Improved satellite retrievals of whitecap coverage and sea-salt aerosols

M.D. Anguelova, M.H. Bettenhausen, K. St. Germain, P.W. Gaiser, R.M. Bevilacqua

Remote Sensing Division, Naval Research Laboratory, 20375, Washington DC, USA

Keywords: marine aerosols, sea spray generation, remote sensing, satellites.

Oceanic whitecaps form when waves break and mark areas where bursting bubbles actively produce sea spray droplets, which then transform to sea-salt aerosols. Thus, dependence of sea spray generation on wind speed is usually introduced in the sea spray source function (SSSF) trough whitecap coverage *W*, e.g. *W*(*U*). Field measurements have consistently demonstrated high variability of sea-salt aerosol concentrations, which cannot be accounted for with dependence on local wind speed alone. Numerous meteorological and environmental factors affect wind energy input, sea state, and frequency of breaking waves, which in turn influence the extent and lifetime of whitecaps. Thus, models of *W* accounting for at least some, if not all, of the additional factors would provide more realistic SSSF and therefore improved prediction of sea-salt aerosol loadings into the atmosphere, which are necessary for climate models.

Existing measurements of whitecap coverage from photographs do not provide enough information to quantify the dependence of *W* on other, in addition to wind speed, environmental and meteorological variables. Method using passive microwave satellite measurements to retrieve *W* on a global scale under various conditions encountered in world ocean has been developed (Anguelova, 2002) as an alternative. Sea spray number flux estimated with satellite-retrieved *W* reveals magnitude similar to and global distribution different from flux estimates obtained with conventional *W*(*U*) models based on photographic data for *W*. These spatial differences can be explained with the concerted influence of the additional factors on the wind action and provide new physical insights for global distributions of whitecaps and sea-salt loadings, which available *W*(*U*) models do not capture.

The method for estimating whitecap coverage from satellite measurements relies on changes of ocean surface emission at microwave frequencies induced by the presence of whitecaps. Ocean surface emissivity, *e*, is a composite of two contributions: emissivity due to the rough sea surface, e_r, in places free of whitecaps, and emissivity due to foam, e_f, in foam-covered areas: $e = e_r(1-W) + e_f W$. Provided that all the emissivities in this expression can be calculated, whitecap coverage can be determined as $W = (e - e_r)/(e_f - e_r)$. Composite ocean emissivity *e* is retrieved from satellite-measured brightness temperatures, T_B, while emissivities of rough surface and foam, e_r and e_f, are computed using theoretical or empirical expressions.

While the initial version of the method proves the potential and feasibility of the concept, it has used highly simplified models for emissivities of rough sea and foam, e_r and e_f. Also, satellite data for T_B and the parameters needed for atmospheric correction to derive ocean surface emissivity *e* were obtained from the same satellite data set (SSM/I). Thus, some dependence of satellite-retrieved *W* on the assumptions in the SSM/I retrieval algorithm is expected. The encouraging initial results command further improvements in the method implementation.

First, the recent launch of the polarimetric microwave radiometer WindSat (Gaiser et al., 2004) opens possibility to resolve the issue of using independent data sets: WindSat measurements for T_B and SSM/I products for atmospheric correction variables can be combined, after temporal and spatial matching, to obtain surface emissivity *e*. Next, the emissivity of rough sea surface, e_r, has recently been placed on a more sound physical ground. Instead of the empirical expression used formerly, e_r is now obtained with the so-called two-scale model (St. Germain et al., 2002), which best describes changes of ocean emissivity for winds up to 10-12 m s^{-1} due to Bragg scattering from short gravity and capillary waves riding on long waves with a Gaussian distribution of slopes. Finally, emissivity of foam, e_f, which was modeled with the Fresnel formula for foam reflectivity and constant void fraction (a measure of the air content in the air-water mixture of foam), can now be replaced with newly developed full radiative transfer model for the emission of a foam layer with depth profile of the void fraction. These new developments will be described and preliminary results of improved satellite retrievals for *W* will be presented. Challenges in the models will be discussed.

This research was performed while the first author held a National Research Council Research Associateship Award at Naval Research Laboratory.

Anguelova, M. (2002), *Whitecaps, sea-salt aerosols, and climate*, Ph.D. thesis, Univ. of Delaware.

Gaiser, P., et al. (2004), *IEEE Trans. Geosci. and Remote Sensing*, 42, 2347 – 2361.

St. Germain, K., G. Poe, and P. Gaiser (2002), *Progress in Electromagnetics Research, PIER 37*, 1–30.