Sea Spray Aerosol Production

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Sea-spray aerosol (SSA) consists of a suspension, in air, of particles that are directly produced at the sea surface.

Focus on bubble-mediated production (\(r_{80} < \text{a few } \mu \text{m})

MAP-cruise, June 2006

Breaking wave, wind ca. 30 m/s

Spume

Surfacing Bubbles
Sea spray aerosol production

Contents

1. Introduction
2. Production of Sea-Spray Aerosol and Flux Formulation
3. Methods of Determining SSA Production Fluxes
4. Recent Experimental and Observational Findings
5. Parameterizations of the Sea-Spray Production Flux
6. Discussion
7. Conclusions

Appendix: Formulations

The starting point for our review was Lewis and Schwartz (2004)

Lewis and Schwartz, (2004):

Shaded area indicates uncertainty limits (factor 7)

Based on a very large number of published determinations!
Methods

1. **Whitecap method**
   1. Determination of the Oceanic Whitecap Fraction
      1. In situ
      2. Satellites
   2. Determination of the SSA particle Flux per White Area
      1. Laboratory experiments
      2. Surf zone
      3. SSA production flux formulations

2. **Micrometeorological methods**
   1. SSA production flux formulations
   2. Gradient method

3. **Chemical Composition of Sea-Spray Aerosol**

Often the SF is written as a product of an amplitude function and a shape function:

\[
\frac{dF(r_{80}, a, b, \ldots)}{d \log r_{80}} = f(a, b, \ldots)g(r_{80})
\]

\[
dF_{M86} = \frac{1.373}{10^{1.19}} U_{10}^{3.4} (1 + 0.057r_{80}^{1.05}) \times 10^{1.19} e^{-a^2}
\]

Monahan et al., 1986 (whitecap)

\[
F_N = 10^{0.20U_{10} - 1.71}
\]

Nilsson et al., 2001 (first application of EC method over open ocean.)

The Whitecap method forms the basis for most of the parameterizations that currently are mostly used in global transport and global circulation models (GTM & GCM)
Whitecap Method

\[ \frac{dF}{d \log r_{80}} = W \times \frac{dF_{wc}}{d \log r_{80}} \]

- Ocean Flux = Whitecap fraction \( \times \) Flux per white area
- Whitecap fraction determined by field observation: photography, satellite
- Flux per white area determined by lab experiment or field observation (surf zone)
- The whitecap method assumes that the flux per white area is constant, independent of conditions.
- There is little field or laboratory demonstration of this and much evidence against it.

Size distributions of SSA production flux normalized to maximum value in representation \( dF/d\log r_{80} \) as a function of \( r_{80} \) from laboratory experiments

Note different conditions (production method, water temperature, wind speed)
• Spread in observations shows influence of factors other than wind speed.
• Note many zero’s in prior data. New photographic observations tend lower; better statistics, no zero’s.
• Monahan–O’Muircheartaigh fit based on prior data is widely used; gray lines are factor of 3 above/below to guide the eye.

Satellite observations give widespread coverage over large
Satellite observations tend *higher*; better statistics, no zero’s.

Prior and recent production flux

Production flux, $dF/d\log r$

$[\text{cm}^{-2} \text{s}^{-1}]$

Radius at 80% RH, $r_{80}/\mu m$, or ambient, $r_{\text{amb}}/\mu m$, or dry diameter, $d_p/\mu m$

Monahan et al., 1986
Smith et al., 1993
Nilsson et al., 2001
Gong, 2003
Mårtensson et al., 2003, 5°C
Mårtensson et al., 2003, 25°C
Lewis & Schwartz, 2004, dry dep. method
Lewis & Schwartz, 2004, multiple methods
Petelski & Piskozub, 2006, gradient
Petelski & Piskozub, 2006, dry dep.
Tyree et al., 2007, 1.6 cm s$^{-1}$
Tyree et al., 2007, 0.09 cm s$^{-1}$
Keene et al., 2007
Norris et al., 2008

production flux per white area (cm$^{-2}$ s$^{-1}$)

Bubble volume flux (cm s$^{-1}$)

Mårtensson et al., 2003
Keene et al., 2007
Tyree et al., 2007

5°C
25°C
Conclusions (1)

- A major finding of recent work is the recognition of the large contribution of organic substances to SSA particles, especially in locations of high biological activity, which becomes increasingly important with decreasing particle size, and which may be dominant for $r_{80} < 0.25 \, \mu m$
- Recent flux determinations show higher production than in the best estimates based on older data (LS04), increasing with decreasing $r_{80} < 1 \, \mu m$;
- Determinations of the SSA production flux have been made at sizes smaller than those previously examined, with some formulations extending to particle size as low as $r_{80} = 0.01 \, \mu m$;
- The best estimate for the production flux of SSA particles with $r_{80} > 1 \, \mu m$ remains as that given by LS04 based on multiple methods, with uncertainty a multiplicative factor of 4 to 5
Conclusions (2)

- Recent advances in determination of the whitecap fraction $W$, also central to evaluation of the SSA production flux by the whitecap method, by both photographic methods and satellite retrievals may eliminate some of the subjectivity in measurement of this quantity, but direct relation to SSA production is lacking.

- Results from laboratory experiments depend on how the white area is produced as well as conditions: the basic assumption of the whitecap method is not valid;

- Despite the many gains in understanding in recent years, the uncertainty in the SSA production flux remains sufficiently great that present knowledge of this quantity cannot usefully constrain the representation of emissions of SSA in chemical transport models or climate models that include aerosols.
Thank you for your attention