The Latitudinal Variation in the Wind-Speed Parameterization of Oceanic Whitecap Coverage; Implications for Global Modelling of Air-Sea Gas Flux and Sea Surface Aerosol Generation

By

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In a recent publication Salisbury et al (2014) compared their estimates of oceanic whitecap coverage, derived from microwave measurements taken by satellite-borne radiometers, with whitecap coverage deduced from the application of one of the wind speed power-law parameterizations found in Monahan and O'Muircheartaigh (1980). Specifically, they compare their global maps of whitecap coverage with those determined using for n, the power-law exponent in Eq. 1, the value of 3.41, as obtained by Monahan and

$W_B = C\, U^n$, where U is the 10-meter elevation wind speed. Eq.1

O'Muircheartaigh via the application of the technique of robust biweight fitting to the whitecap data found in Monahan (1971) and Toba and Chaen (1973).
A comparison between the whitecap coverage as deduced at a microwave frequency of 37GHz and that deduced using Eq.1 above is found in Fig. 3b of Salisbury et al (2014). We focus on this comparison as the microwave measurements at this frequency detect whitecap foam as thin as 1 mm, and thus should correspond roughly to the Stage B whitecaps (decaying foam patches) analyzed by Monahan and O'Muircheartaigh (1980). It is apparent from this figure of Salisbury et al that MM80 (their notation) overestimates whitecap coverage at both the high northern and high southern latitudes. Those authors conclude that Eq.1 incorporates too high a wind speed dependence of whitecap coverage at such high latitudes. This conclusion is consistent with the discussion found in Monahan and O'Muircheartaigh (1986) where, looking at the n's associated with 5 data sets, they detected a diminution in n with decreasing surface sea water temperature (SST), and concluded that this was a reflection of the general decrease in SST with increase in latitude. (MM86 attributed this latitude dependence of n primarily on the latitudinal variation of the characteristic duration of high wind speed events.)

The current authors have, in the work presented here, made use of 14 Stage B whitecap data sets (each resulting from the manual analysis of photographs), and 1 data set recently collected in the Southern Ocean involving high resolution digital images (and the use of an automatic analysis protocol). A simplified listing of the relevant Southern Ocean whitecap data can be found in Appendix A of this paper.

The initial test involved using all of the non-null W_B,U data points from these 15 data sets, having first sorted them into two categories by temperature, i.e. SST > 15^0C and SST < 15^0C. The result is illustrated in Fig. 1, where the n(SST > 15^0) = 3.53, and the n(SST< 15^0) =2.89. It is noted that Monahan and O'Muircheartaigh(1980), analyzing only two W_b data sets, for both of which SST > 15^0C, by ordinary least squares fitting, had arrived at an n-value of 3.52. It should also be noted that these n-values are all greater than the n-values obtained by Salisbury et al (2014) for their W_{37}(and W_{10}) power-laws.

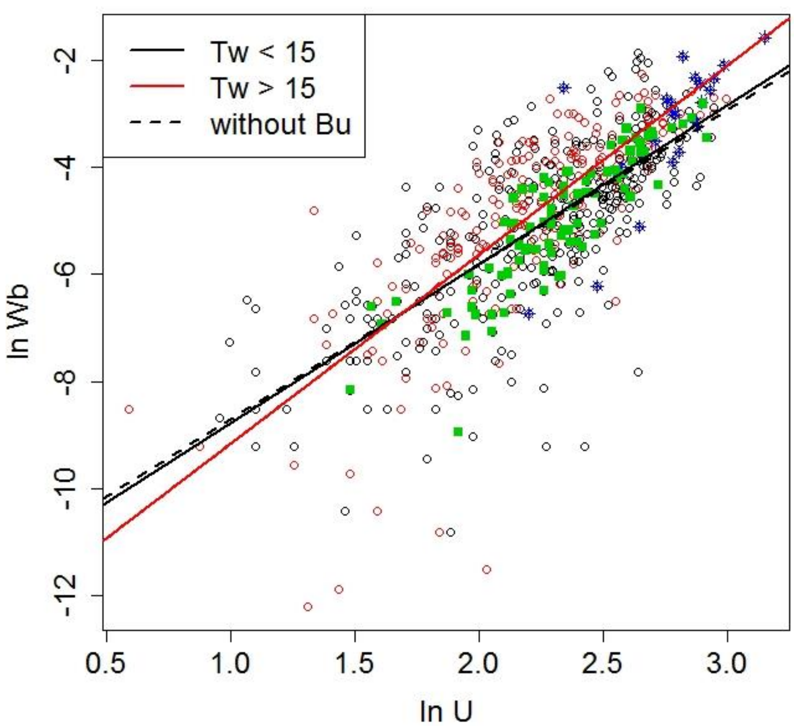

Figure 1. ln W_B vs ln U, for SST > 15^0 C and SST< 15^0C. Green dots: from high resolution digital imagery taken in the Southern Ocean.

The slopes of these two lines on this log-log plot, i.e. the two n's, are significantly different (P = 0.01625).

A further analysis was conducted using that subset of 8 W_B-data sets for which the current authors had information on the mean latitude of the observations. A three-dimensional graphical summary of these results is shown in Fig. 2. Note here that results from both hemispheres are plotted along the same branch of the x axis, i.e. what is plotted here is the absolute value of latitude. When one looks at the intersection of the gray "data surface" in this figure with the left-hand (high (absolute) Lat.) wall of this "data cube" one sees that the slope of this intersection, i.e. the high Lat. n, is much less than the slope of the intersection of this "data surface" with the right-hand (low (absolute) Lat.) wall of this "data cube", i.e. the low Lat. n. Thus we see that n does decrease with increasing (absolute) latitude. It should be acknowledged that the “twist” with latitude of this "data surface" is only marginally significant, but it is consistent with the findings illustrated in Fig. 1, where the difference between the "cold water" and "warm water" n's is significantly different.

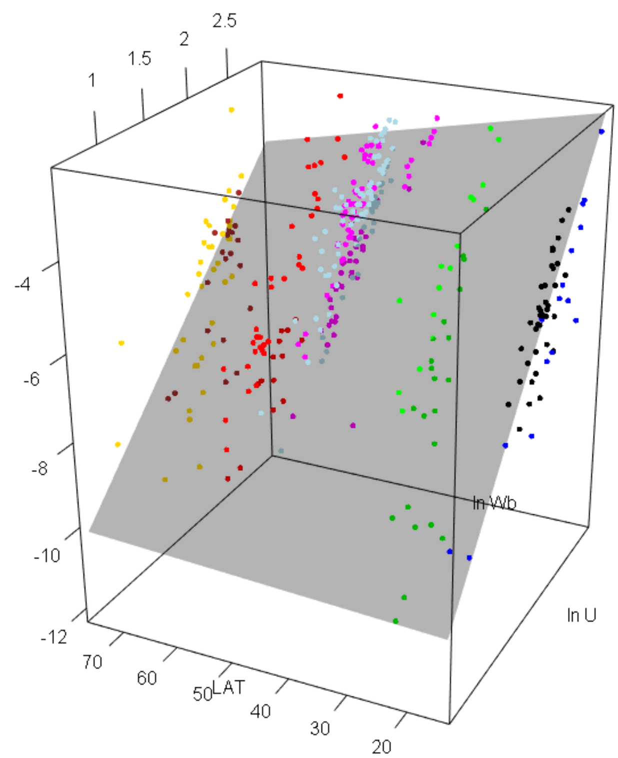

Figure 2. 3-D plot of absolute latitude (x-axis); ln U, where U is the 10 m-elevation wind speed (y-axis); and $\ln W_B$, where W_B is the simple fraction of the sea surface covered by decaying foam patches (z-axis). Key: BOMEX+ = black, BOMEX(Flip) = blue, S. China Sea (Toba & Chaen) = green, JASIN = red, MIZEX83 = brown, MIZEX84 = gold, STREX (Doyle) = light blue, and Southern Ocean (Zappa) = magenta.

A series of air-sea gas transfer models, beginning with Monahan and Spillane (1984), have parameterized the gas transfer coefficient, or “friction velocity”, explicitly in terms of the fraction of the sea surface covered by Stage B (current usage) whitecaps. If such a model is to be evaluated where, of necessity, wind speed is being used as a surrogate for W_B, then it is critical that the latitude-appropriate exponent, n, be used in assessing W_B from Eq. 1. Most of the early studies of k(trans. coeff.) as a function of W_B used photographs, or digital systems working in the visible portion of the E-M spectrum, to estimate W_B. If W_{37}, or some other microwave frequency measurement of whitecapping, is to be substituted in such parameterizations for k, a robust relationship, i.e. an inter-calibration, between W_B and $W_{\mu wave}$ need be established.

Grythe et al (2014) and others have recently concluded that the Monahan et al (1986) sea surface aerosol source function is still "the most widely used source function", and one of the terms in this function is W_B. While clearly the substitution in this function, or in modifications of it, of a climatologically derived W_B-expression, or W_B-values from satellite-derived synoptic maps, is to be encouraged, but again a clearer understanding of the W_B,$W_{\mu wave}$ relationship is needed.

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Appendix A: Table of Southern Ocean GasEx Whitecap Data

Obs. No.	U(m/sec)	T_A(°C)	T_W(°C)	W_B[1]
1	7.2	5.27	6.33	0.00134
2	10.7	5.01	5.31	0.00456
3	8.2	3.89	3.36	0.00121
6[2]	11.8	8.02	6.20	0.00637
7	9.9	7.50	6.50	0.00368
8	11.2	6.02	5.21	0.00410
9	11.0	6.03	5.91	0.00453
10	10.2	8.89	5.82	0.00237
11	10.3	7.71	5.65	0.00244
12	9.3	6.38	5.69	0.00397
13	11.8	6.60	5.43	0.00522
14	10.3	6.41	5.41	0.00510
15	10.4	6.51	5.74	0.00571
16	9.6	6.60	5.69	0.01051
17	9.6	7.09	5.61	0.00290
19	8.5	6.81	5.58	0.01029
20	5.0	7.72	5.73	0.00097
21	7.2	8.38	5.99	0.00184
22	9.6	5.24	5.72	0.00264
23	8.3	5.40	5.62	0.00250
24	8.4	3.27	2.65	0.00172
25	14.2	3.05	2.91	0.02752
26	14.6	3.04	2.98	0.03284
27	14.4	2.81	3.14	0.02463
28	13.9	2.68	3.19	0.03156
29	12.4	2.09	3.29	0.01674
30	9.6	2.97	3.22	0.00182
31	12.1	4.09	3.20	0.00642
33	11.0	3.15	3.26	0.01107

34	12.9	6.72	5.76	0.01493
35	13.6	6.59	5.86	0.01056
36	8.4	6.15	5.17	0.00470
37	11.4	4.99	4.99	0.01135
38	9.1	5.83	4.96	0.00591
39	9.9	5.70	4.95	0.00707
40	7.8	5.35	5.01	0.00117
43	13.2	2.49	4.84	0.03038
45	12.6	3.15	5.03	0.02785
46	14.8	6.47	4.79	0.03566
47	14.9	6.67	4.79	0.03307
48	13.6	7.02	4.81	0.02481
49	13.2	6.71	4.79	0.01609
50	13.3	6.86	4.77	0.01218
51	7.8	4.09	4.60	0.00085
53	7.0	2.55	4.97	0.00079
55	8.7	4.09	4.90	0.00427
56	9.2	3.77	4.83	0.01232
57	9.9	3.95	4.01	0.00852
59	9.0	5.08	4.88	0.00400
60	8.3	5.22	4.90	0.00258
61	9.6	5.22	4.90	0.00654
62	10.6	4.69	4.87	0.00565
63	9.8	4.93	4.92	0.00437
64	11.8	3.43	5.22	0.01127
65	11.6	3.37	4.88	0.01623
66	10.4	3.17	4.90	0.01289
67	13.4	3.37	4.84	0.03775
68	14.2	3.18	4.76	0.05481
69	10.5	1.96	4.86	0.01680
70	9.6	1.82	4.75	0.01503
71	9.8	1.84	4.78	0.01378
72	8.8	1.91	4.77	0.01214
73	8.2	1.99	4.77	0.00660
74	8.5	2.25	4.76	0.00647
75	10.8	6.19	4.89	0.00894
76	9.9	5.39	4.77	0.00627
77	9.9	3.17	4.53	0.00741
82	7.7	2.18	4.85	0.00277
83	10.6	2.21	4.77	0.01684
84	10.4	2.63	4.82	0.01085
85	11.4	3.20	5.00	0.01406
86	7.1	4.45	4.91	0.00247
87	4.4	5.20	5.09	0.00029

88	4.8	5.29	5.19	0.00136
89	5.3	5.03	5.33	0.00150
91	6.5	5.57	4.77	0.00121
92	8.9	5.63	4.84	0.00390
93	8.1	5.57	4.88	0.00242
94	8.7	5.54	4.92	0.00321
95	7.3	5.72	4.97	0.00117
97	6.8	10.67	12.98	0.00013
98	15.2	11.39	13.06	0.01323
99	18.5	11.58	13.03	0.03193
100	14.2	14.52	12.75	0.02423
101	13.7	14.60	14.07	0.02042
102	14.1	15.13	14.11	0.02868
103	12.8	13.28	14.00	0.01740
104	16.8	17.04	14.82	0.04125
105	17.4	15.80	14.84	0.04606
106	18.2	15.62	14.74	0.06001
107	16.1	15.63	14.98	0.03783

Footnotes: 1) Total (Stage A + Stage B) whitecap coverage, as simple fraction; 2) Missing observations are those for which whitecap observations not recorded.