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AN UPDATED COMPARISON OF SURFACE WINDS ON THE GREAT LAKES AS REPORTED BY BUOYS AND SHIPS

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1. INTRODUCTION

The Data Buoy Program of the Great Lakes was established to provide environmental information in data sparse areas. The NOAA Data Buoy Office started its Great Lakes Program in May of 1979 with the establishment of a station (45001) in central Lake Superior; the second station (45002) was activated in northern Lake Michigan in September of that year (NOAA Data Buoy Office, 1980a). The buoy system uses 6-m boat-shaped NOMAD buoys. The meteorological variables recorded include wind speed, wind direction, air temperature, and barometric pressure. Characteristics of the lakes which are measured are surface water temperature, significant wave height, wave period, and wave spectra. Observations from the buoys are transmitted via the GOES satellite to Wallops Island, Va. and then to the National Meteorological Center from where they are disseminated over Weather Service communication circuits.

The buoy observations are useful at Weather Service Forecast Offices (WSFO's) to supplement the observations available from Great Lakes ships. A problem was encountered (WSFO, Cleveland) in using the buoy observations for this purpose; the wind speeds measured on the buoys are usually significantly less than wind speeds observed on nearby ships. This might be expected, as buoys measure wind speed at a much lower level of the atmosphere than do the ships. Most of the ship anemometers are about 15 meters (49 feet) above the water, whereas the buoys report the wind speed at the 5-m (16-ft) level. Another factor is the different period of record between the ship and buoy observations. Ship wind speed observations are 1-min averages and the buoy wind speeds are 8.5-min averages.

By using the 1979 buoy and ship observations, an adjustment factor to estimate ship wind from buoy wind was determined by comparing the buoy wind observations to wind observations from nearby ships (Pore, et al., 1981). It was found that the wind at ship anemometer height could be estimated by multiplying the buoy wind speed by 1.5 and that no adjustment in wind direction between the two levels is needed. These results were based on the meager data sample obtained from the first two buoys during 1979. A total of 125 matched sets of observations were available for that year.

With the addition of three buoys to the Great Lakes program in 1980, many more sets of matched observations became available for analysis. The three additional buoys were located in northern Lake Huron (45003), eastern Lake Superior (45004), and western Lake Erie (45005) (NOAA Data Buoy Office, 1980b). Over 1100 sets of matched observations are available from the 1980 data. These data were combined with the 1979 data and the total set was analyzed. This report is on the analyses of the combined 1979-1980 data.

2. COMPARISON OF BUOY AND SHIP OBSERVATIONS

One way to adjust wind speeds from one level to another is to use a logarithmic wind profile relationship. Such a profile can be used to determine the wind speed at various levels when the wind speed at one level is known. A problem with this approach for the determination of ship anemometer-level wind from buoy-level wind is the proper form of drag coefficient. Many forms of drag coefficient have been proposed and they result in many different wind profiles. An alternate approach to determine ship anemometer-level wind speed was used; ship and buoy observations were compared and relationships between the two types were determined. The locations of the five buoys used in 1979 and 1980 are shown in Fig. 1. The buoy wind observations were compared to observations from ships which passed relatively close to the buoys. The ship observations were used if the ship was within the rectangular areas shown in Fig. 1. These rectangular areas are centered over the buoy locations and have the dimensions of 0.6° latitude by 0.8° longitude or about 36 by 33 nautical miles.

Buoy observations were considered for the regular 6-h observation times of 0000, 0600, 1200, and 1800 GMT. If a ship observation was available for the same time within the rectangular areas, a comparison was made. If more than one ship observation was available within a rectangular area, the observation of the ship closest to the buoy was used. The few cases in which wind was reported as calm were not used. There were 1289 cases during 1979 and 1980 in which buoy and ship observations could be compared.

The 1289 observations were classified, depending upon air-water temperature difference, in order to look into the effect of atmospheric stability. The buoys report water temperature for essentially the upper 1 meter and the air temperature is measured at 5 meters. An arbitrary stability classification, similar to that of Strong and Bellaire (1965), was used. This classification is simply based on the difference between air temperature (T_a) and water temperature (T_w). The classification and number of cases in each class is shown in Table 1.

Table 1. Stability ($T_a - T_w$) classification and number of cases in each class.

Class	$(T_a - T_w)$	Cases
Stable	$> +2.8°C$	156
Neutral	$\leq +2.8°C$ to $\geq -2.8°C$	815
Unstable	$< -2.8°C$	318

A. Wind Speed

A plot of ship wind speeds against buoy wind speeds is shown in Fig. 2. In this type of figure the number of cases is represented by alphabetical characters. For example, the letter A represents one case, B represents two cases, and so forth. It is quite evident that the wind speeds reported by the ships are significantly higher than those reported by the buoys. The correlation coefficient between the two types of wind speed observations is 0.78; the associated least squares regression line is shown in Fig. 2. The root-mean-square error (RMSE) of the regression line is 4.7 kt. This line does not very well fit the higher wind speeds.

The data were then stratified into three classes--stable, unstable, and neutral. Regression lines were derived for each of the three classes (Fig. 3). The derived regression lines for neutral and unstable cases are almost identical, whereas the regression line for stable cases is quite different. Above a buoy wind speed of about 10 knots, the ships report higher wind speeds for the stable cases. This stability effect, which has been referred to as the "blanket effect" by Strong and Bellaire (1965), has to do with momentum transfer from upper level winds to levels near the water surface. During stable conditions momentum transfer from higher levels to the water surface is retarded, whereas during unstable conditions momentum is readily transferred from the higher levels to the water surface.

Exponential type curves were also fit to these data. The curve, fit to all the data, was determined by least squares regression and logarithmic transformation of the buoy and ship wind speeds and is shown in Fig. 4. This type of curve was also derived for each of the three stability classes; they are shown in Fig. 5. These exponential type curves do not fit the higher wind speeds well just as the straight line relationships did not, as shown in Figs. 2 and 3. In fact, for high wind speed cases the derived relationships call for the ship wind speeds to be less than the buoy wind speeds; this of course is quite unsatisfactory.

In order to find a relationship that does fit the data fairly well, including the higher wind speed cases, the mean ratio of ship wind speed to buoy wind speed was considered. The mean ratio for all data combined was 1.60. This relationship is shown in Fig. 6. The mean ratio of ship wind speed to buoy wind speed varied from 1.5 to 1.7, being 1.5 for unstable cases, 1.6 for neutral cases, and 1.7 for stable cases. These relationships are shown in Fig. 7.

Comparison of Figs. 2, 4 and 6 show the relationship based on the mean ratio of ship wind speed to buoy wind speed (Fig. 6) to be better for the higher wind speed classes. The root-mean-square error of the mean ratio method is only 0.8 knot greater than that for the linear relationship of best fit (Fig. 2). For these reasons it is recommended that the relationship based on the mean ratio be used for operations. This means simply multiply the buoy wind speed by 1.6 for an estimate of the equivalent ship wind. A minor refinement can be made for stability as shown in Fig. 7. When considering stability the multiplication factors to use, as shown in Fig. 7, are 1.5, 1.6, and 1.7 respectively for unstable, neutral, and stable conditions.

B. Wind Direction

In an effort to determine the average shift in direction between the 5-m wind observation of the buoys and the 15-m observations of the ships, the wind directions at the buoys and ships were compared. We might not expect to find a clear-cut variation of wind direction between the buoys and the ships as the buoys and ships are not exactly at the same location and the two types of observations are of different durations. Also, the wind observations of the ships may be affected by disruption of the flow by the ship.

The frequency distribution of the direction difference for all stability classes combined is shown in Fig. 8. This distribution is very symmetrical. The most prevalent direction difference between the wind observed on the ships and the buoys is 0°; this difference accounts for about 18% of the cases. About 15% of the cases are for a 10° difference veering with height; another 15% is for a 10° difference backing with height. Similar graphs were made for each of the three stability classes. They are not shown here as the distributions were not much different than that for all stability classes together. It seems best to consider no shift of direction between the buoys and ships for operational use of the buoy data.

3. SUMMARY

In attempting to supplement the regular ship wind observations on the Great Lakes, problems have been encountered in using buoy observations as the wind speeds reported by the buoys are usually considerably less than winds reported by nearby ships. This is probably because the buoy observations are at a lower level than the ship observations and the buoy observations are averaged over much longer time periods. Based on the combined observations for 1979 and 1980, it appears a good way to adjust the buoy wind speed to represent ship anemometer-level wind speed is to multiply the buoy wind speed by 1.6. The direction reported by the buoys can be used with no change.

REFERENCES

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Strong, A. E., and F. R. Bellaire, 1965: The effect of air stability on wind and waves. Pub. No. 13, Great Lakes Research Division, University of Michigan, 283-289.

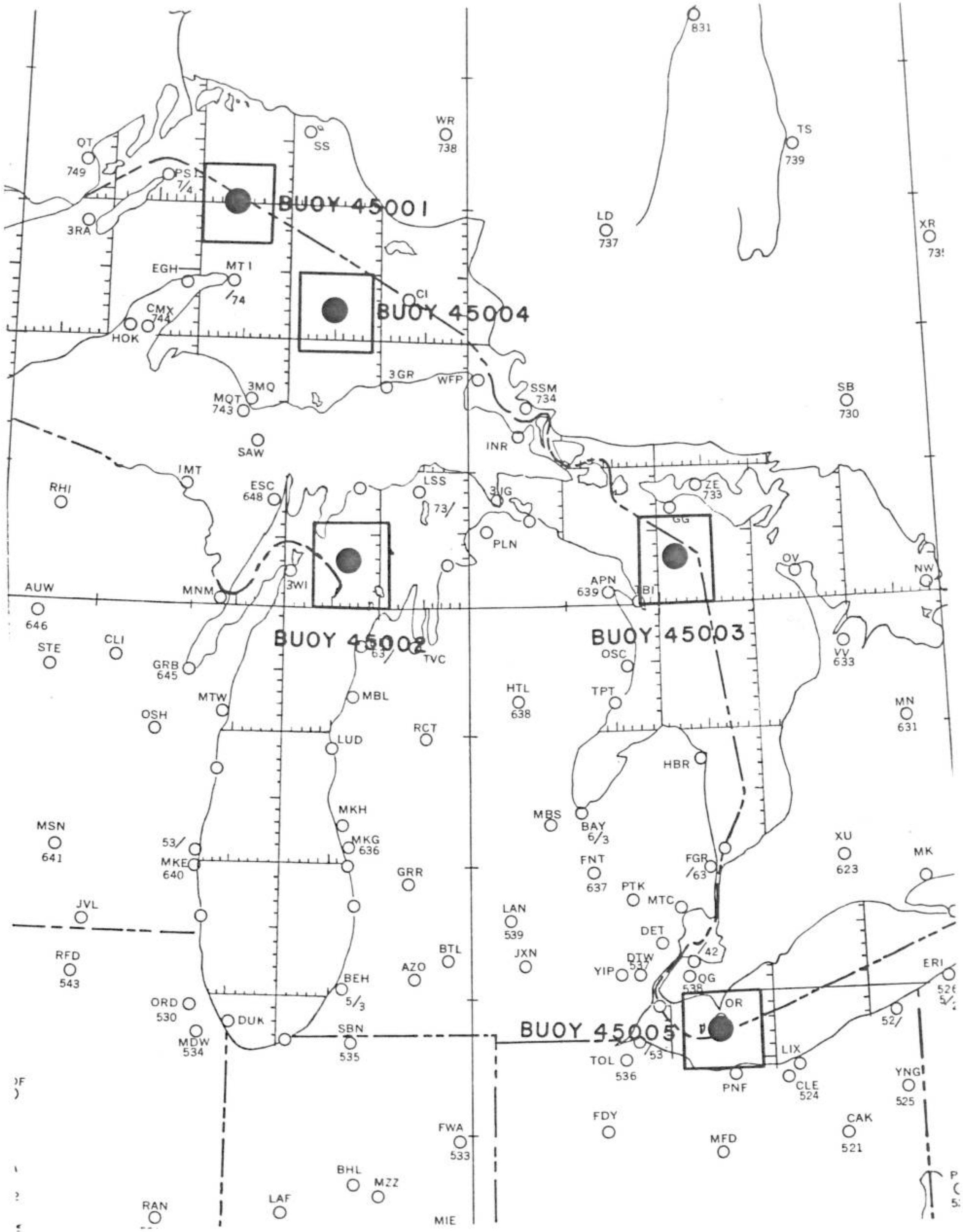

Figure 1. Locations of the five data buoys used on the Great Lakes during 1979 and 1980. The boxes show the areas in which ship observations were used for comparison to the buoy observations.

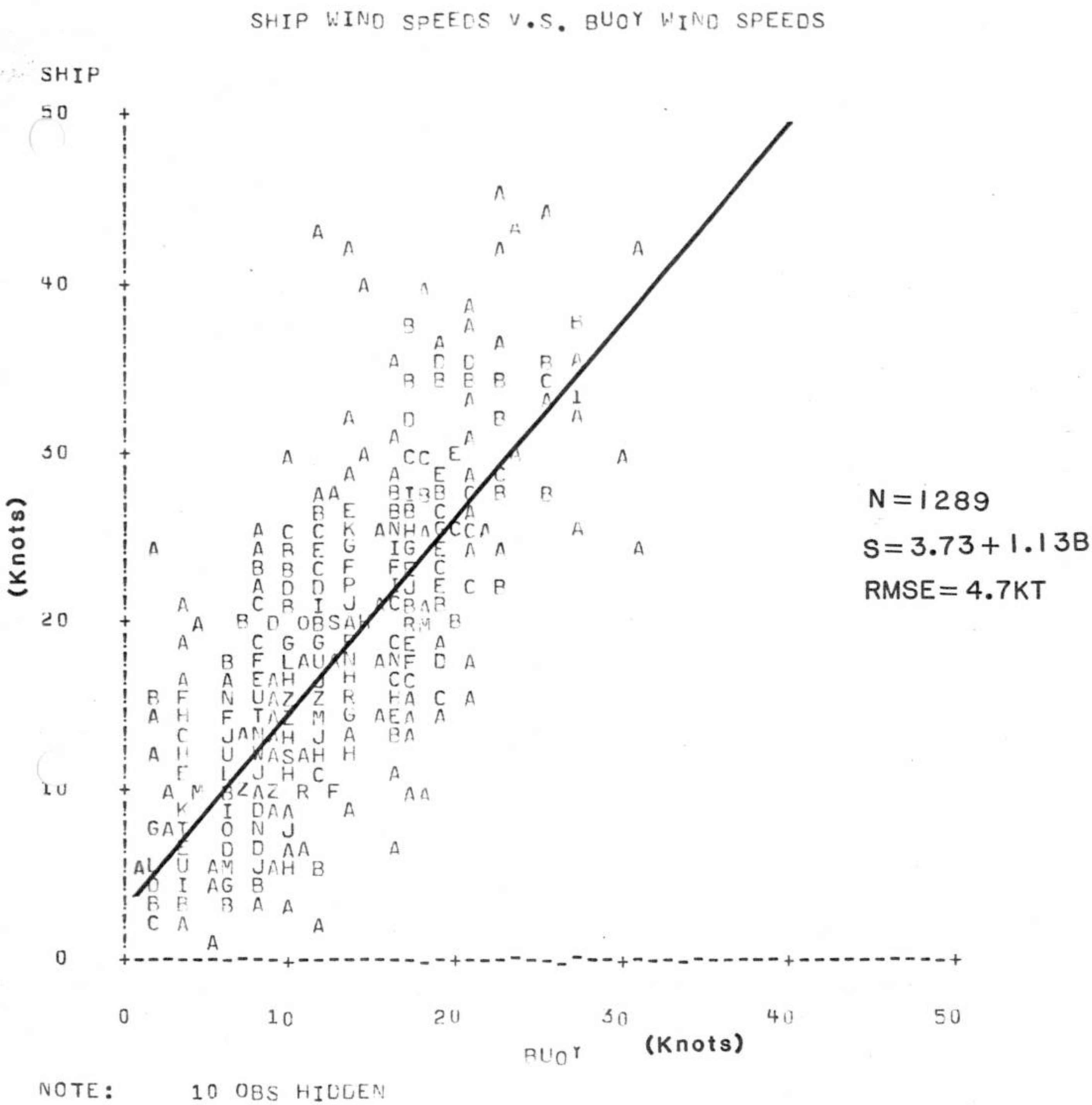

Figure 2. Plot of observed wind speeds at Great Lakes data buoys and the corresponding wind speeds observed on nearby ships. The regression line shown was determined by the method of least squares; it gives the ship wind speed (S) as a function of the buoy wind speed (B). The associated correlation coefficient is 0.78 and the root-mean-square error is 4.7 kt.

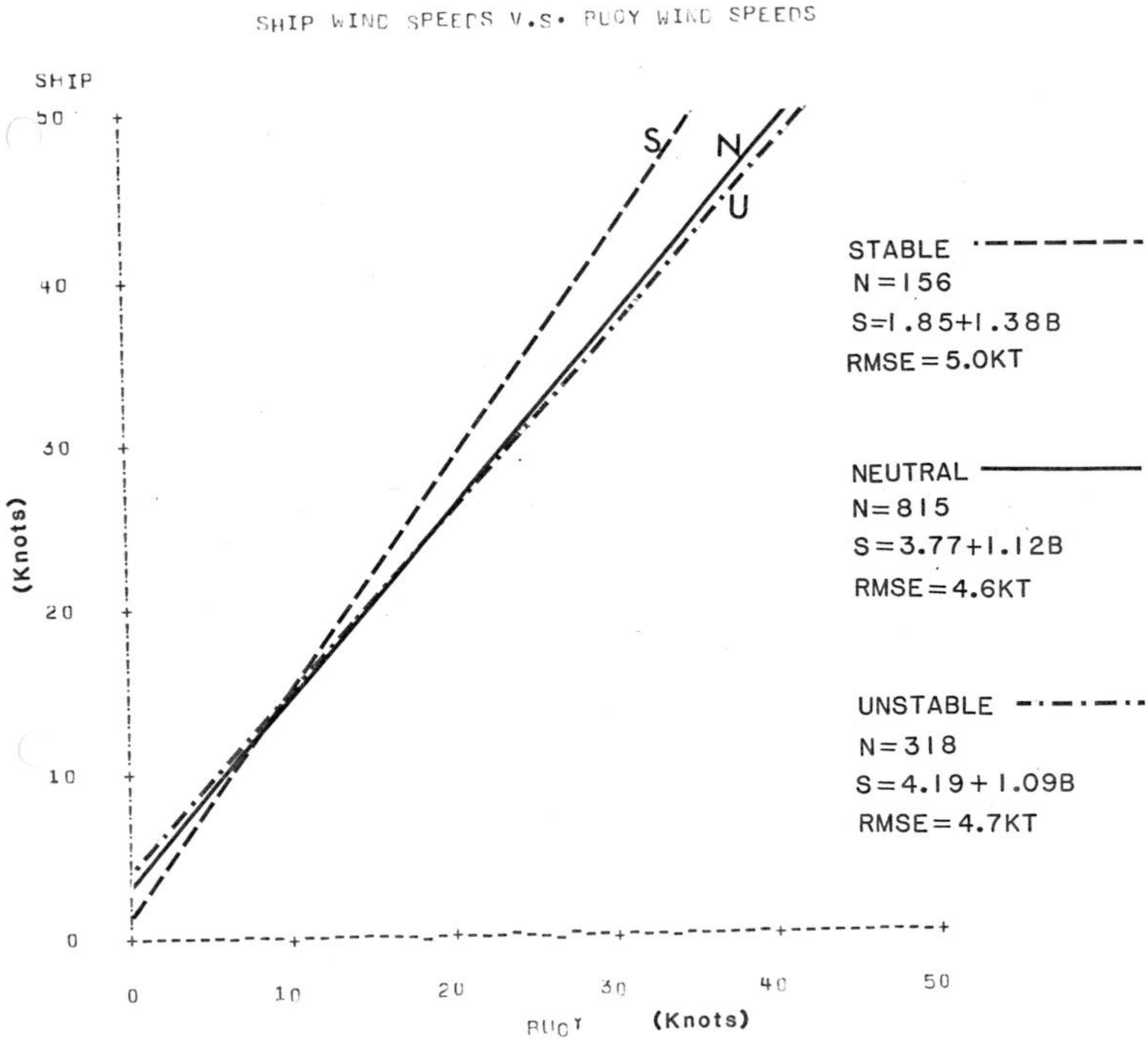

Figure 3. Regression lines for stable, neutral, and unstable conditions. The regression lines were determined by the method of least squares; they give ship wind speed (S) as a function of buoy wind speed (B). The associated correlation coefficients are 0.75, 0.78, and 0.77 for stable, neutral, and unstable conditions respectively.

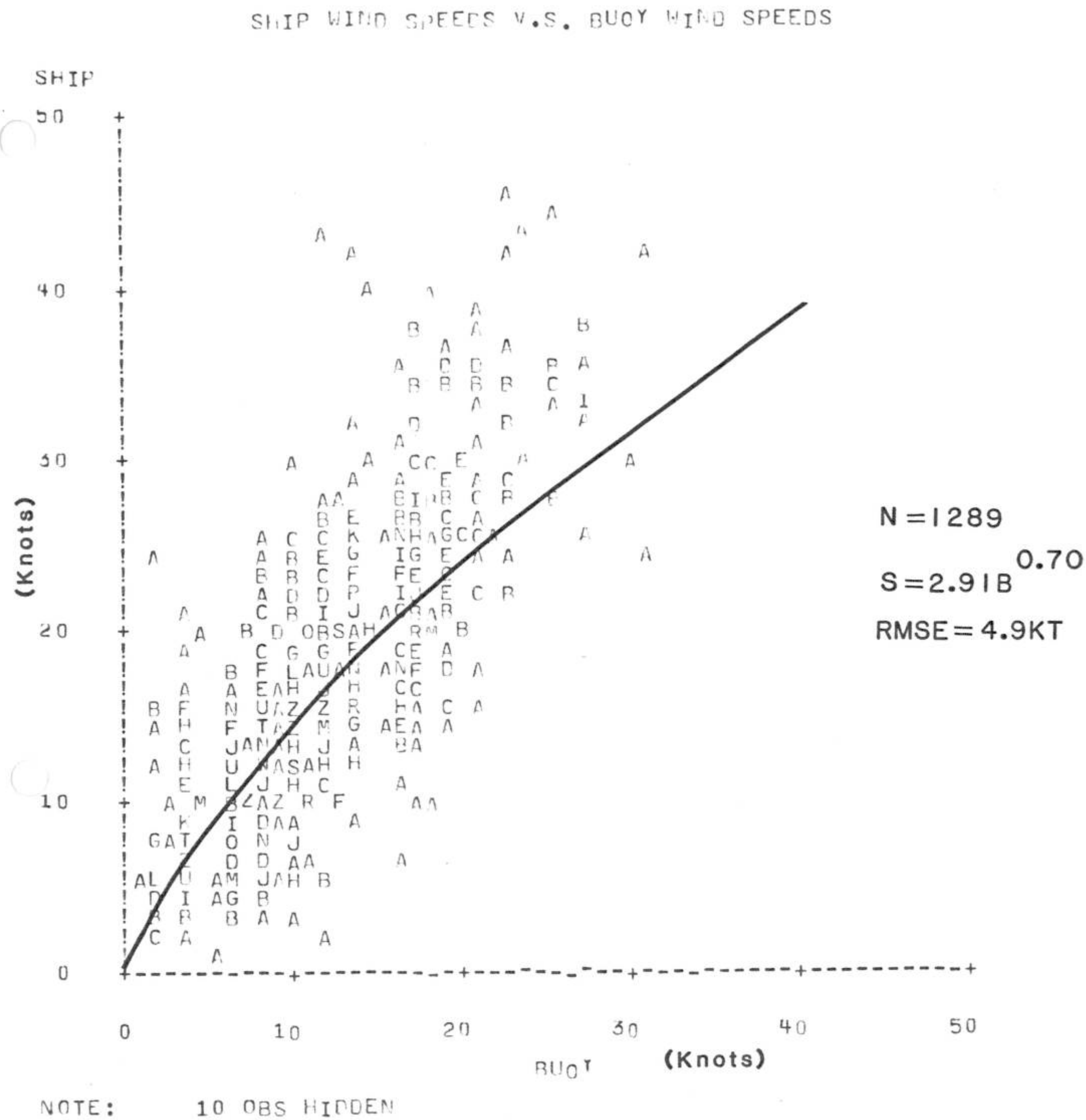

Figure 4. Plot of observed wind speeds at Great Lakes data buoys and the corresponding wind speeds observed on nearby ships. The exponential curve shown was determined by the method of least squares and logarithmic transformation of the buoy and ship wind speeds. The curve gives the ship wind speed (S) as a function of the buoy wind speed (B). The associated root-mean-square error is 4.9 kt.

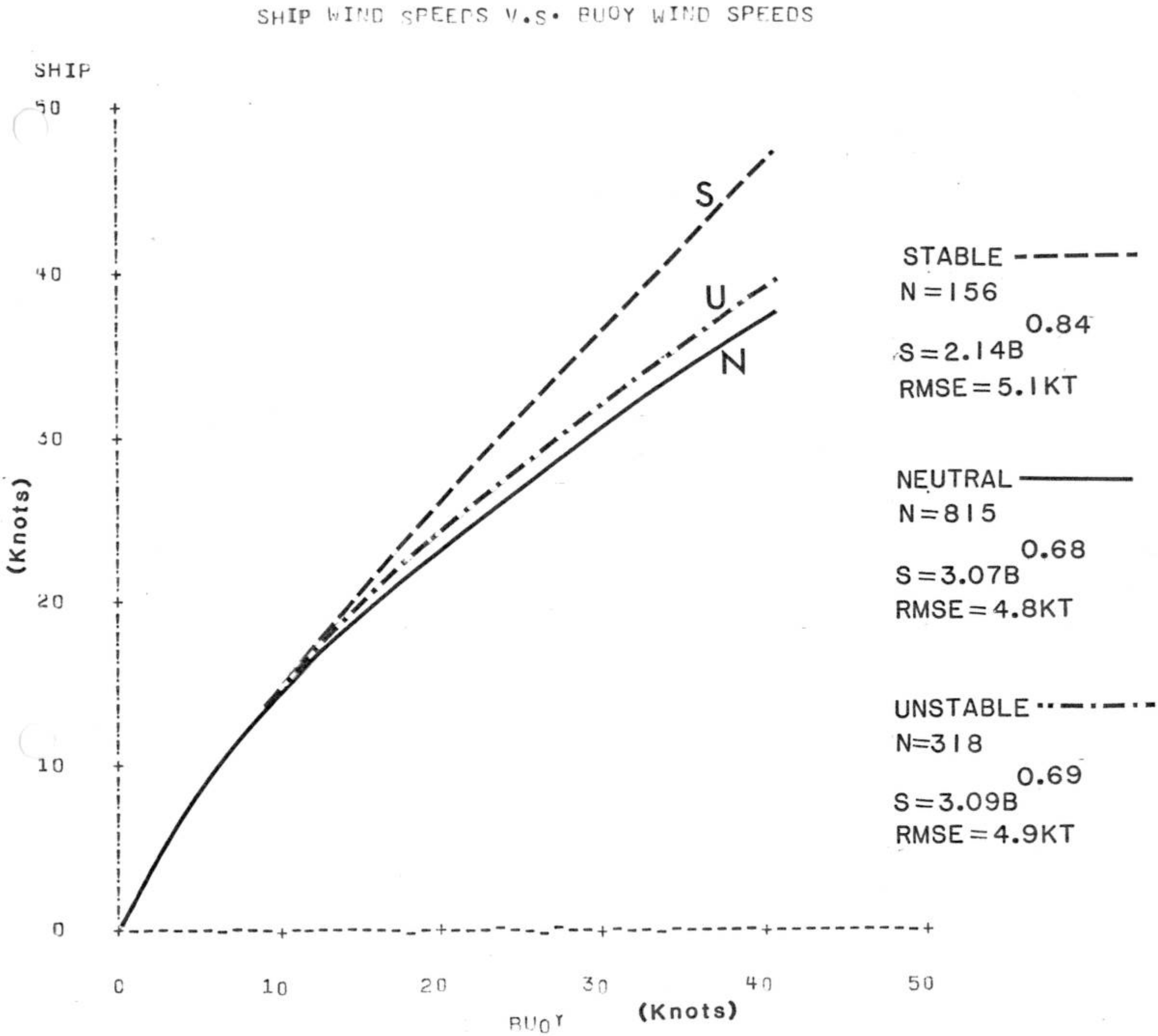

Figure 5. Exponential curves for stable, neutral, and unstable conditions which give ship wind (S) as a function of buoy wind speed (B). The curves were determined by the method of least squares and logarithmic transformation of the buoy and ship wind speeds. Associated root-mean-square errors are 5.1 kt, 4.8 kt, and 4.9 kt for stable, neutral, and unstable conditions respectively.

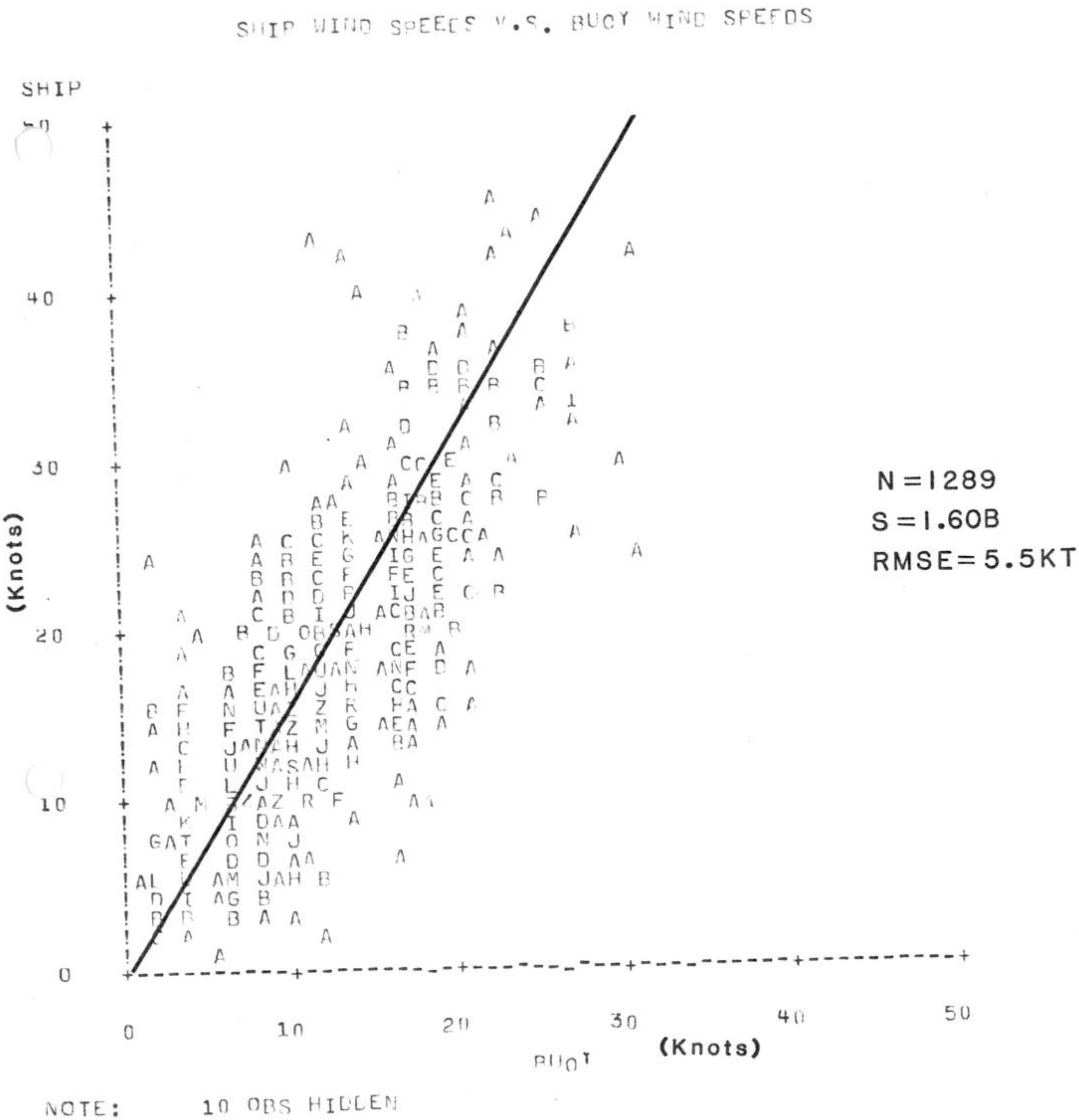

Figure 6. Plot of observed wind speeds at Great Lakes data buoys and the corresponding wind speeds observed on nearby ships. The line shown has a slope of 1.60, which is the mean ratio of ship wind speed to buoy wind speed. The line gives the ship wind speed (S) as a function of the buoy wind speed (B). The associated root-mean-square error is 5.5 kt.

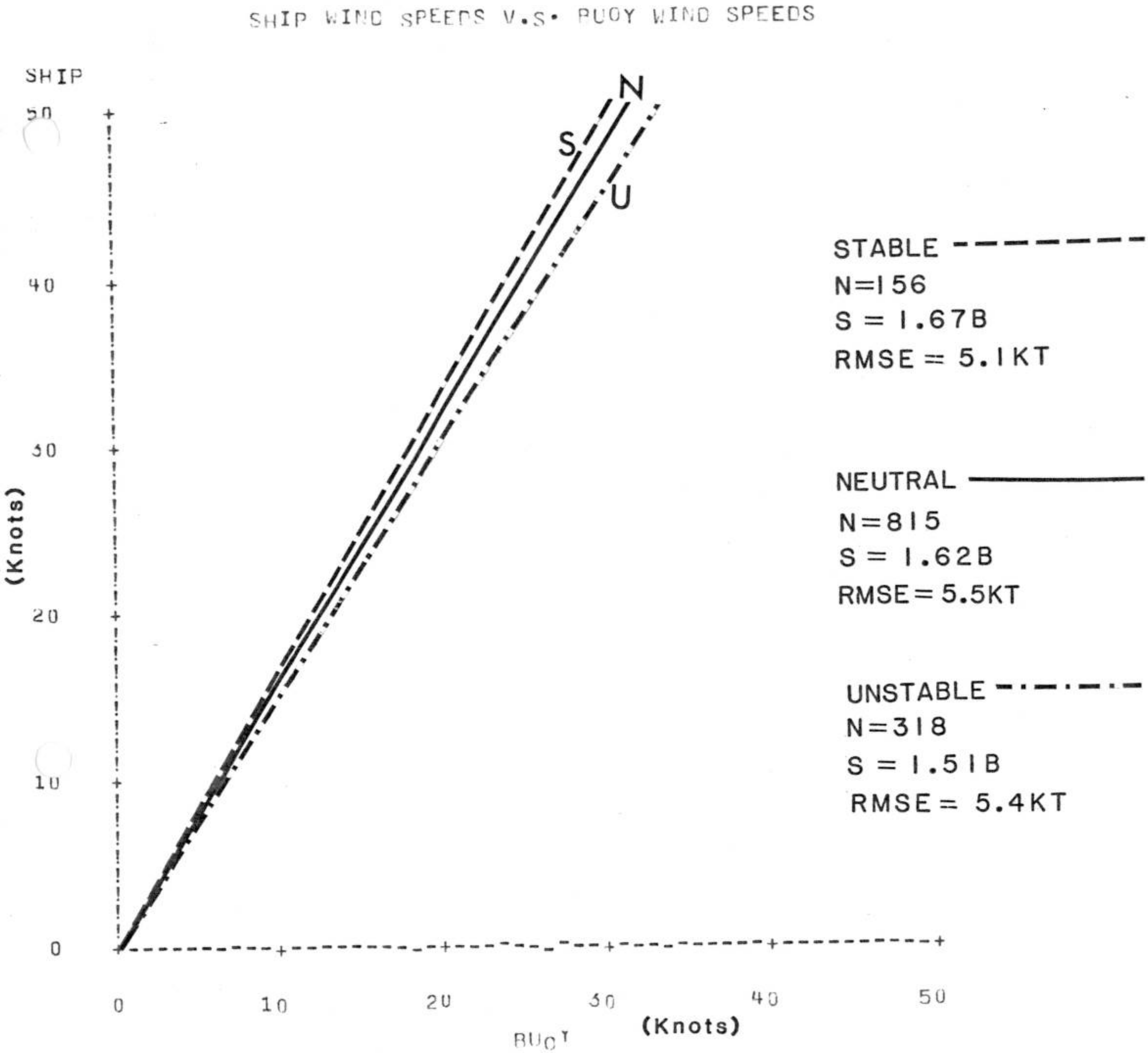

Figure 7. Lines which give ship wind speed (S) as a function of buoy wind speed (B) for stable, neutral, and unstable conditions. The lines have slopes of 1.67, 1.62, and 1.51, which are the mean ratios of ship wind speed to buoy wind speed for stable, neutral, and unstable conditions respectively. Associated root-mean-square errors are 5.1 kt, 5.5 kt, and 5.4 kt.

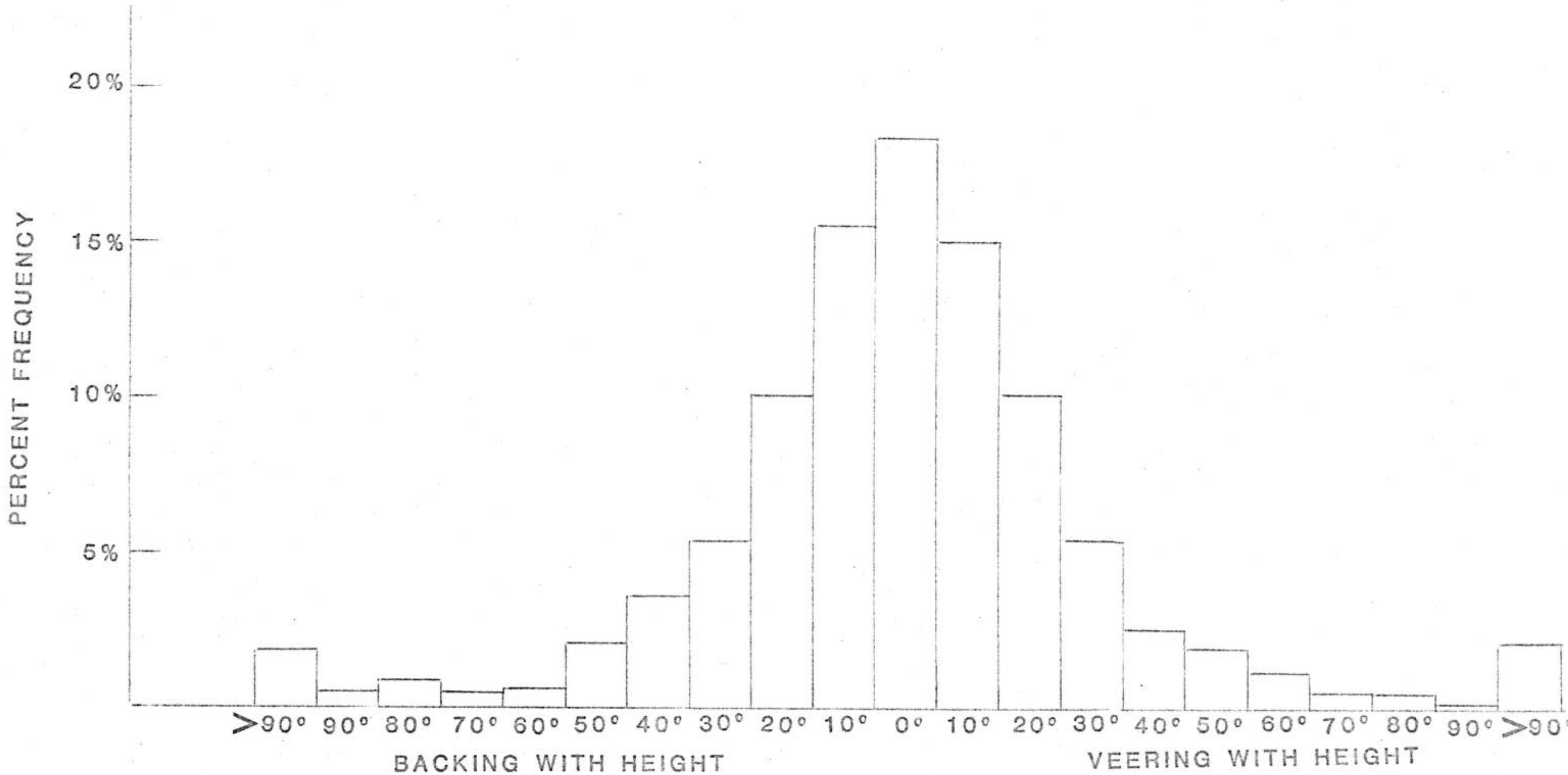

Figure 8. Frequency distribution of direction difference between wind observed on Great Lakes ships and buoys.