WHITECAPS, SEA-SALT AEROSOLS, AND CLIMATE

by

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LIST OF ABBREVIATIONS

ACE-1	The first Aerosol Characterization Experiment
ACE-2	The second Aerosol Characterization Experiment
APC	Antenna Pattern Correction
ATSR	Along-track scanning radiometer
AVHRR	Advanced Very High Resolution Radiometer
CCN	Cloud Condensation Nuclei
CTD	Conductivity-Temperature-Depth
DMS	Dimethyl Sulfide
DMSP	Defense Meteorological Satellite Platform
DN	Digital Numbers
ERBE	Earth Radiation Budget Experiment
ems	Electromagnetic spectrum
Gas Ex-98	Gas Exchange Experiment 98
GCM	General Circulation (Climate) Model
GHRC	Global Hydrology Resource Center
HDF	Hierarchical Data Format
IPCC	Intergovernmental Panel on Climate Change
JPL	Jet Propulsion Laboratory
MBL	Marine Boundary Layer
MODIS	Moderate Resolution Imaging Spectroradiometer
MSFC	Marshall Space Flight Center

N	North
NH	Northern Hemisphere
NCDC	National Climatic Data Center
NODC	National Oceanographic Data Center
nss	non-sea-salt
OCL	Ocean Climate Laboratory
PO.DAAC	Physical Oceanography Distributed Active Archive Center
RH	Relative Humidity
RTE	Radiative Transfer Equation
S	South or chemical element sulfur depending on the context
S1 … S20	Salinity bin number 1 … 20
SeaWiFS	Sea-viewing Wide-Field-of-View Sensor
SH	Southern Hemisphere
SMMR	Scanning Multichannel Microwave Radiometer
SSM/I	Special Sensor Microwave Imager
SST	Sea Surface Temperature
T1 … T12	Temperature bin number 1 … 12
WOA98	World Ocean Atlas 1998
WOD98	World Ocean Database 1998

LIST OF FREQUENTLY USED SYMBOLS

a	Regression coefficient (slope) or absorption of seawater depending on the context
a_L	Attenuation coefficient of cloud liquid water
a_O	Attenuation coefficient of oxygen
a_V	Attenuation coefficient of water vapors
b	Regression coefficient (exponent)
C	Surfactant concentration, rel. units
d	Wind duration, h
dF/dr_0	Sea-salt generation function in terms of r_0
dF/dr_{80}	Sae-salt generation function in terms of r_{80}
df/dr_0	Size distribution (dependence) of the sea-salt generation function in terms of r_0
df/dr_{80}	Size distribution (dependence) of the sea-salt generation function in terms of r_{80}
dm/dr_0	Size distribution of particle mass concentration for r_0
dm/dr_{80}	Size distribution of particle mass concentration for r_{80}
dN/dr_0	Size distribution of particle number concentration for r_0
dN/dr_{80}	Size distribution of particle number concentration for r_{80}
e	Composite emissivity of seawater
E_{ei}	Sensitivity coefficients for composite seawater emissivity
e_f	Foam emissivity

E_{fi}	Sensitivity coefficients for foam emissivity
E_{ri}	Sensitivity coefficients for rough seawater emissivity
e_s	Specular emissivity of seawater
E_{si}	Sensitivity coefficients for specular seawater emissivity
f	Wind fetch, km
f_r	Frequency of radiation, Hz
F	Total particle number flux, s^{-1}
F_m	Total particle mass flux, kg s^{-1}
h	Horizontal polarization of radiation
k	Atmospheric extinction coefficient
L	Cloud liquid water, mm
N	Total number concentration of particles or number of pixels depending on the context
Q	Water fraction of a foamy mixture
r	Reflectivity of seawater
$r.e._W$	Relative error of whitecap coverage
r_f	Reflectivity of foam
r_0	Droplet radius at formation, μm
r_{80}	Droplet radius at RH = 80%, μm
S	Salinity, psu
t	Atmospheric transmittance
T_{CB}	Brightness temperature of cosmic background, K
T_B	Brightness temperature, K
$T_B(h)$	Brightness temperature [K] at horizontal polrization

T_{BD}	Brightness temperature of downwelling radiation, K
T_{BU}	Brightness temperature of upwelling radiation, K
T_s	Sea surface temperature, °C
U_{10}	Wind speed at 10-m reference height, m s^{-1}
V	Water vapor content, mm
v	Vertical polarization of radiation
W	Whitecap coverage, fraction or %
W_x	Sensitivity coefficients for W due to variable x
a	Void fraction of a foamy mixture
ΔT	Atmospheric stability
Δe_r	Correction for emissivity of rough seawater
w	Dielectric constant of seawater (a complex number)
e', e''	Real and imaginary parts of dielectric constant of seawater
e_f	Dielectric constant of foam (a complex number)
e'_f, e''_f	Real and imaginary parts of dielectric constant of foam
e_s	Static dielectric constant of seawater
e_∞	Dielectric constant of seawater at infinite radiation frequency
l	Wavelength of radiation, m
ω	Frequency of radiation, rad.
s	Conductivity of seawater
s_x	Standard deviation of a variable x
s_x^2	Variance of a variable x
$s_{Y\|X}$	Standard deviation of a regression
r	Density of sea-salt droplets, kg m^3

q	Incidence angle of radiation, deg.
t	Relaxation time of a material
t_W	Lifetime of an individual whitecap

ABSTRACT

Oceanic whitecaps are the major source of sea-salt aerosols to the atmosphere. The inclusion of the effects of sea-salt aerosols into various atmospheric processes improves the predictions of climate models. This study proposes modifications to the sea-salt generation function used in models in order to predict more realistic loading of sea-salt aerosols. A new method for estimating whitecap coverage on a global scale has been developed for this purpose.

The new method relates whitecap coverage to the microwave emissivity of the foam-free and foam-covered ocean surface, which is retrieved from satellite-measured brightness temperature. Whitecap coverage evaluated with this method incorporates the effects of various environmental and meteorological factors such as atmospheric stability, sea surface temperature, salinity, wind fetch, wind duration, and surfactant concentration.

The influence of these factors on the production of sea-salt aerosols is incorporated in the sea-salt generation function by assimilating the whitecap coverage estimates obtained with the new method. The applicability of the generation function is extended toward smaller aerosol radii, from 1.6 μm down to 0.4 μm. With these two modifications, a sea-salt generation function relevant for climate studies is proposed. The performance of the modified generation function is examined by comparison with predictions of the currently used generation function and *in situ* observations. Sea-salt aerosol loadings into the atmosphere are calculated for all months of 1998 using the modified generation function. The direct and indirect effects of sea-salt aerosols on climate and the role of these aerosols in atmospheric chemistry are evaluated.

An extensive database of daily and monthly whitecap coverage values with their corresponding standard deviations for the entire 1998 is compiled. Each retrieved value of whitecap coverage is accompanied by concomitant measurements of wind speed, sea surface temperature, and salinity. Spatial and temporal characteristics of oceanic whitecaps, as well as parameterization of the whitecap coverage in terms of sea surface temperature and salinity, are derived from the database.

Global whitecap coverage is about 3%. The composite effect of all environmental factors yields a more uniform latitudinal distribution of whitecap coverage and sea-salt fluxes compared to those traditionally predicted from wind speed. Sea surface temperature significantly alters the effect of wind speed on whitecap formation and sea-salt production. The effect of low to moderate wind is enhanced in warm waters and the effect of high wind is suppressed in cold waters.

Regression analysis is employed to parameterize the effect of sea surface temperature and incorporate it in the existing relation between whitecap coverage and wind speed. Parameterization with exponential law in terms of both wind speed and sea surface temperature is a better predictor of whitecap coverage and sea-salt production than wind speed alone. The proposed parameterization still cannot predict the full range of variability of whitecap coverage and sea-salt fluxes.

Future work on the generation of sea-salt aerosols from oceanic whitecaps can proceed with improving the estimation of satellite-measured global whitecap coverage, extending the applicability of sea-salt generation function down to 0.1 μm radii, and refining the parameterization of whitecap coverage.