone's scale. No further correction is made for stratification, since the Beaufort estimates already incorporate this effect. The Cardone conversions fit the form:

$$U_{20} = 2.61 U_r^{7/9}$$

where U_r is the reported wind speed in knots. The method assumes that the estimate is made from the state of-the-sea rather than the apparent wind, which may or may not be true.

Dobson (1981) suggests that measured wind speeds from ships not be adjusted for height differences unless corrections are made at the same time for flow distortion effects. Since it is virtually impossible in practice to know even the sign of the flow distortion, let alone the magnitude, such a correction is never carried out except in limited experimental studies using calibrated ships. Nevertheless, the most commonly used techniques for adjustment of measured winds do incorporate some form of height adjustment. In this application, all wind measurements are adjusted for height and stability to the so called "effective neutral wind" at 20 m elevation, defined by Cardone (1969) as:

$$U_e(Z) = (U_*/k)\log[Z/Z_0(U_*)]$$

where U_* is the friction velocity, k is the von Karman constant, and Z_0 is a roughness parameter. If the marine surface layer is neutrally stratified, the effective and actual 20 m wind speeds are the same. For non-neutral stratification, U_e is related to the actual wind through U_*. U_* is first calculated from the measured wind speed and air-sea temperature difference; then U_e, is calculated from (1), using anemometer heights determined from the WMO ship list where possible. However, many observations do not contain the call sign, or the anemometer height is not available for the reported call sign. In those cases the anemometer height is assumed to be 20 m, close to the 19.3 m average height found by Cardone et al. (1990) based on nearly 3000 ships. In recent years the average anemometer height on Canadian cooperating vessels has risen to nearly 30 m, while buoys and drilling vessels provide measurements at about 5 m and 100 m respectively. Considerable efforts are made to identify data from such sources which depart significantly from the mean anemometer height. One further adjustment is made to Canadian buoy data, to account for the fact that those measurements are 10-min.

vector averages, while all other measurements are scalar values. The effect may be as much as 7-12% for higher wind speeds. The approach is based on a linear analysis of the 8-sec gust speed reported by the buoy to the 10-min mean wind speed.

Figures 1(a-d) show the results of Cardone et al. (1990) in applying these techniques for the South China Sea. The measured winds as observed are significantly higher than the uncorrected estimated winds for speeds up to 15 m/s. This tendency became more pronounced when the measured winds alone were corrected; when the estimated winds alone were corrected using Cardone's revised scale, there was an overcompensation, and the estimated winds were higher. Only when both the estimated and measured winds were corrected as described above did the wind speeds match reasonably well.

It can be seen from Figs. 2 and 3 that, when wave hindcasts are run with winds adjusted according to the procedures described above, the results are very accurate, implying that the wind fields are temporally and spatially consistent. Figure 4 shows that when these wind adjustments are applied (Run 4), the results are considerably improved for all wave height classes than when observed winds are assimilated uncorrected into NWP model runs. It should be recognized however that many problems may still exist with individual wind observations, including observer errors, instrument calibration, flow distortion effects, improper averaging intervals, uncertainties in atmospheric stability, unknown true anemometer height. Cardone et al. (1990) point out that such sources are apt to introduce random errors which are likely to average out if sufficient data are available. However, the Beaufort equivalency scale introduces systematic errors. Because it is biased low at low wind speeds and high at high winds speeds it alters patterns as well as overall amplitudes.

Correlation Analyses

The blending of wind observations into an analysis field requires information on the shape of the spatial auto correlation function for each data source, and the intrinsic noise level of each data source. The slope of the decay of wind speed correlation with distance provides information on the structure of the wind field and the quality of the data - the magnitude of the correlation coefficient in minimum separation classes gives an indication of the noise in the observation method. By itself, spatial correlation cannot distinguish "true" noise (i.e. from sensors, flow distortion, etc.) from small-scale wind variability, and it yields no information about the accuracy of a wind observation technique. When applied to a number of different observing techniques, spatial correlation analysis provides useful information without the problem of which method should be considered the independent variable. Brown and Swail (1988) applied spatial correlation analysis techniques to investigate the structure and noise levels of marine wind observations off the east coast of Canada for measured and estimated ship winds, as well as winds from drilling platforms winds, satellite and buoys. In the analysis, pairs were constructed of all possible combinations of wind speeds observations at the same report time, randomly reversed to ensure no geographic bias, and the great circle distance between them calculated. Separation classes for both coarse scale (100 km) and fine scale (10 km) were considered.

The correlation results are shown in Table 1. For most distance classes, measured ships have higher correlation's than estimated ships. The drilling platform winds show much higher correlation's than the measured ship winds. There are several likely explanations for this: (1) 8-10 platforms accounted for most of the drilling platform comparisons; (2) the platforms are mostly structurally similar, i.e. semi-submersibles with anemometers mounted on top of the derricks, (3) the range in anemometer heights is not large, (4) since the platforms are not moving, no errors are introduced in computing the true wind from the relative wind. As would be expected, correlation's of wind data from satellite scatterometer were very high. Microwave radiometer coefficients were significantly less than the scatterometer values; this is likely attributable to data problems with the SMMR instrument. Decreases in correlation of estimated winds at night (0.52) were consistent with similar decreases found by Laing (1985) for waves; measured winds were not greatly affected at night, except for increased variability.

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Table 1: Summary of Minimum separation class values for r_s, as a function of observing method.

Method	r_s(0-10 km)	r_s(0-100 km)
SEASAT-A Scatterometer	–	0.93
Buoy	0.90*	0.81‡
Drilling Platforms	0.84	0.85
NIMBUS-7 RADIOMETER (SSMR)	–	0.79
Ship (measured)	0.65	0.69
Ship (estimated)	0.66	0.64
Ship wind-wave (Laing, 1985)	–	0.43†

Figure 1: Comparison of monthly mean wind from (a) estimated and ship winds as reported, (b) adjusted estimated winds and reported measured winds, (c) reported estimated winds and adjusted measured winds, (d) both estimated and measured winds adjusted. Mean difference and ratio of points below the line to total points are given. (after Cardone et al., 1990).

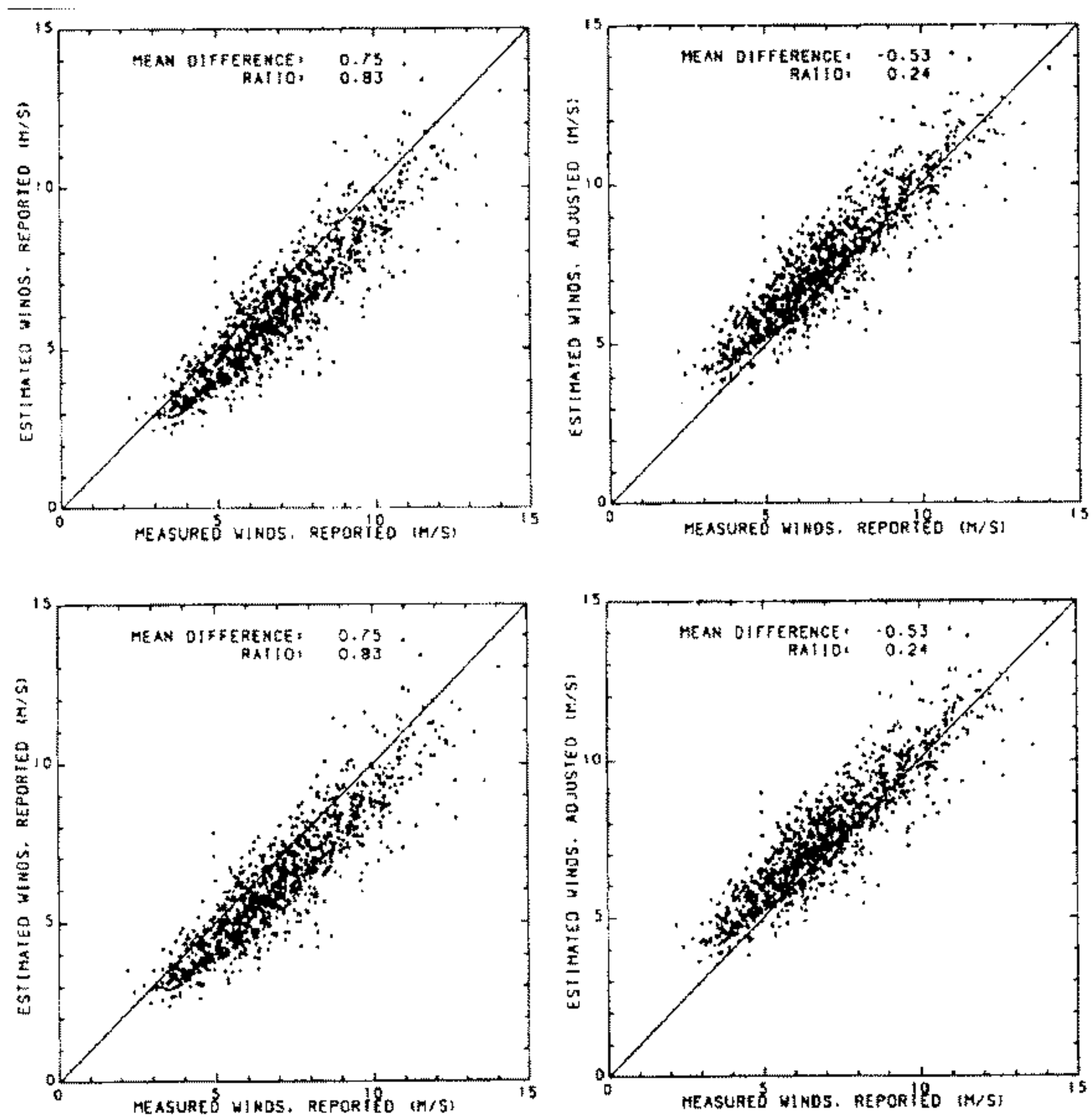

Figure 2: 3-G hindcast from kinematic winds, and measured HS at buoys north (a) and south (b) of the cyclone track in SWADE IOP-1. (after Cardone and Swail, 1994).

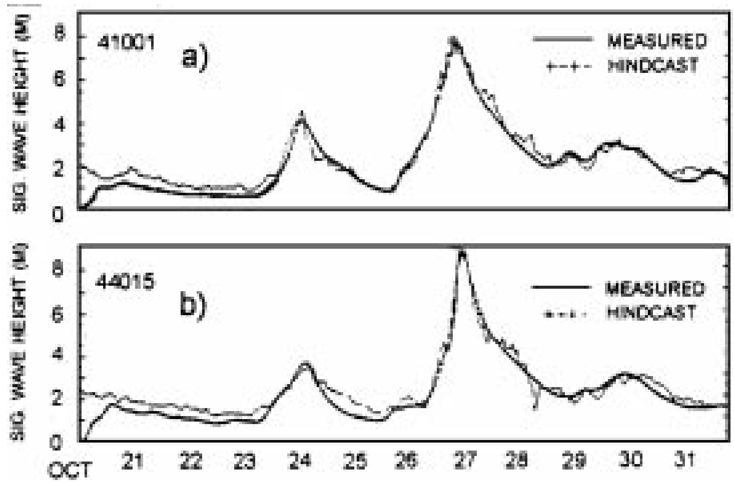

Figure 3: Wave Hindcast at buoy 41002 using adjusted wind fields in the Storm of the Century, March 11-18, 1993.

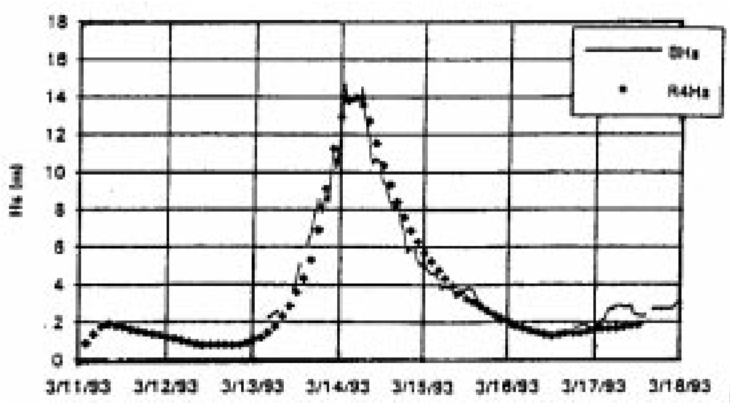

Figure 4: Wave height error statistics by percentile for adjusted wind speeds (solid line) versus model winds (dashed lines) compared to boy observations in the northwest Atlantic ocean.