WHAT IS THE SIZE- AND COMPOSITION-DEPENDENT PRODUCTION FLUX OF SEA SPRAY AEROSOL

AND WHY DO WE CARE?

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www.ecd.bnl.gov/steve
OVERVIEW

Why do we care? -- Aerosol forcing and climate sensitivity

Sensitivity of aerosol indirect (Twomey) forcing to natural CCN concentrations

Influence of organics on CCN properties; organics in small sea spray particles

Whitecap method, whitecap fraction

New estimates of size-dependent sea spray production flux

Sea salt aerosol in global models

Concluding remarks
Total forcing includes other anthropogenic and natural (solar) forcings. Forcing by tropospheric ozone, \(~0.35\) W m\(^{-2}\), is the greatest of these. Uncertainty in aerosol forcing dominates uncertainty in total forcing.
CLIMATE MODEL DETERMINATION OF CLIMATE SENSITIVITY

Effect of uncertainty in forcing

\[
F_{\text{eff}} = F - H
\]

\[
\Delta T = SF_{\text{eff}}
\]

\[
F_{\text{eff}} = \Delta TS^{-1}
\]

Uncertainty in aerosol forcing allows climate models with widely differing sensitivities to reproduce temperature increase over industrial period.
ALLOWABLE FUTURE CO₂ EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial

Equilibrium Climate Sensitivity, K/(W m⁻²)

Maximum Increase in GMST \( \Delta T_{\text{max}} \), K

\[ \Delta T_{\text{max}} \]

\[ E_{\text{CO}_2} \]

\[ T_{\text{2X}} \]

\[ \text{Pg C} \]

\[ \text{ Widely accepted maximum } \Delta T \]

Schwartz, Charlson, Kahn, Ogren, Rodhe, J. Climate, In press

**Allowable future emissions** or amount by which present GHGs exceed the allowable threshold depend on climate sensitivity and \( \Delta T_{\text{max}} \).
\[ \Delta \alpha \propto \Delta \ln \tau \]

\[ \tau \propto z_{\text{cld}} W N^{1/3} \]

\[ \Delta \ln \tau = \frac{1}{3} \Delta \ln N = \frac{1}{3} \ln \frac{N}{N_0} \]

"Other things being equal"
Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate

Robert J. Charlson, James E. Lovelock, Meinrat O. Andreae & Stephen G. Warren

NATURE VOL. 326 16 APRIL 1987

Dimethylsulfide --> sulfate --> CCN --> brighter clouds

"Seasalt particle concentrations at cloud height are typically not more than 1 cm^{-3} [Radke, 1968; Hobbs, QJ, 1971; Pruppacher, 1978]."
## Biological regulation of climate

**Duncan C. Blanchard**  
**Ramon J. Cipriano**

*NATURE* Vol. 330 10 December 1987

<table>
<thead>
<tr>
<th>Study</th>
<th>Location</th>
<th>Number conc cm(^{-3})</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dinger JAS, 1970</td>
<td>Below tradewind inversion, Caribbean</td>
<td>20</td>
<td>Nonvolatile</td>
</tr>
<tr>
<td>Woodcock JGR, 1972</td>
<td>Cloud base, Hawaii</td>
<td>15</td>
<td>(r \geq 0.2) µm</td>
</tr>
<tr>
<td>Cipriano, Monahan... JGR, 1987</td>
<td>Model: Lab expts; Field measmts of SSA production; Whitecap fraction</td>
<td>18</td>
<td>(s &lt; 0.5%) ((r_{dry} &gt; 0.02) µm)</td>
</tr>
</tbody>
</table>

“With a steady-state *background concentration of sea-salt particles with a concentration of 15-20 cm\(^{-3}\)*, all of which can serve as CCN, a biological regulation of climate is less obvious.”
Cloud-top albedo, TOA albedo, Global mean albedo, and Forcing

Global means calculated for marine stratus only (30% of global area). Increase in number concentration of 30% --> forcing of 1 W m$^{-2}$. 

Climate Forcing by Anthropogenic Aerosols


SCIENCE 24 JANUARY 1992
Particles above cloud layer showed greater increase in supersaturation than particles below cloud.

Composition measured with PILS (particle into liquid sampler) showed high organic fraction in above cloud aerosol.

Measurements with aerosol mass spectrometer showed organic material in CCN size range.

*Ghan, Schwartz, BAMS, 2007*
SEA SALT FRACTION OF MARINE AEROSOL, BY NUMBER

Dependence on radius at relative humidity 80%, $r_{80}$

Lewis and Schwartz, *Sea Salt Aerosol Production*, AGU, 2004
ORGANIC FRACTION IN PRIMARY SEA SPRAY AEROSOL

Shipboard measurements, northeast Atlantic, west of Ireland during phytoplankton bloom

Laboratory Bubble Bursting

Ambient Aerosol

Water insoluble organic matter dominates composition for radius < 0.25 µm.

This insoluble organic matter would be expected to decrease CCN activity.
WHITECAP METHOD FOR DETERMINING SEA SPRAY AEROSOL FLUX

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

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

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.

Nonetheless it is widely used by modelers.
PRIOR DETERMINATIONS OF WHITECAP FRACTION

Large symbols, photographic; small symbols, video. Note many zero’s. Spread in observations shows influence of factors other than wind speed and/or measurement uncertainty, definition issues – What is white?

Shaded gray band encompasses the bulk of the photographic data; width about central solid line decreases from factor of 7 to 3.
New eddy correlation measurements (Geever, not size resolved) and surf-zone measurements (Clarke) indicate high flux at low $r_{80}$. Lab experiments (Keene, seawater with frit; Tyree, frit) also indicate high flux at low $r_{80}$; Tyree flux depends strongly on flow rate. **Production flux remains quite uncertain.**
SEA SALT AEROSOL MASS EMISSION FLUX

Annual average in 11 AEROCOM models; g m\(^{-2}\) yr\(^{-1}\)

Range of global annual mean is a factor of 50.

Textor et al., ACP 2006; courtesy, Michael Schulz
http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl
SEA SALT AEROSOL SEDIMENTATION AND DRY DEPOSITION

Annual average in 11 AEROCOM models; g m$^{-2}$ yr$^{-1}$. Note different scales.

http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

Range of global annual mean is a factor of 100.
SEA SALT AEROSOL WET DEPOSITION
Annual average in 11 AEROCOM models; g m\(^{-2}\) yr\(^{-1}\)

Range of global annual mean is a factor of 18.
SEA SALT AEROSOL COLUMN MASS LOADING

Annual average in 11 AEROCOM models; g m$^{-2}$

http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

Range of global annual mean is a factor of 3.9.
SEA SALT AEROSOL
MASS SCATTERING EFFICIENCY

Annual average in 11 AEROCOM models; m² g⁻¹

http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

Range of global annual mean is a factor of 7.
SEA SALT AEROSOL CONTRIBUTION TO OPTICAL DEPTH

Annual average in 11 AEROCOM models

Range of global annual mean is a **factor of 5**.

http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl
AEROSOL OPTICAL DEPTH IN 17 MODELS (AEROCOM)

Comparison also with surface and satellite observations

Surface measurements: AERONET network.
Satellite measurements: composite from multiple instruments/platforms.
Are the models getting the “right” answer for the wrong reason?
Are the models getting the “right” answer because the answer is known?
Are the satellites getting the “right” answer because the answer is known?
CONCLUDING OBSERVATIONS

• Aerosol indirect (Twomey) forcing is highly dependent on natural CCN concentrations.

• Increasing indication of substantial primary organic material in sea spray particles radius $< 250$ nm.

• Whitecap fraction dependence on controlling variables is not well constrained, despite new measurements and approaches (satellite).

• Concerns over the whitecap method itself: Are all white areas created equal?

• Global sea salt models are well ahead of the understanding: Right (?) answers for the wrong reasons.