PARAMETERIZATION OF OCEANIC WHITECAP FRACTION BASED ON SATELLITE OBSERVATIONS

M. F. M. A. Albert[1], M. D. Anguelova[2], A. M. M. Manders[1], M. Schaap[1], and G. de Leeuw[1,3,4]

[1]TNO, P.O. Box 80015, 3508 TA Utrecht, The Netherlands
[2]Remote Sensing Division, Naval Research Laboratory, Washington, DC, USA
[3]Climate Research Unit, Finnish Meteorological Institute, Helsinki, Finland
[4]Department of Physics, University of Helsinki, Helsinki, Finland

ABSTRACT

Satellite-based whitecap fraction (W) data have been used to predict sea spray aerosol (SSA) emission rates. This allows to evaluate how an account for natural variability of whitecaps in the W parameterization would affect SSA mass flux predictions when using a sea spray source function (SSSF) based on the whitecap method. Data set containing W data for 2006 together with matching wind speed U_{10} and sea surface temperature (SST) T has been used. Whitecap fraction W was estimated from observations of the ocean surface brightness temperature T_B by satellite-borne radiometers at two frequencies (10 and 37 GHz). A global scale assessment of the data set yielded approximately quadratic correlation between W and U_{10}. A regional scale analysis yielded a new $W(U_{10}, T)$ parameterization which explicitly accounted for the effect of SST on W. The analysis of W values obtained with the new $W(U_{10})$ and $W(U_{10}, T)$ parameterizations indicates that the influence of secondary factors on W is for the largest part embedded in the exponent of the wind speed dependence. In addition, the $W(U_{10}, T)$ parameterization is capable to model the spread (or variability) of the satellite-based W data. The satellite-based parameterization $W(U_{10}, T)$ was applied in an SSSF to estimate the global SSA emission rate. The thus obtained SSA production rate is within previously reported estimates, however with distinctly different spatial distribution.

Index Terms— passive remote sensing, whitecap fraction, breaking waves, sea spray, brightness temperature

1. INTRODUCTION

Whitecaps are used as a proxy for the bubbles formed by breaking waves at the ocean surface. Upon bursting, these bubbles generate sea spray droplets which transform to sea spray aerosol (SSA) when they equilibrate with the surroundings. SSA particles contribute to the scattering of shortwave electromagnetic radiation and thus to their direct radiative effect on climate. Also, SSA particles are a source for cloud condensation nuclei and as such influence cloud microphysical properties and thus exert indirect radiative effects on the climate system [1]. The production rate of SSA particles is calculated with a sea spray source function (SSSF) defined as the number of SSA particles produced per unit of sea surface area per unit of time. The most commonly used SSSF is based on the whitecap method and predicts bubble-mediated production of SSA [2]. Estimates of SSA production flux using the whitecap method still vary widely [1], precluding reliable estimates of the direct and indirect effects by SSA on the climate system.

The objective of the study to be presented is to evaluate how accounting for natural variability of whitecaps in the parameterization of the whitecap fraction W would affect mass flux predictions when using a SSSF based on the whitecap method. The study uses satellite-based W data estimated from measurements of the ocean surface brightness temperature T_B by satellite-borne microwave radiometers at frequencies of 10 and 37 GHz, W_{10} and W_{37} (green and magenta symbols in Fig. 1a). Global and regional data sets comprising W_{10} and W_{37} data, wind speed U_{10}, and sea surface temperature (SST) T for 2006 were used to derive parameterizations $W(U_{10})$ and $W(U_{10}, T)$. The widely-used SSSF proposed by [2] combined with the new $W(U_{10}, T)$ was used to estimate SSA emission.

2. METHOD

Our processing approach, presented in detail in [3], involves three steps. We first assess the satellite-based whitecap database to evaluate the wind speed dependence of W in a power-law form over as wide a range of U_{10} values as possible: $W = a(U_{10} + b)^n$. Exponent n in the obtained global $W(U_{10})$ expression resulting from this analysis adjusts the trend of W with U_{10} implicitly to the concerted, globally averaged influence of all secondary factors such as atmospheric stability (often expressed in terms of air-sea temperature difference), SST, wave field, and surfactant activity [4].

We next apply the established $W(U_{10})$ expression to W data on regional scales to assess the variability caused by secondary factors in different locations during different seasons. Different regions were selected using two criteria, namely (i) regions with a high number of valid data points (100 to 300), and (ii) a selection representative of different conditions in the Northern and Southern hemispheres. With these criteria, 12 regions of interest were selected and W, U_{10}, and T data for each region were extracted from the whitecap database. We analyze the regional variations of W remaining after the implicit adjustment with the $W(U_{10})$ expression and parameterize them explicitly in terms of SST. The new $W(U_{10}, T)$ parameterization is compared to previous $W(U_{10})$ parametrizations (e.g., [5]) to assess to what extent SST can account for the W variability.

Finally, the new $W(U_{10}, T)$ parameterization is used to estimate SSA emissions and compare results to previous predictions of SSA emissions.

3. RESULTS

The global W data set can be parameterized reasonably well with a quadratic correlation between W and U_{10}, $n \approx 2$. The derived $W(U_{10})$ for both W_{10} and W_{37} replicate the trend of the satellite-based data well (black symbols in Fig. 1a). That is, the adjusted quadratic wind speed exponent in $W(U_{10})$ accounts implicitly for most of the SST variations and other forcing factors. The new quadratic $W(U_{10})$ predicts a whitecap fraction significantly different from that obtained with the widely-used $W(U_{10})$ of [5].

Applying the global $W(U_{10})$ parameterization on regional scale shows that the seasonal variations of its regression coefficients a and b are not statistically significant, while the regional variations are. On this basis, by relating annually averaged a and b values to the annually averaged T for each region, the explicit SST dependences $a(T)$ and $b(T)$ were derived. The new $W(U_{10}, T)$ parameterization is able to model the variability (spread) of the satellite-based W data (red and cyan symbols in Fig. 1a). The capability of the new $W(U_{10}, T)$ parameterization to model both the trend and the spread of the W data sets it apart from all previous $W(U_{10})$ parameterizations.

Though SST entails small variations in the trend of W with U_{10}, an important consequence of the newly derived $W(U_{10}, T)$ parameterization is that it shapes significantly different spatial distribution compared to previous $W(U_{10})$ parametrizations. Figure 1b shows a difference map between the global annual average W distributions for 2006. The $W(U_{10})$ relationship of [5] yields a wider W range with higher values in regions with the highest wind speeds. In particular, this occurs between about 40° and 70° in the Southern Ocean and in the North Atlantic. The latitudinal variations from the Equator to the poles are more

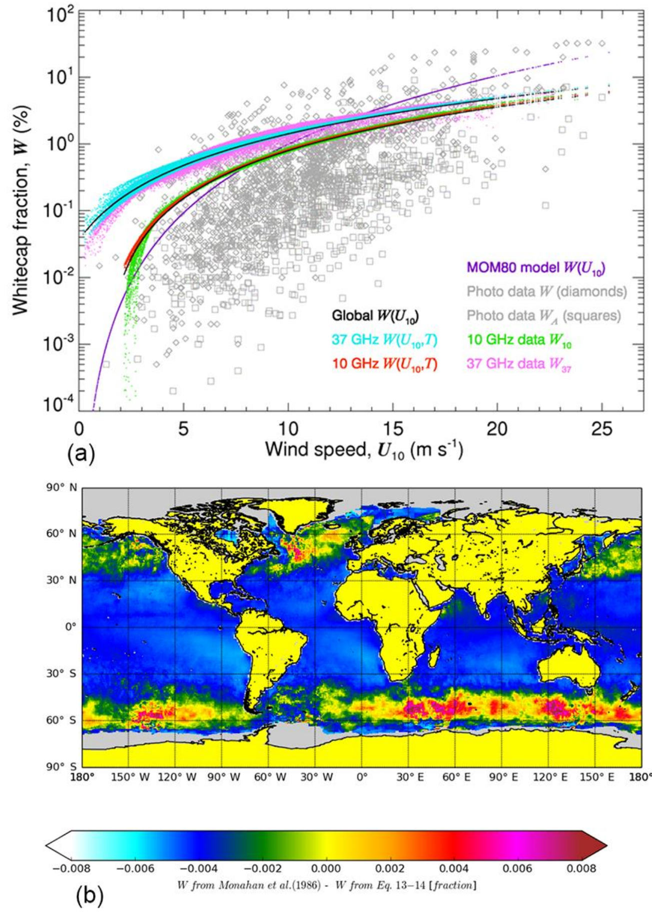

Figure 1. (a) Satellite-based W data for 17 March 2007 at 10 and 37 GHz (green and magenta symbols, respectively) compared to W values obtained from our new expressions for 10 and 37 GHz: $W(U_{10})$ (black symbols) and $W(U_{10}, T)$ for 10 (red) and 37 GHz (cyan); in situ W data (gray symbols) are shown for reference; as well as the $W(U_{10})$ of [5] (purple line). (b) Difference map of annual average W distribution for 2006 calculated using $W(U_{10})$ of [5] minus our new $W(U_{10}, T)$. The calculations use wind speed U_{10} and SST T from the whitecap database.

pronounced when using the $W(U_{10})$ relationship of [5] as compared to our $W(U_{10}, T)$ expression. The new $W(U_{10}, T)$ parameterization provides a global spatial distribution with similar patterns, but the absolute values are lower at high latitudes and higher at low latitudes.

Application of the new $W(U_{10}, T)$ parameterization in the SSSF of [2] resulted in a total (size-integrated) SSA mass emission estimate of 4.4×10^{12} kg yr^{-1} for 2006. Scaled for modeling differences, this estimate is 7.78×10^{12} kg yr^{-1}, which is comparable to previously reported estimates. Comparing our and previous total SSA emissions, we have been able to assess to what degree accounting for the SST influence on whitecaps can explain the spread of SSA emissions. SSA emissions obtained with the new $W(U_{10}, T)$ parameterization vary by ~50%. Different approaches to account for SST effect yield ~71% variations. Different models for the size distribution applied to different size ranges can yield up to 42% variations in SSA emissions.

4. CONCLUSIONS

The results show that understanding and constraining the various sources of uncertainty in the SSSF would eventually improve the accuracy of SSSF predictions. Including the natural variability of whitecaps in the SSSF using new parametrizations such as $W(U_{10}, T)$ is a viable way toward such accuracy improvement.

While the new $W(U_{10}, T)$ parameterization is able to model the trend and the spread of the satellite-based W data, the SST variations are relatively small. To model the full variability of W, future work should focus on the parameterization of the wave field effect. The extended version of the whitecap database contains wave field characteristics and is thus suitable for such quantification.

4. REFERENCES

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