6.1 OCEANIC WHITECAPS AND THE 10m-ELEVATION WIND SPEED: TOWARD IMPROVED POWER-LAW DESCRIPTIONS FOR USE IN CLIMATE MODELING

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1. INTRODUCTION

A number of current models for the air-sea exchange of radiatively important gases, and for the rate of production at the sea surface of marine aerosol particles, are cast in terms of the fraction of the ocean surface instantaneously covered by whitecaps. Since whitecap coverage can be inferred from satellite data, e.g. the enhanced microwave brightness temperature of the sea surface, such expressions are of immediate use to the remote sensing community. For many other modelers, a gas transfer coefficient, or sea surface aerosol flux, expressed in terms of the 10-m elevation wind speed, and perhaps other meteorological parameters, would be of great utility.

2. DATA BASE

A recent extensive review of the literature, published and unpublished, by the authors has uncovered 262 equations describing whitecap coverage in terms of wind speed, atmospheric stability, surface water temperature, fetch, duration, wave height, wave age, and other independence environmental parameters. Some of these formulations involve upwards of two dozen such parameters. With the above mentioned applications in mind, the authors have initially focused their attention on the subset of 88 equations where the fraction of the sea surface covered by decaying foam patches, i.e. Stage B whitecaps, is described by a simple power-law in U (Eq. 1), as was first done by D.C. Blanchard in 1963.

$$W_B = C_o U^n \qquad (1)$$

These 88 $W_B(U)$ expressions were then subject to an objective culling to remove those where their originators had, *a priori*, taken the power-law exponent, n, to be a simple integer (for computational convenience), or a value based on theoretical considerations (e.g., the n of 3.75 of Wu, 1979). When the remaining list of 77 equations was further edited to remove those $W_B(U)$ expressions derived from observations where the lower atmosphere was explicitly stable, or unstable (as opposed to near-neutral), and those equations derived from the analysis of film (or video) images that were recorded when the wind was acknowledged to be of limited duration or fetch, the remaining set of equations was reduced in number to 66. Finally, when the 10 $W_B(U)$ equations based on the analysis of whitecap coverage derived from the necessarily subjective visual estimates of lighthouse keepers, and the two such equations derived from a data set where the winds had been measured aboard one ship and the whitecap observations recorded on another, were likewise struck from the list, the authors were left with 54 $W_B(U)$ power-law equations upon which to base their subsequent statistical analyses.

3. CAVEAT

Before discussing some of the findings of these analyses, it should be mentioned that the various authors responsible for these 54 $W_B(U)$ equations had recourse to only 19 W_B,U-data sets. The majority of these equations (29) were each derived from the consideration of one of 9 data sets, taken in whole are in part. The other equations (25) are based on the interpretation of 19 composite data sets, that collectively encompass at least portions of 17 different W_B,U-data sets, 7 of which have been also been treated individually. The BOXEX+ data set of Monahan (1971) was used alone or in combination with one or more other data sets in the derivation of more than 40% (23 of 54), while the East China Sea data set of Toba and Chaen (1973) was used in the derivation of almost as many (22 of 54) , of the $W_B(U)$ equations. These two data sets, taken alone or together, represent the sole data base used by the various authors in deriving 24% of the 54 $W_B(U)$ equations. The 19 W_B,U-data sets used by the various investigators in deriving these 54 $W_B(U)$ equations are described in Appendix A.

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4. RESULTS

As an initial demonstration of the utility of the extensive list of $W_B(U)$ power-law equations, the authors have taken the 47 equations associated with data sets that included surface sea water temperatures and regressed n, the power-law exponent versus the average surface water temperature, T_W. They did this because previously, using the five W_B,U-data sets which were the only ones then available to them, and applying a variety of statistical approaches, they arrived at the five n_{avg},T_W points displayed on Fig. 10 in Monahan and O'Muircheartaigh (1986). These points in turn yield Eq. 2.

$$n(T_W) = 1.750 + 0.0574\ T_W \qquad (2)$$

Applying now the same approach to the 47 n-values in the current list of $W_B(U)$ power-law equations yields Eq. 3.

$$n(T_W) = 2.272 + 0.0365\ T_W \qquad (3)$$

While Eq. 2 is based on 22 analyses of 5 W_B,U-data sets, Eq. 3 is based on the 47 analyses of no less than 15 W_B,U-data sets, taken individually or in various combinations.

And if one were to now go back to the five data sets used in Monahan and O'Muircheartiagh (1986) and limit themselves to the n-values arrived at by fitting, for each of these data sets, a straight line to the W_B,U-data pairs in log-log space (omitting any null W_B points), the resulting $n(T_W)$ expression would be that given in Eq. 4.

$$n(T_W) = 2.123 + 0.0486\ T_W \qquad (4)$$

Again applying the same approach to the 40 power-law coefficients, C, in the current list of $W_B(U)$ equations (those equations for each of which an explicit value for C was given, and whose associated data sets contained values for the surface sea water temperature) yields, based on a simple linear fit in logC,T_W space, the following Eq. 5 for $C(T_W)$.

$$C(T_W) = 4.81 \times 10^{-5} \times 10^{-0.0303T_w} \qquad (5)$$

Combining Eq. 3 and Eq. 5 results in Eq. 6, the first explicit power-law formulation of W_B in terms of U and T_W:

$$W_B = 4.81 \times 10^{-5} \times 10^{-0.0303T_w} \times U^{2.272 + 0.0365T_w} \quad (6)$$

5. CONCLUSIONS

The current finding, as summarized in Eq. 3, validates the previous result as to the apparent T_W-dependence of n. As was pointed out in Monahan and O'Muircheartaigh (1986), "both typical wind duration and mean sea water temperature vary latitudinally". As the latitude increases, the wind duration, and the mean surface water temperature, tend to decrease. While other factors may well be involved, and are enumerated in the 1986 paper, the authors posit that it is the typical decrease in wind duration with increasing latitude that is the primary cause of the finding summarized in Eq. 3.

In the absence of time series data documenting the duration of the local wind, Eq. 6 is put forward as a preferred expression for estimating W_B from current U and T_W measurements.

6. APPENDIX A

The 19 Stage B whitecap data sets used singly, or in combination, by the various authors in deriving the 54 $W_B(U)$ power-law expressions used in the current analysis were as follows:

1. Great Lakes (i.e. fresh water) : Monahan (1969), 20 obs.
2. BOMEX Plus: Monahan (1971), 70 obs.
3. East China Sea: Toba and Chaen (1973), 48 obs.
4. Atlantic O. Plus: Ross and Cardone (1974), 13 obs.
5. JASIN: Monahan and O'Muircheartaigh (1980), 57 obs.
6. Bight of Abaco: Snyder et al (1983), 39 obs.
7. STREX: Doyle (1984), 85 obs.
8. MIZEX83: Monahan et al (1984), 43 obs.
9. MIZEX84: Monahan and Woolf (1986), 56 obs.
10. Bo Hai: Wang et al (1990a, 1990b), 40 obs.
11. FETCH98: Lafon et al (2004), 45 obs.
12. EMMA01: Lafon et al (2007), 29 obs.
13. Typhoon75: R.S. Bortkovskii (pers. comm.), 45 obs.
14. Monsoon77: R.S. Bortkovskii (pers. comm.), 24 obs.
15. Typhoon78: R.S. Bortkovskii (pers. comm.), 15 obs.
16. R/V Bugaev (N. Atlantic O.): R.S. Bortkovskii (pers. comm.), 23 obs.

17. R/V Prof. Zubov (Southern O.): R.S. Bortkovskii (pers. comm.), 57 obs.
18. R/V Priliv (Pacific O.): R.S. Bortkovskii (pers. comm.), 30 obs.
19. R/V Ocean (Pacific O.): R.S. Bortkovskii (pers. comm.), 22 obs.

Note: The “obs” listed with each entry are the number of whitecap observation intervals, each such interval typically included from 4 to 20 images of the sea surface.

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