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# Response to Comment on "Global Trends in Wind Speed and Wave Height"

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# Response to Comment on "Global Trends in Wind Speed and Wave Height"

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We acknowledge that the special sensor microwave/imager (SSM/I) studies identified by Wentz and Ricciardulli were overlooked. These studies report wind speed trends 1.4 to 2.4 times smaller than our altimeter data. However, the reported altimeter wind speed trends are consistent with limited buoy data and exhibit scatter consistent with the calculated error statistics.

We would like to thank Wentz and Ricciardulli (*1*) for bringing to our attention the Wentz *et al.* (*2*) and Tokinaga and Xie (*3*) results, which add a valuable additional data set to the discussion of wind speed trends.

Let us first consider the relative magnitudes of the trends reported. Because differences in spatial variation make such comparisons difficult, the global average trend in mean wind speed has been used as the reference. Wentz *et al.* (*2*), in a paper that concentrates on evaporation and precipitation, report a global mean trend of 0.08 $ms^{-1}$ $decade^{-1}$ (1987 to 2006) using special sensor microwave/imager (SSM/I) data. Tokinaga and Xie (*3*)—in a paper that appeared when our paper, Young *et al.* (*4*), was in press—report 0.134 $ms^{-1}$ $decade^{-1}$ (1988 to 2008) for SSM/I data. When calculated for the altimeter data in (*4*), the global mean trend is 0.192 $ms^{-1}$ $decade^{-1}$ (1991 to 2008). The National Centers for Environmental Prediction (NCEP) model data reported in (*4*) yields 0.108 $ms^{-1}$ $decade^{-1}$ (1991 to 2008), or 0.150 $ms^{-1}$ $decade^{-1}$ if the Indian Ocean is excluded. In summary, the altimeter data set in (*4*) produces trends 1.4 to 2.4 times as large as the reported SSM/I data, rather than the 2.5 to 5 times stated by Wentz and Ricciardulli. Figure 14 of Tokinaga and Xie (*3*) does suggest that the trend may be stronger in recent years, a result supported by the present altimeter data. This may account for some of these differences, noting that (*4*) uses data from more recent years.

In conducting such long-term trend assessments, an essential requirement is that there is a consistently validated and calibrated data set over the period. Changes in satellite orbit, instrumentation, and instrumental drift can easily result in influences as large as any trends that may exist. In the case of the altimeter database, a consistent multiplatform validation and calibration exists over the full period of the study (*5*). For these reasons, we believe that the database of Zieger *et al.* (*5*) provides a high-quality database for such studies.

The SSM/I data set reported by Wentz *et al.* (*2*) has also been the subject of calibration and validation studies (*6*). Numerous studies of radar altimeter winds (*5*) indicate that the root mean square (RMS) error for such measurements is between 0.8 m/s and 1.5 m/s, depending on the retrieval algorithm used. Wentz (*6*) reports an SSM/I RMS error of 0.9 m/s. Hence, these calibrations indicate comparable performance from the instruments. We do not believe that one can infer that one instrument is superior, based on these comparisons with in situ data. Both instruments have limitations in the recovery of the wind speed. The SSM/I retrieval process yields the wind stress rather than the wind speed. Numerous studies have considered the variability of the drag coefficient $C_d$ as a function of wind speed (*7–11*). As reported by Babanin and Makin (*11*), $C_d$ can vary by an order of magnitude for a given value of wind speed. Similarly, the altimeter transfer function is a nonlinear function of radar cross section and, hence, as indicated by (*4*), the measurement of wind speed is less accurate than wave height.

Wentz and Ricciardulli (*1*) state, "Young *et al.* give no error estimates on their results." This statement overlooks the extensive analysis of statistical variability in the supporting online material for (*4*). Notably, this analysis recognizes that the statistical variability of the trend estimate depends on both the accuracy of the measured data and the chosen trend extraction method. Because (*1*) and (*4*) use different trend extraction methods, this may also account for some of the differences.

Wentz and Ricciardulli plot the data from table 1 of (*4*) and state that the comparison between altimeter- and buoy-derived values of trend indicates large errors in the altimeter estimates. This figure is reproduced in Fig. 1. The 1:1 correlation line is shown along with the 95% confidence limits reported in (*4*) (i.e., ±0.264 $ms^{-1}decade^{-1}$). It should be noted that because the RMS error for SSM/I data is similar to that of the altimeter data, the 95% confidence limits on SSM/I estimates will be comparable in magnitude. Figure 1 shows that the data scatter is consistent with the confidence limits, and the data scatters about the 1:1 line with 9 of 12 points within the 95% confidence limits. Because the data set is small and the scatter significant, we do not claim that this validates the altimeter data, only that the results are comparable. If the altimeter values in this figure were reduced by a factor of 2, to be consistent with the SSM/I results, all the data points would fall below the 1:1 line. That is, the SSM/I data, as reported, would be significantly smaller than the buoy data. Hence, we conclude that the altimeter results are consistent with the in situ buoy data.

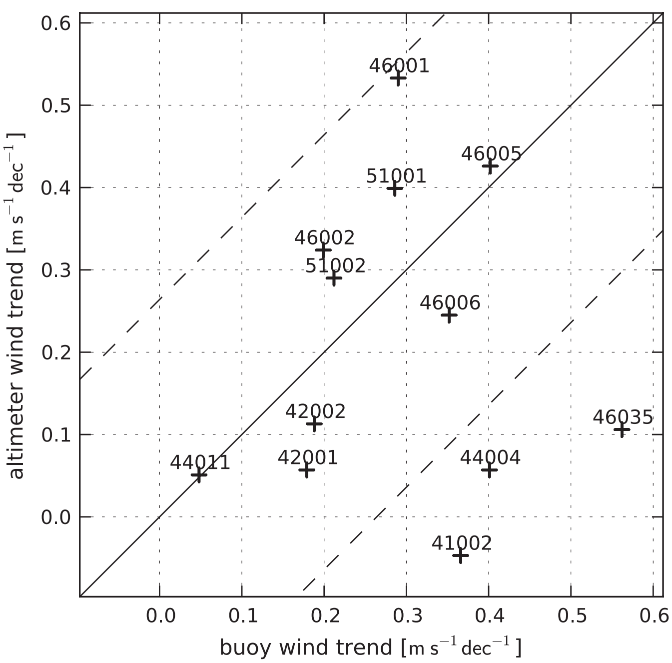


**Fig. 1.** Scatter plot of trends in mean wind speed from table 1 of Young *et al.* (*4*). Dashed lines show 95% confidence limits (±0.264 $ms^{-1}$ $decade^{-1}$) as reported in (*4*).

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Wentz and Ricciardulli indicate that the reported trends are inconsistent with our knowledge of evaporation. Because the difference between the trends in (*4*) and the SSM/I results is smaller than assumed in (*1*), the strength of this criticism obviously is reduced. However, we should point out that evaporation is a complex physical process depending on other parameters—including sea surface temperature, ocean mixing, and humidity—in addition to wind speed. Therefore, we do not believe it prudent to discard the altimeter-derived trends, based on the inferred impact on evaporation.

In terms of 90th and 99th percentile results, Wentz and Ricciardulli state that based on the challenges of sampling extreme events accurately, they "find it hard to place much credence on the claim that high winds have increased..." This statement ignores the very detailed analysis undertaken by us in (*4*), considering the validity of high–wind speed altimeter measurements, the impact of sampling size, and variation over time. This was a comprehensive analysis, which should not be discarded without basis.

In summary, the results of Young *et al*. (*4*) indicate trends 1.4 to 2.4 times as large as SSM/I data, rather than 2.5 to 5 times as stated by Wentz and Ricciardulli. These trends are consistent with the buoy data reported in (*4*), with the scatter also consistent with the error statistics in (*4*). The variability in these results, and indeed between the SSM/I data as reported by different authors, indicates that further study is required. The combined use of altimeter, SSM/I, and scatterometer (as longer data sets become available) will provide an invaluable data set.

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