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ARE MOORED BUOY WINDS TOO LOW IN HIGH SEAS?

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Introduction

Wind measurements from buoys operated by the National Data Buoy Center (NDBC) are used extensively by operational forecasters for real-time assessment of ocean conditions and model initialization. The research community relies on buoy winds for a wide variety of purposes such as climatology development, providing ground truth for remotely sensed observations, and for numerical model validation. The accuracy of buoy observations is obviously an important consideration to both the operational and research communities, and studies addressing the issue have occasionally been conducted. Buoy measurements were found to be an excellent calibration reference for remotely sensed winds when used with the proper constraints (Gilhousen, 1987). Austin and Pierson (1999) showed that most of the scatter seen in comparisons of scatterometer and buoy winds are a result of mesoscale effects inherent in buoy wind averages. While such studies explore the variability of buoy wind measurements, there is not much information available in terms of absolute accuracy.

A striking feature of the Comprehensive Ocean-Atmosphere Data Set (COADS) is that areas with moored buoys appear to have wind speed deficits greater than 2 m/s relative to areas dominated by ship observations (Woodruff and Lubker,1993). While these differences can largely be accounted for by such factors as the poor quality of ship observations and the relatively high placement of ship anemometers (Wilkerson and Earle,1990), it has been suggested that buoy winds may in fact be too low in relation to the "true wind". Thomas (1998) reported that many forecasters within Environment Canada, presumably assuming buoy winds to be low in high sea states, use peak instead of mean buoy wind speed in their marine wind analyses. Large et al. (1995) found buoy neutral stability equivalent 10-m wind speeds were systematically low in relation to numerically modeled wind field analyses and suggested the cause was wave distortion of the wind profile.

The purpose of this study is to evaluate if wave height does indeed influence the accuracy of buoy wind speeds. To accomplish this, moored buoy wind speed measurements taken during periods of high sea states were compared with those of a nearby coastal site and with numerical model forecast winds.

Buoy-shore Station Comparison

Data Set

The Coastal-Marine Automated Network (C-MAN) station, NWPO3, located on the Oregon Coast near Newport and the nearby moored buoy station, 46050, are uniquely situated to provide data for this study. The C-MAN station is low lying but well exposed to onshore winds. The site elevation is 9.1 m above sea level with an anemometer height 9.4 m above site elevation. Buoy 46050 is a 3-m hull with an anemometer height of 5 m above the water line, located 36 km due west of NWPO3. Each station is equipped with redundant R M Young propeller anemometers. The distance between stations is large but within limits recommended by Gilhousen (1987) for such comparisons and well within the windows typically used for comparisons of buoy and scatterometer winds. See, for example, Freilich and Dunbar (1999).

Concurrent hourly wind measurements were available from these stations over a seven year period from 1991 through 1997. Hourly wind speeds of both stations represent scalar means sampled at 1 Hz. However, the length and time of data acquisition are different. The C-MAN station uses a 2 min acquisition period ending on the hour, while the buoy samples over an 8 min period that ends 10 min before the hour. The effects of these differences are likely to be small compared to those caused by spatial separation or orographic effects. To minimize such effects, concurrent measurements used in the study were confined to onshore winds, reported between 200 and 340 degrees by NWPO3 and within 20 degrees of those reported by 46050.

Buoy winds were adjusted to 10 m assuming neutral stability since many observations were missing air or water temperature and under high wind and sea conditions, the boundary layer would tend to be neutral in any case (Hsu, 1988). This also allowed for a direct comparison to the method proposed by Large et al.(1995) which accounts for wave height but neglects the effects of stability in high winds and seas. The method of adjusting wind speed to 10 m is just that proposed by Large et al. without the wave height correction. No adjustments were made to NWPO3 wind speeds.

Analysis

Figure 1 is a scatter plot of all concurrent observations meeting the criteria established for the study. Large markers represent sample averages of bins bounded by lines perpendicular to the 1:1 line at 3 m/s intervals. The scatter is broad about the 1:1 line, but bin averages show good agreement in the mean up to 15 m/s. Above that, buoy wind speeds tend to be less than the C-MAN station, showing a negative 10 percent bias at 20 m/s.

To determine if wave height influenced the results in any systematic way, C-MAN and 10 m buoy wind speed pairs were sorted by wave height and compared. Observation pairs were sorted by observed significant wave height, in 1 m increments, from 3 to 6 m. All observations with wave heights over 6 m were included in one grouping. If wave height is the primary factor contributing to low bias of buoy wind speeds seen in Fig. 1, it ought to be apparent in comparisons of wind speeds observed at increasingly higher wave heights. This, however, is not the case. Bin averages of each wave height increment (Fig. 2) are tightly grouped and close to the 1:1 line up to 15 m/s, not too different from bin averages of the total sample. At higher wind speeds, they scatter in haphazard fashion showing no relation to wave height. In fact, observation pairs with wave heights above 6 m show the least bias at high wind speeds, although this is likely just a result of small sample size at the higher wind speeds and wave heights. These results suggest that wave height is not a significant factor causing buoy winds to report low at wind speeds up to between 15 to 20 m/s or significant wave heights up to 6 or 7 m.

Large et al. (1995) found a similar but larger bias in comparisons of buoy wind speeds to European Center for Medium Range Weather Forecasts (ECMWF) wind field analyses. They suggested that the cause was failure to account for distortion of the wind profile by waves when adjusting observed buoy winds to 10 m. They proposed an adjustment method that includes the effects of waves, scaled by wave height, analogous to the commonly used stability correction. Their method was applied to the data set using buoy reported wave heights. The results are shown in Fig. 3 along with those from Fig. 1. Bin averages of the non-adjusted 5 m buoy winds are also included to show the degree of adjustment by each method. Little difference among bin averages is evident up to wind speeds of 10 m/s. Above this, non-adjusted buoy winds are light relative to the C-MAN station. When buoy winds are adjusted to 10 m, assuming neutral conditions, the relationship is closer, but when winds are adjusted accounting for the effects of waves, buoy wind speeds are high by about as much as the normally adjusted wind speeds are low. It should be noted that the method suggested by Large et al. was based on a buoy wind speed sample having a much larger bias relative to numerically modeled wind speeds and with wave heights estimated from wind speed rather than actual observations. Swell also made a significant contribution to wave height observations. If the contribution of swell were eliminated, for instance, the results might have been more favorable. As will be seen in the next section, however, the application of a wave height correction does not appear to be warranted in any case.

Buoy-numerical Model Comparison

Data Set

By simply comparing buoy winds with those of a shore station as in section 2, the actual influence of wave height on the wind profile might be masked. Other factors, like the difference between roughness lengths over land and water, or the anemometer height of the shore station were not considered, but likely are playing a role. To eliminate the influence of such factors, a similar study was conducted which compared the wind speeds of open ocean buoys with numerical model wind fields. Wind speeds from three Pacific 6-m buoys were compared with National Center for Environmental Prediction (NCEP)

Reanalysis Project 6 hr forecasts of 10-m winds. The buoys, depicted in Fig. 4, are located well offshore where the surrounding wind fields should be free of orographic effects. Each buoy has redundant RM Young propeller anemometers 5 m above the water line. Data sampling rates and averaging periods of the 6-m buoys are the same as those of the 3-m buoy already described. Buoy wind speeds were adjusted to 10 m in the same manner as in the previous section. Buoy observations were from the entire years of 1996 and 1997. Two observations each day were used, corresponding to model 6 hr forecast times valid at 06Z and 18Z.

The model, described by Kalnay et al. (1996), uses the NCEP T62 grid which has a horizontal resolution of approximately 2 deg. Wind speeds were linearly interpolated from model grid points to buoy locations. Observations from the three buoys were combined into a single sample for collective comparison with model winds. While the buoy observations were presumably included in model initialization, direct influence of the observations on the results of the comparisons should be mostly eliminated by the model's optimization process and the use of 6 hr forecasts.

Analysis

The results of the buoy and model wind speed comparison are shown in Fig. 5. The scatter of points is broad but symmetric about the 1:1 line. Bin averages indicate good agreement between the model and buoy observations at speeds in excess of 15 m/s. To determine if wave heights might be influencing the results, buoy and model wind speed pairs were sorted according to significant wave height and compared in the same manner as in section 2.2. The results are shown in Fig. 6. Results are very similar to those seen in the comparison of buoy and shore station winds. Bin averages are tightly grouped and close to the 1:1 line up to beyond 15 m/s. Above that, the bin averages scatter as sample size becomes small, but effects directly attributable to wave height are not evident.

Conclusion

Buoy wind speeds compared with a nearby coastal station show good agreement in the mean up to speeds of about 15 m/s, above which, buoy winds tend to be less than those of the coastal station. The bias at high wind speeds does not appear to be directly related to wave height, since bin averages of observation pairs sorted by wave height behave in a similar fashion to those of the total sample, regardless of wave height. A method to adjust buoy wind speeds to 10 m using observed wave height adjusted wind speeds too high.

While there may be a number of unknown factors influencing the buoy and coastal station wind speed comparisons, the results tend to be confirmed through a comparison of open ocean buoy winds with NCEP Reanalysis Project wind fields. Good agreement of wind speeds in excess of 15 m/s is again seen, even when only the highest wave heights are considered. Wave height does not appear to produce systematic errors in the accuracy of buoy wind speed measurements over the range of wave heights and wind speeds considered in this study. At wind speeds up to 20 m/s and significant wave heights up to 7 m, buoy wind speeds adjusted in the conventional manner should be considered accurate enough for most purposes. At higher winds and seas wave height may indeed be a factor, but the small sample size makes it difficult to draw firm conclusions.

This study focused on wave height since it is readily from moored buoys, and has been most often questioned as a factor influencing buoy wind speed accuracy. Wave height, of course, does not tell the whole story on the state of the sea. Similar studies concerning the influence of other factors such as wave period or steepness would also be appropriate.

References

Austin, S., and W. J. Pierson, 1999: Mesoscale and synoptic-scale effects on the validation of NSCAT winds by means of data buoy reports. *J. Geophys. Res.*, **104**, 11437-11447.

Freilich, M. H., and R. S. Dunbar, 1999: The accuracy of NSCAT 1 vector winds: Comparisons with National Data Buoy center buoys. *J. Geophys. Res.*, **104**, 11231-11246.

Gilhousen, D. B., 1987: A field evaluation of NDBC moored buoy winds. *J. Atmos. Oceanic. Technol.*, **4**, 94-104.

Hsu, S. A., 1988: *Coastal Meteorology*. Academic Press,260 pp.

Kalnay, E., et al., 1996: The NCEP/NCAR Reanalysis 40-year project. *Bull. Amer. Meteor. Soc.*, **77**, 437-471.

Large, W. G., J. Morzel, and G. B. Crawford, 1995: Accounting for surface wave distortion of the marine wind profile in low-level ocean storms wind measurements. *J. Physic. Oceanogr.*, **25**, 2959-2971.

Thomas, B. R., 1998: On the relationship of buoy and measured ship winds. *Second Conference on Coastal Atmospheric and Oceanic Prediction and Processes*, 301-307.

Wilkerson, J. C., and M. D. Earle, 1990: A study of differences between environmental reports by ships in the voluntary observing program and measurements from NOAA buoys. *J. Geophys. Res.*, **95**, 3373-3385.

Woodruff, S. D., S. J. Lubker, K. Wolter, S. J. Worely, and J. D. Elms, 1993: Comprehensive Ocean-Atmosphere Data Set (COADS) release 1a. *Earth System Monitor*, **4**, 1-8.

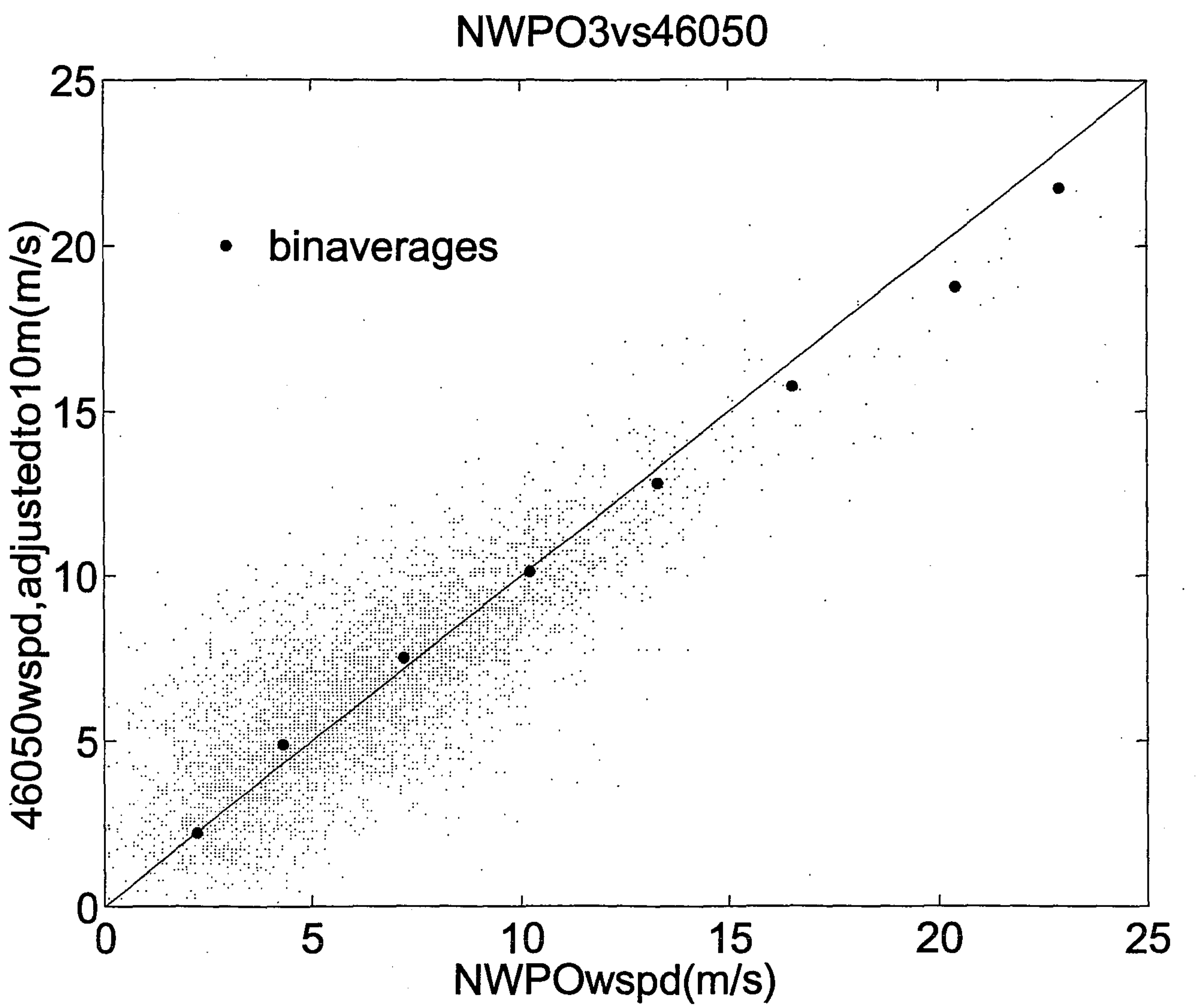

FIG. 1. Scatter plot of NWPO3 vs. 46050 wind speeds adjusted to 10 m with 3 m/s bin averages indicated.

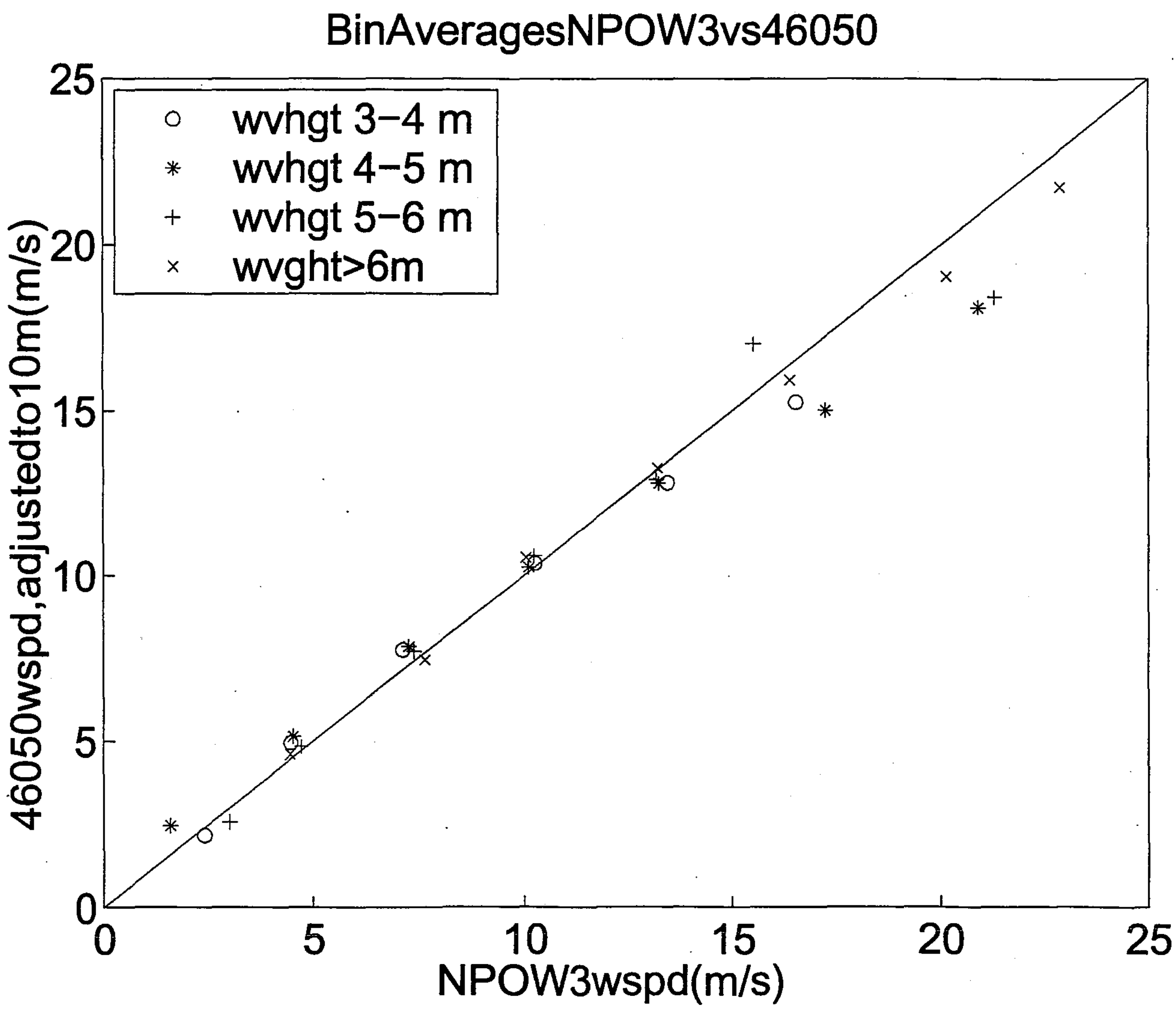

FIG. 2. Bin averages of NWPO3 vs. 46050 wind speeds sorted by significant wave height.

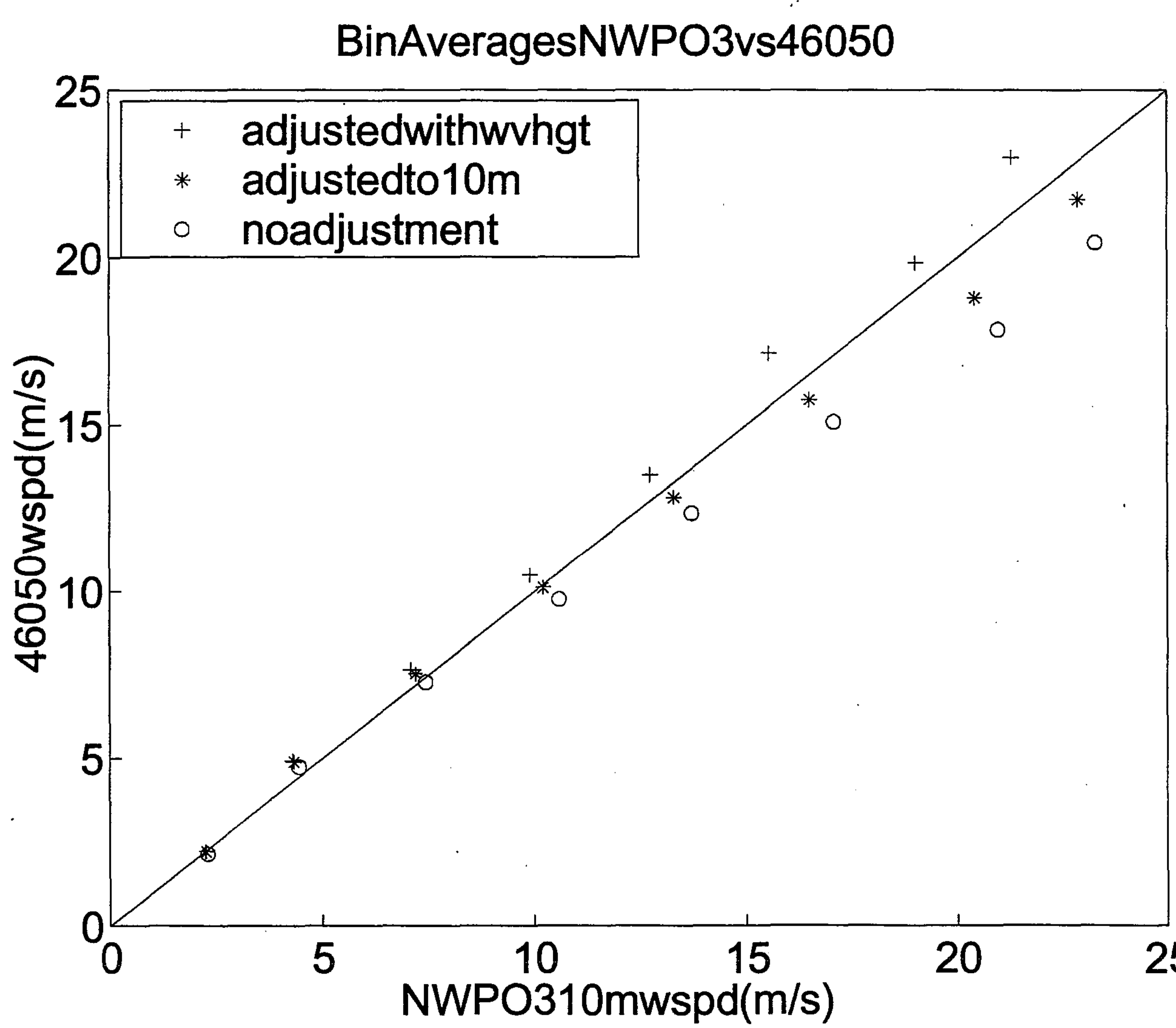

FIG. 3. Bin averages of NPOW3 vs. 46050 wind speeds with no adjustment and adjusted to 10 m, with and without accounting for wave height.

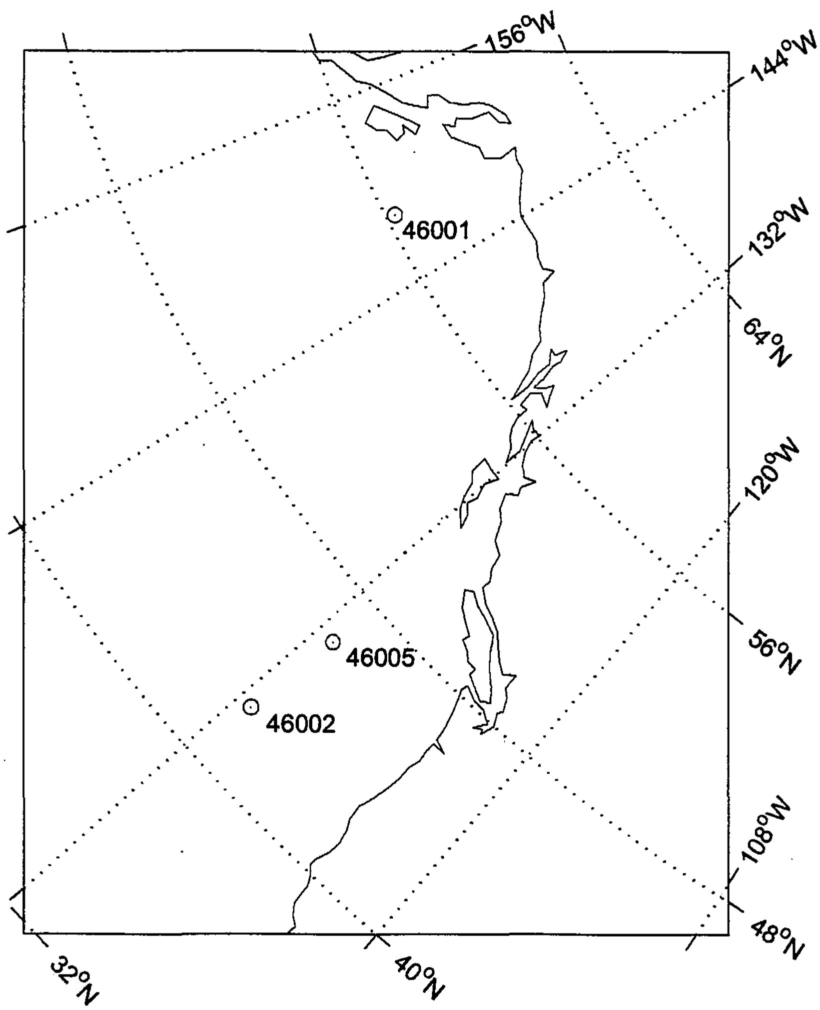

FIG. 4. Map showing the location of buoys used in the model vs. buoy wind speed comparison.

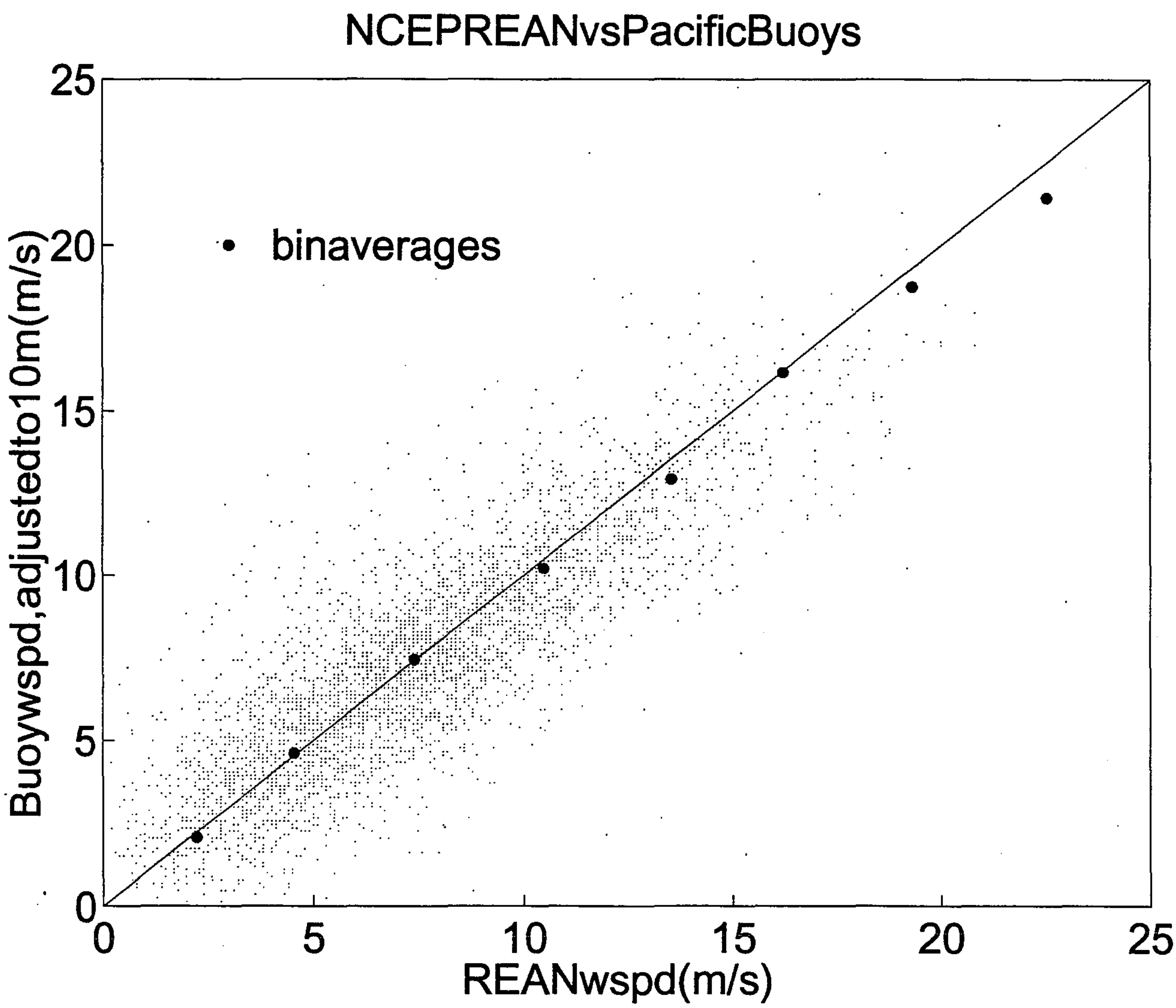

FIG. 5. Scatter plot of Reanalysis 6 hr forecasts of 10 m wind speed vs. buoy 10 m wind speed. Bin averages are indicated.

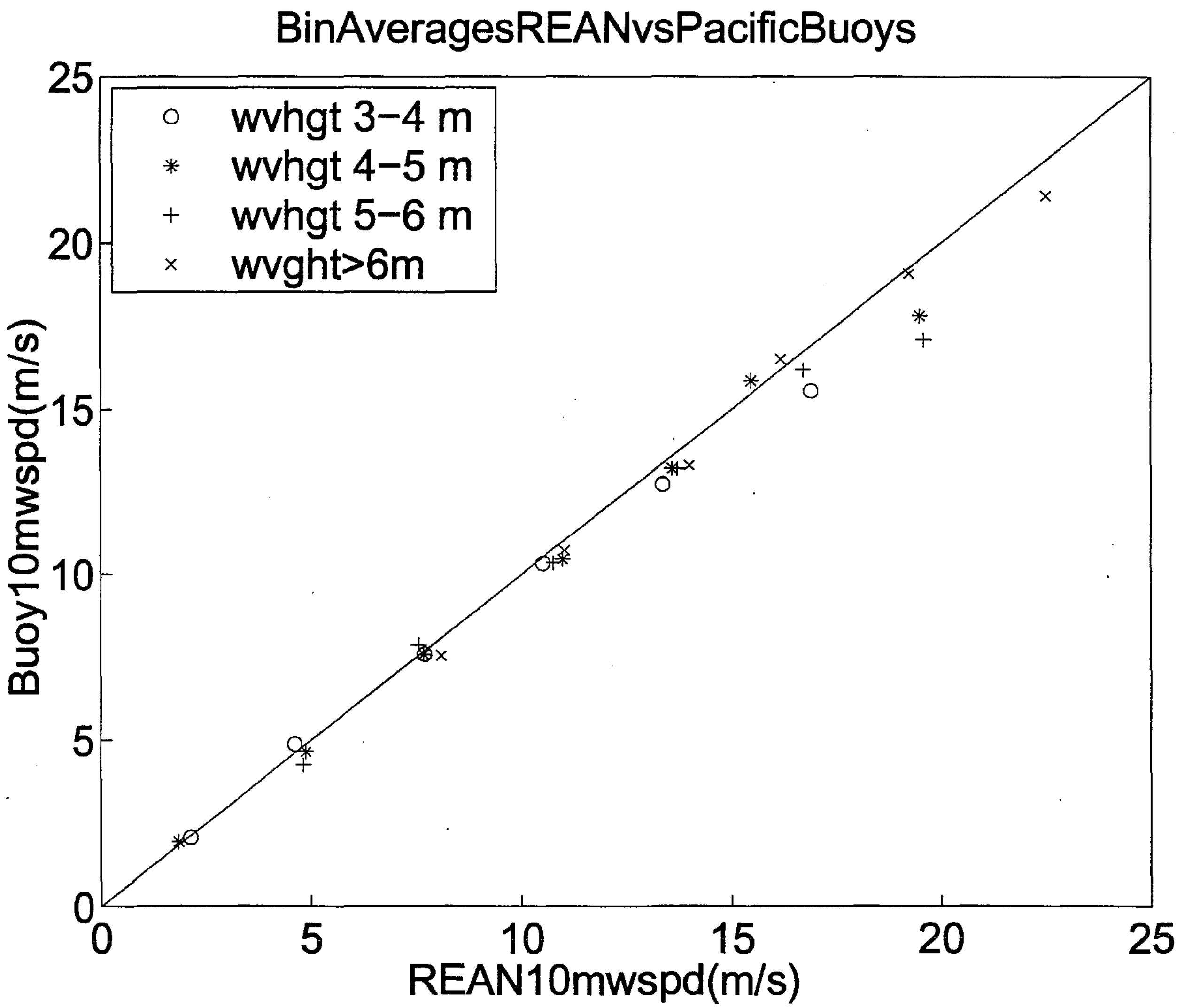

FIG. 6. Bin averages of Reanalysis vs. b