Reply

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As indicated earlier (Wu 1988), we all owe much to Professor Monahan and his associates for providing the air-sea interaction community with most of the available field data on whitecaps. I have indeed taken advantage of the richness of their data in one subject area of my research, the sequence of events associated with whitecaps, bubbles, and spray. It is a privilege to receive their comments (Monahan and Woolf 1989); it also provides me the opportunity to further clarify some of our disagreements on the analysis, and therefore lead to the best use, of those valuable data.

The comments offered by Monahan and Woolf (1989) are quite detailed. Let me attempt to divide them into groups for a better understanding.

MIZEX data. It should be said at the onset that MIZEX data were not included in my final analysis (Wu 1988).

Both sets of MIZEX data were contained in a Whitecaps and Marine Atmosphere Report (Doyle 1984); this type of report has been treated by Professor Monahan and his co-workers as a publication. Examples of such were shown in Monahan and O'Muircheartaigh (1986), and again here in Monahan et al. (1985) and Monahan and Woolf (1986). The MIZEX data were also cited in the last two publications. Differences between the two sets of MIZEX data, obtained respectively with film and video recordings, were not discussed in any of their publications; in fact, both sets were regarded as providing the same results.

As stated by Monahan and Woolf (1989), the difference between the two types of data, video versus film, can be as great as $12\ m^2/0.4\ m^2 = 30$ times at the wind velocity of 10 m s^{-1}. This difference was, as discussed by them, actually caused by procedures selected in identifying the whitecapping area. First, one wonders should such a huge difference call for a rethinking of all reported whitecap data. Then, maybe more fortunately, the reported video and film data were shown to be off by a factor of only 2 not 30 (Wu 1988). In any event, Professor Monahan may wish to present elsewhere a fuller and sounder account of the difference in video and film recordings of whitecaps.

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Atmospheric-stability effects. In order to take into account effects of the atmospheric stability on whitecaps, Monahan et al. (1988) proposed the following

$$W = 2.92 \times 10^{-7} U^{3.204} \exp(0.198 \Delta T) \qquad (1)$$

where W is the fractional area of the sea surface covered by whitecaps, U the "so-called" deck-height wind velocity in m s^{-1}, and ΔT the sea–air temperature difference in °C. This formula is similar to that proposed by Monahan and O'Muircheartaigh (1986), except there are slight differences in numerical coefficient and exponents. Unfortunately, this type of expression is physically wrong, as they show that effects of the sea–air temperature difference and the wind velocity are independent of each other. More specifically, according to the above expression, the whitecap coverage would vary with the sea–air temperature difference by a factor of $\exp(0.198\Delta T)$ regardless of the wind velocity. In other words, this factor of variation say for $\Delta T = 5$°C were considered to be the same say at $U = 3$ m s^{-1} and at $U = 15$ m s^{-1}. The same incorrect physical concept can be said regarding quantitative effects of the wind velocity on the whitecap coverage, emphasizing the importance of a guided curve fitting.

Curve fitting. Much has been written by O'Muircheartaigh and Monahan (1980, 1986) on the topic of curve fitting; they have discussed at length statistical aspects of the relationship between oceanic whitecap coverage and wind velocity. This portion of Monahan and Woolf's (1989) comment is along the same line. We had an earlier exchange on this (O'Muircheartaigh and Monahan 1980; Wu 1982); the line proposed by the so-called "strict statistical fitting" was shown not providing a close representation of the data. Without showing repeatedly those sets of data, it may be instructive to discuss the most recent results reported by Professor Monahan's group collected during the HEXOS project (Humidity Exchange over the Sea); see Fig. 1. The solid straight line fitted with the same computer program and shown in the figure was expressed as (Katsaros and Smith 1987)

$$W = 1.146 \times 10^{-6} U_{10}^{2.881} \qquad (2)$$

where U_{10} is the wind velocity measured at 10 m above the mean sea surface and expressed in m s^{-1}.

Examining Fig. 1 closely, we "see" that those 27

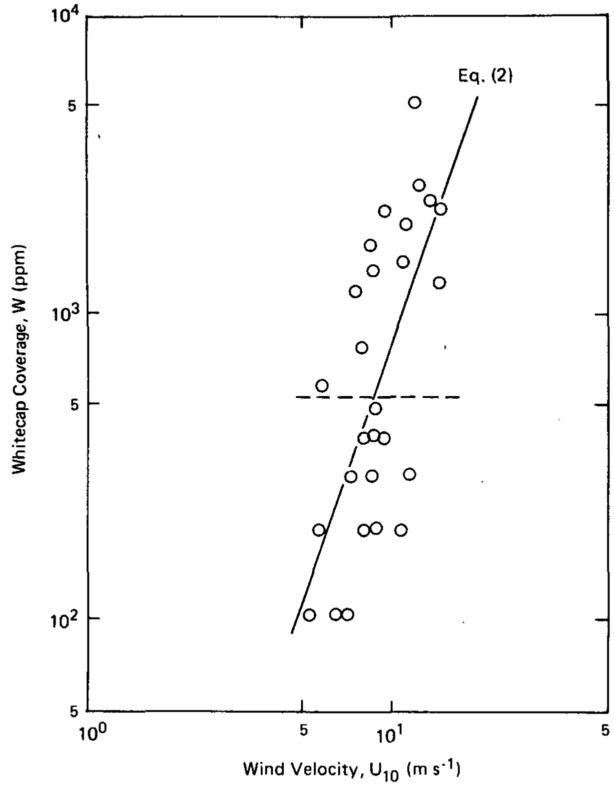

FIG. 1. Increase of whitecap coverage with wind velocity. The data and Eq. (2) were from Monahan (Katsaros and Smith 1987).

data points can be divided by the short, horizontal dashed line into two halves. Points in the upper half are now seen to lie almost exclusively above the fitted line, while those in the lower half below the fitted line. In order to rectify this systematic error, the fitted line must rotate counter clockwise to make its slope steeper; in fact, the data in this case appear to follow a line having a slope even slightly steeper than our suggested value of 3.75 (Wu 1979). In any event, this is what we contend to be typical in curves fitted to the whitecap data reported by Professor Monahan's group; the line simply under-represents the rate of whitecap coverage varying with the wind velocity (Wu 1982, 1988). This discussion is, of course, valid regardless of whether the data are presented in linear or logarithmic scales. (The ill-representation of the fitted line was blamed on the distortion due to use of logarithmic scales at a recent Advanced NATO Workshop on HEXOS.)

Water-temperature effects. Effects of the water temperature on the whitecap coverage was discussed qualitatively in Wu (1979) and then quantitatively in Wu (1988). In the latter, the primary influence due to the wind stress was first removed. Subsequently, the variations of the residual was associated with the water temperature. Otherwise, true effects of the water temperature were hidden as in the analysis of Monahan and O'Muircheartaigh (1986), and cannot be evaluated.

Needless to say, the second point made by Monahan and Woolf (1989) is rather strange. They suggested that the water temperature was actually used as a parameter to represent the effects of the wave age.

Proper presentation. I am honored to receive credit from Monahan and Woolf (1989) for early on establishing (Wu 1979) $U^{3.75}$-law with the data of Monahan (1971) and Toba and Chaen (1973) and subsequently setting out (Wu 1988) the U_*^3-law based on a further consideration of these data and the additional data presented in Monahan et al. (1981) and Doyle (1984). More importantly, however, I would prefer to express my appreciation and give credit to those who provided data and those who worked ahead of me.

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