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

AND WHY DO WE CARE?

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Symposium on Ocean-Aerosol Interactions

American Geophysical Union Ocean Sciences Meeting

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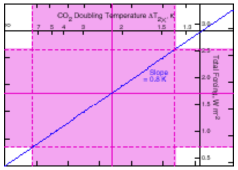
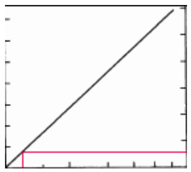
www.ecd.bnl.gov/steve

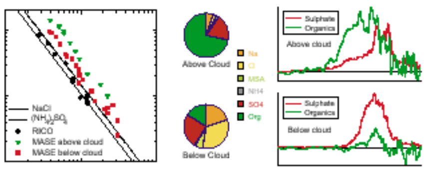
OVERVIEW



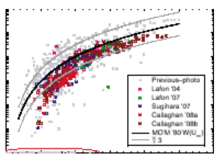
- Why do we care? -- Aerosol forcing and climate sensitivity



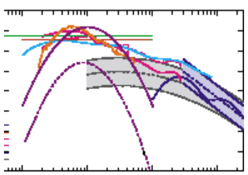
- Sensitivity of aerosol indirect (Twomey) forcing to natural CCN concentrations



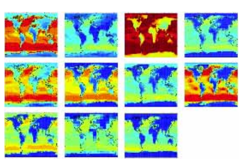
- Influence of organics on CCN properties; organics in small sea spray particles



- Whitecap method, whitecap fraction



- New estimates of size-dependent sea spray production flux

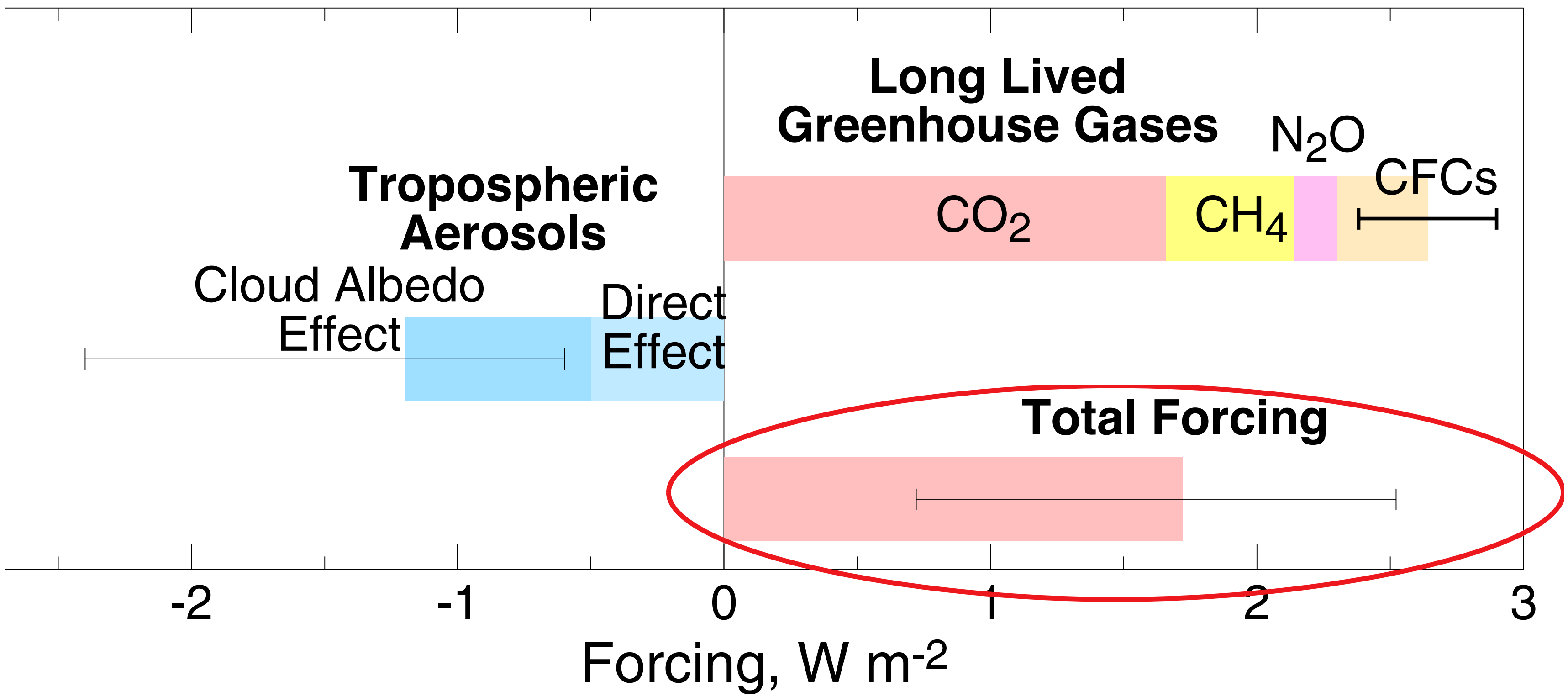


- Sea salt aerosol in global models

- Concluding remarks

CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

Extracted from IPCC AR4 (2007)



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.

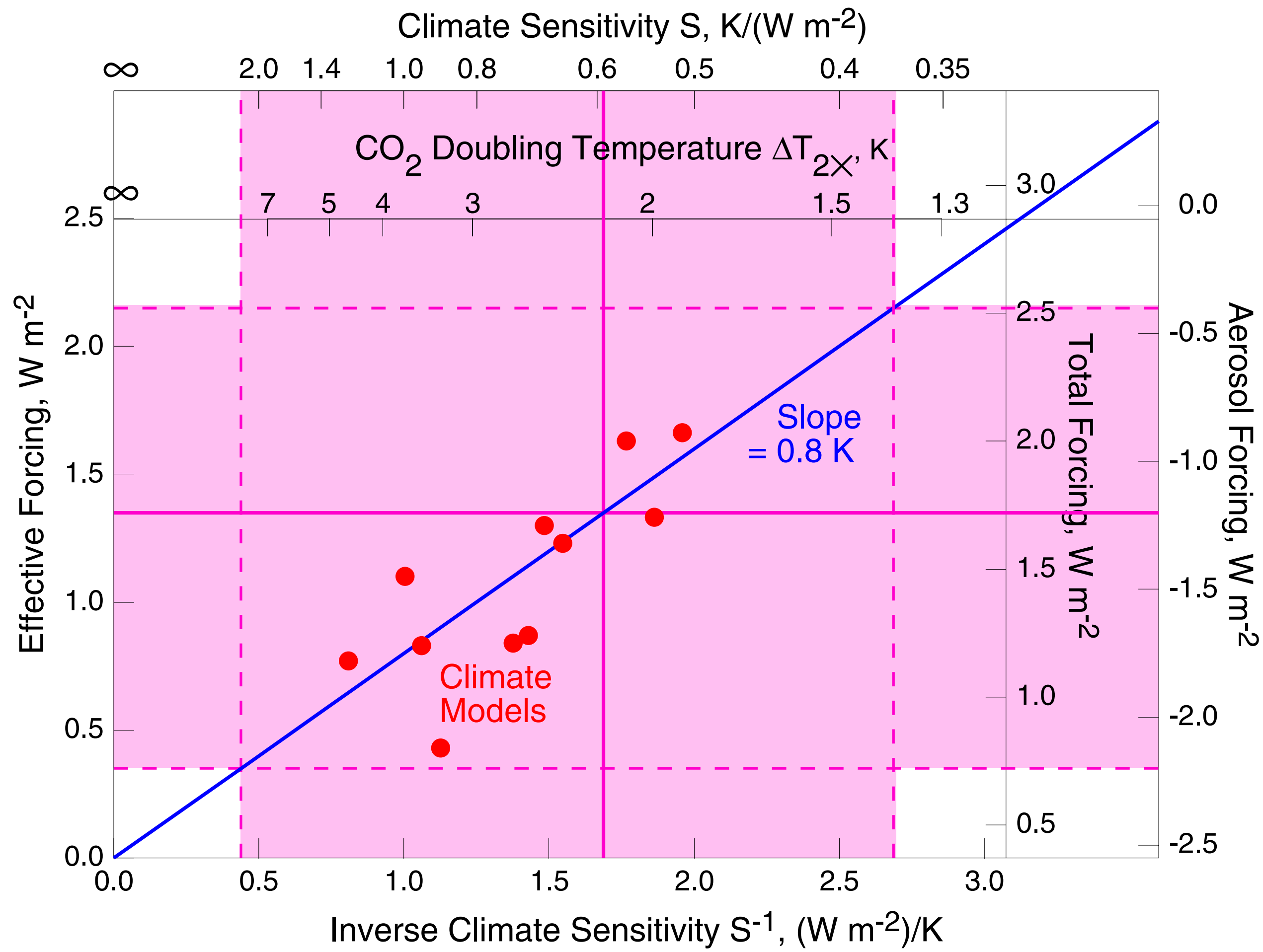
CLIMATE MODEL DETERMINATION OF CLIMATE SENSITIVITY

Effect of uncertainty in forcing

$$F_{\mathrm{eff}} = F - H$$

$$\Delta T = S F_{\mathrm{eff}}$$

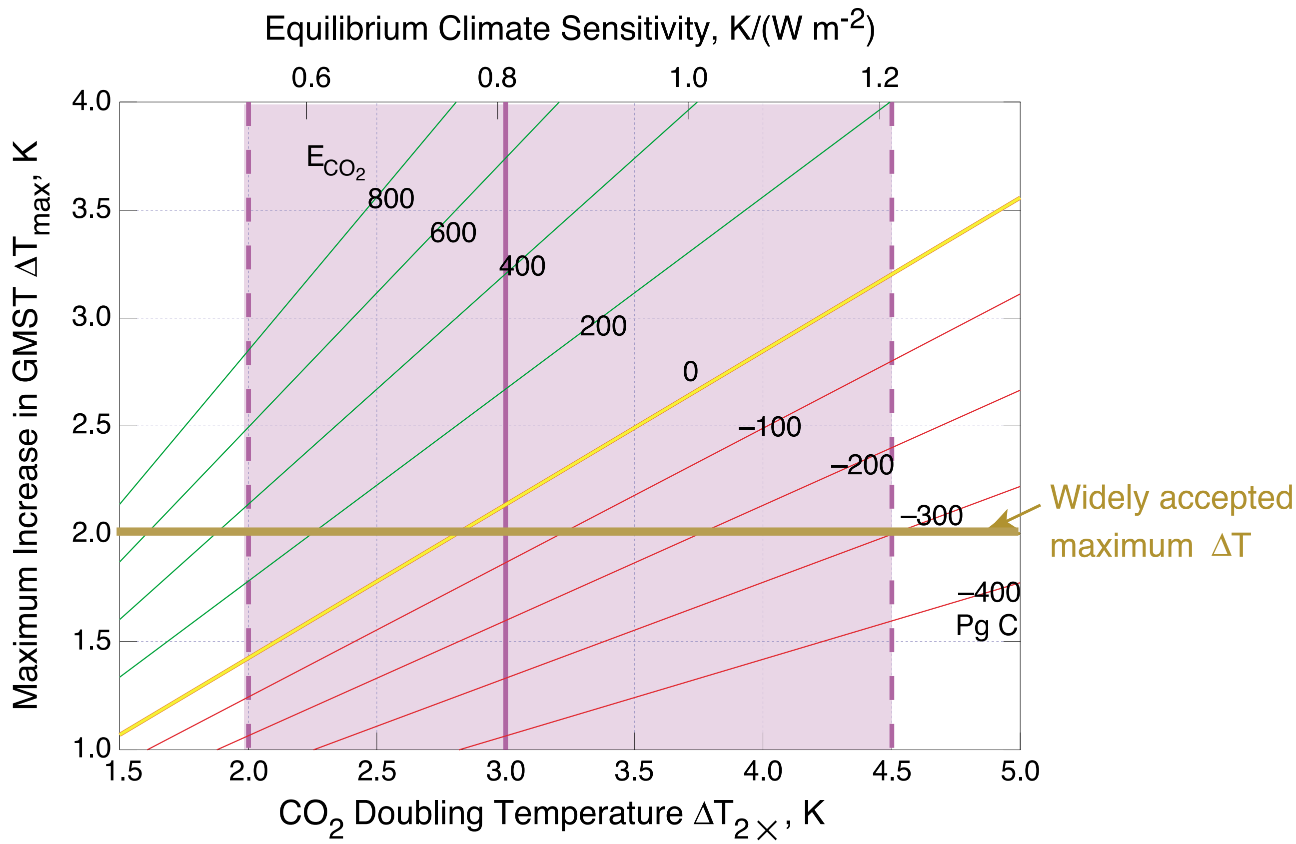
$$F_{\mathrm{eff}} = \Delta T S^{-1}$$



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

ALLOWABLE FUTURE CO_2 EMISSIONS

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



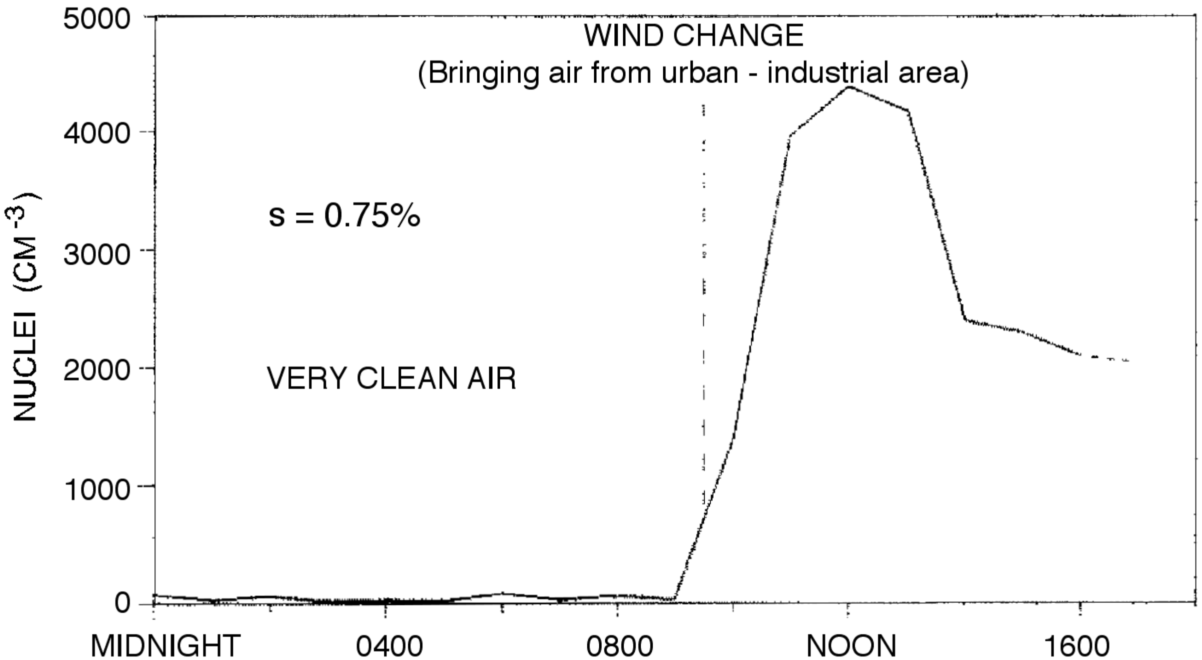
Schwartz, Charlson, Kahn, Ogren, Rodhe, J. Climate, In press

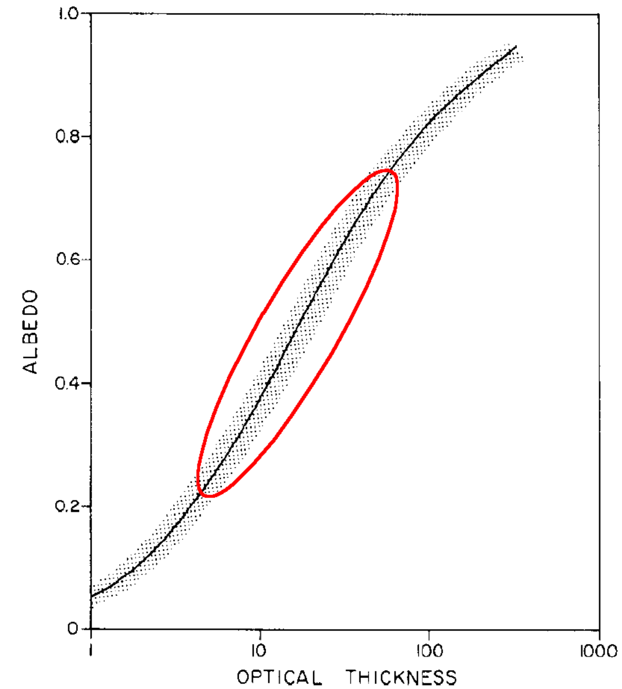
Allowable future emissions ***or amount by which present GHGs exceed the allowable threshold*** depend on climate sensitivity and ΔT_{max}.

POLLUTION AND THE PLANETARY ALBEDO

S. TWOMEY

Atmospheric Environment Vol. 8, pp. 1251 - 1256, 1974





$$\Delta\alpha \propto \Delta \ln \tau$$

$$\tau \propto z_{\mathrm{cld}} W N^{1/3}$$

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

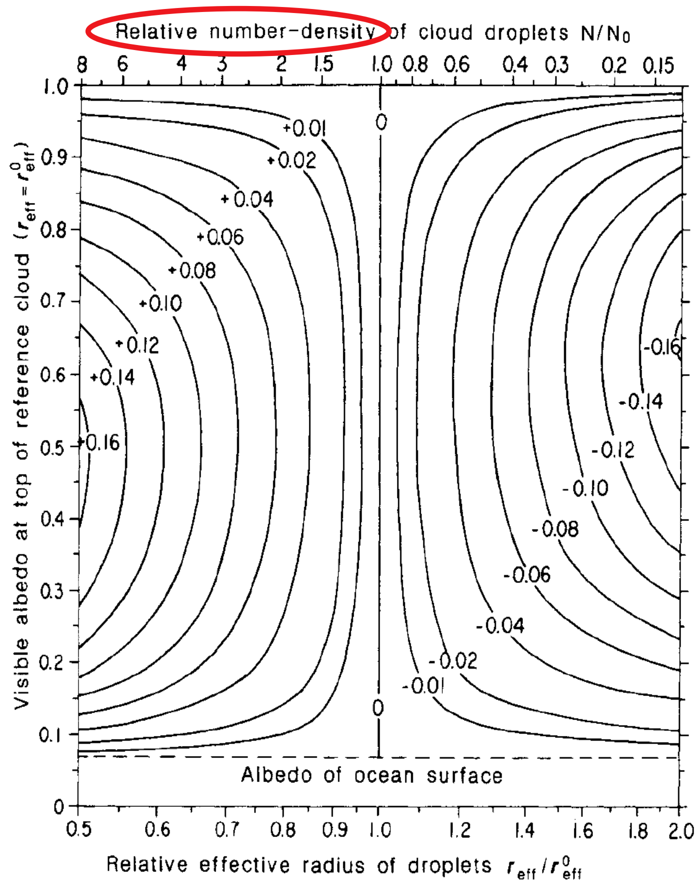
"Other things being equal"

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



Contours denote change in cloud-top albedo.

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

SCIENTIFIC CORRESPONDENCE

Biological regulation of climate

DUNCAN C. BLANCHARD
RAMON J. CIPRIANO

NATURE VOL. 330 10 DECEMBER 1987

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

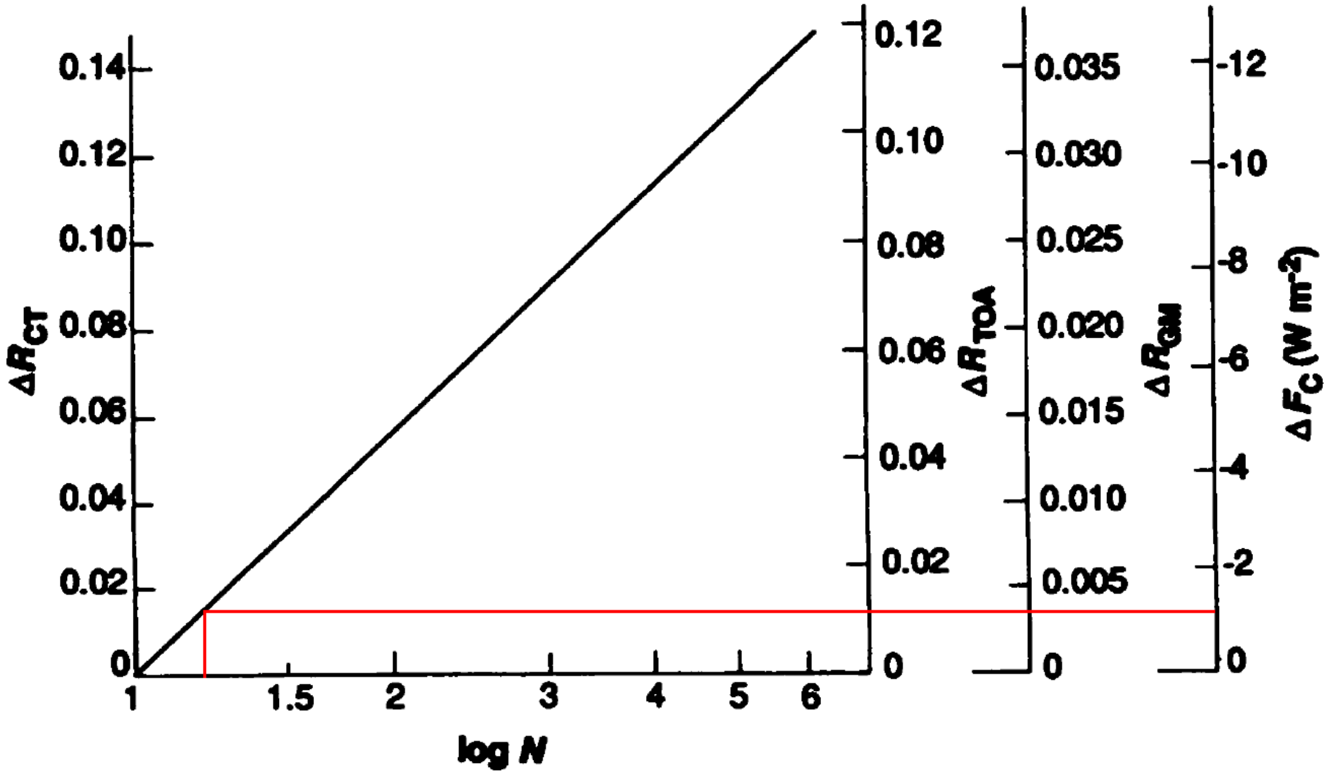
"With a steady-state ***background concentration of sea-salt particles with a concentration of 15-20 cm***$^{-3}$, all of which can serve as CCN, a biological regulation of climate is less obvious.

Climate Forcing by Anthropogenic Aerosols

R. J. Charlson, S. E. Schwartz, J. M. Hales, R. D. Cess,
J. A. Coakley, Jr., J. E. Hansen, D. J. Hofmann

SCIENCE 24 JANUARY 1992

Cloud-top albedo, TOA albedo, Global mean albedo, and Forcing

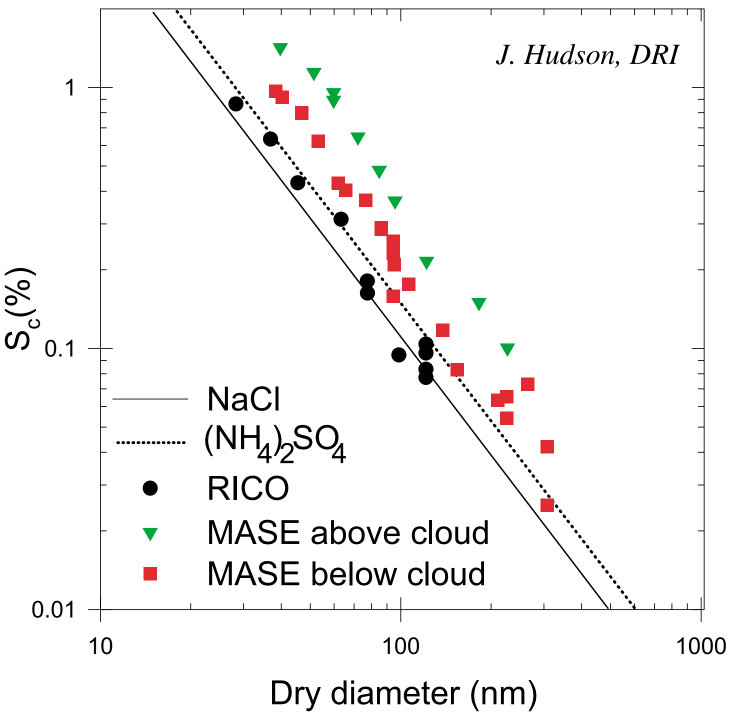


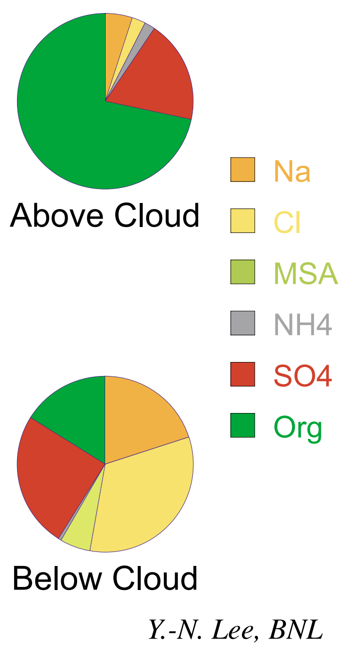
Global means calculated for marine stratus only (30% of global area).

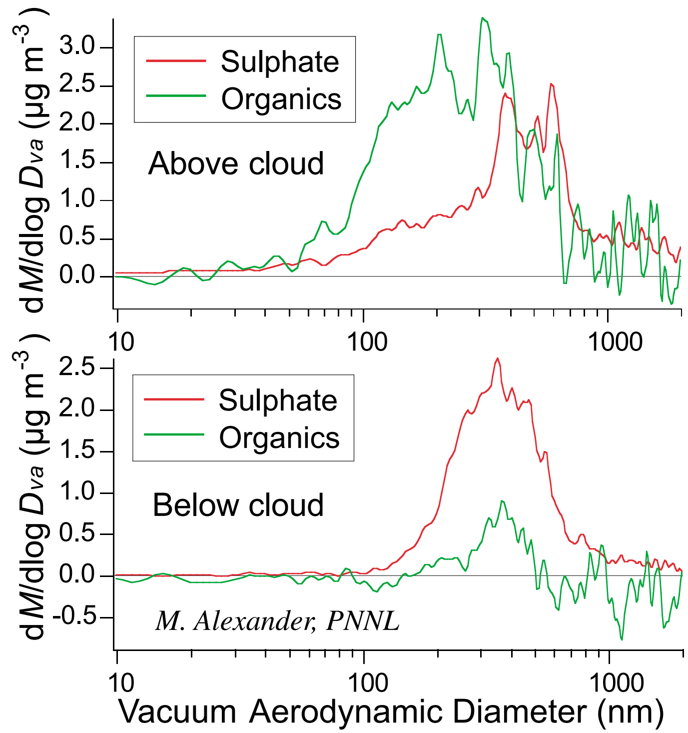
Increase in number concentration of ***30% --> forcing of 1 W m^{-2}***.

CRITICAL SUPERSATURATION

Dependence on particle size and composition







Particles above cloud layer showed greater increase in supersaturation than particles below cloud.

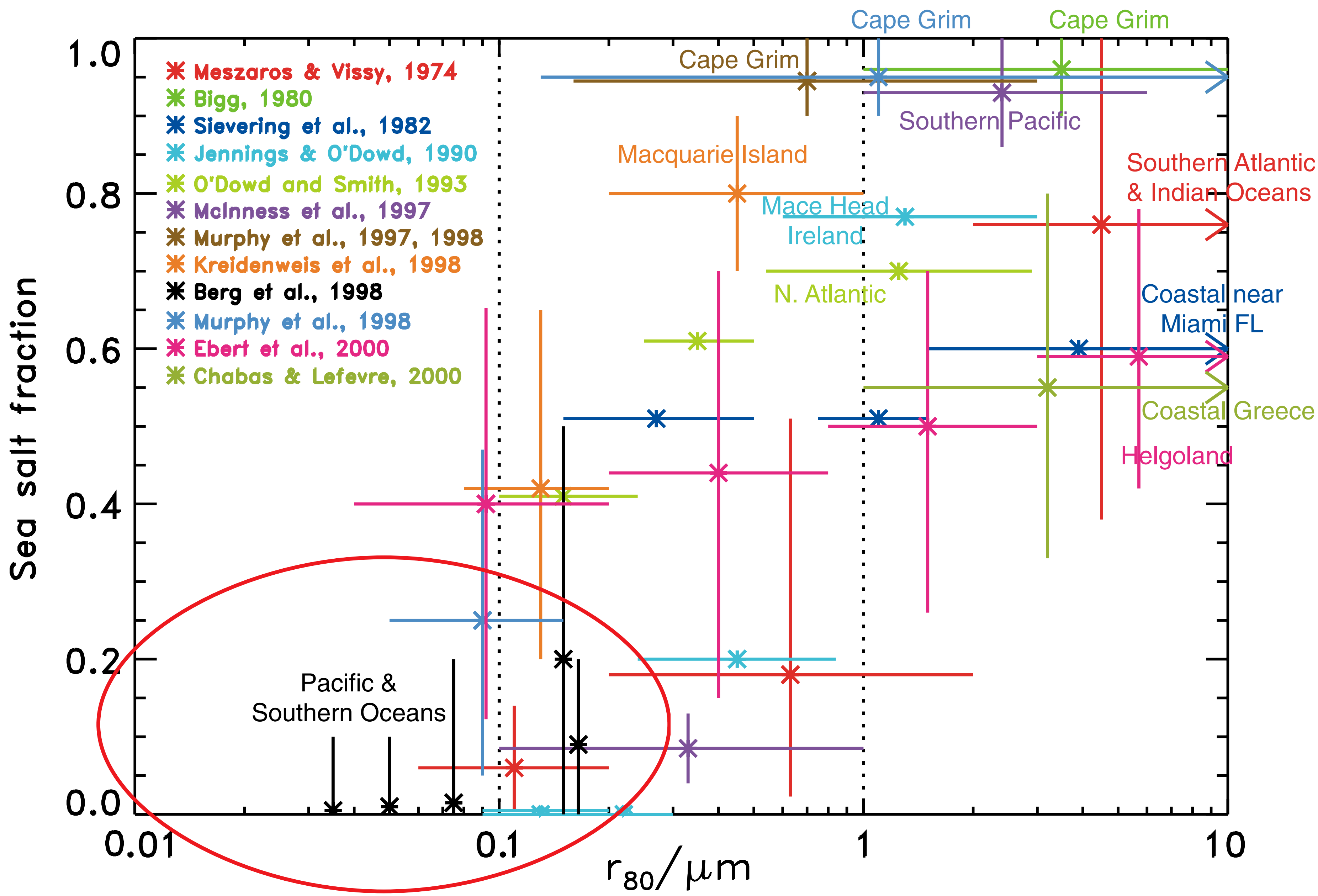
Composition measured with PILS (particle into liquid sampler) showed ***high organic fraction*** in above cloud aerosol.

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

Ghan, Schwartz, BAMS, 2007

SEA SALT FRACTION OF MARINE AEROSOL, BY NUMBER

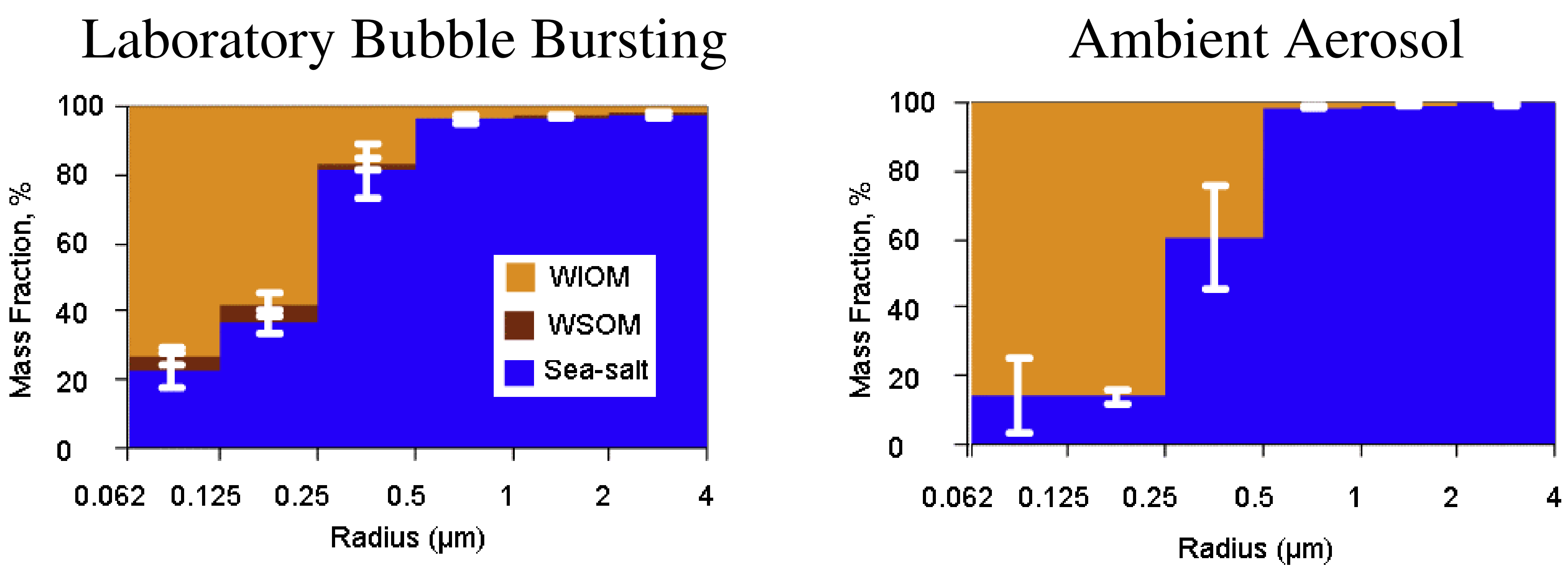
Dependence on radius at relative humidity 80%, r_{80}



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



Facchini et al., GRL, 2008

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

$$\frac{dF}{d\log r_{80}} = W \times \frac{dF_{\mathrm{wc}}}{d\log r_{80}}$$

Ocean Flux = Whitecap fraction × Flux per white area

Whitecap fraction determined by field observation: photography, satellite

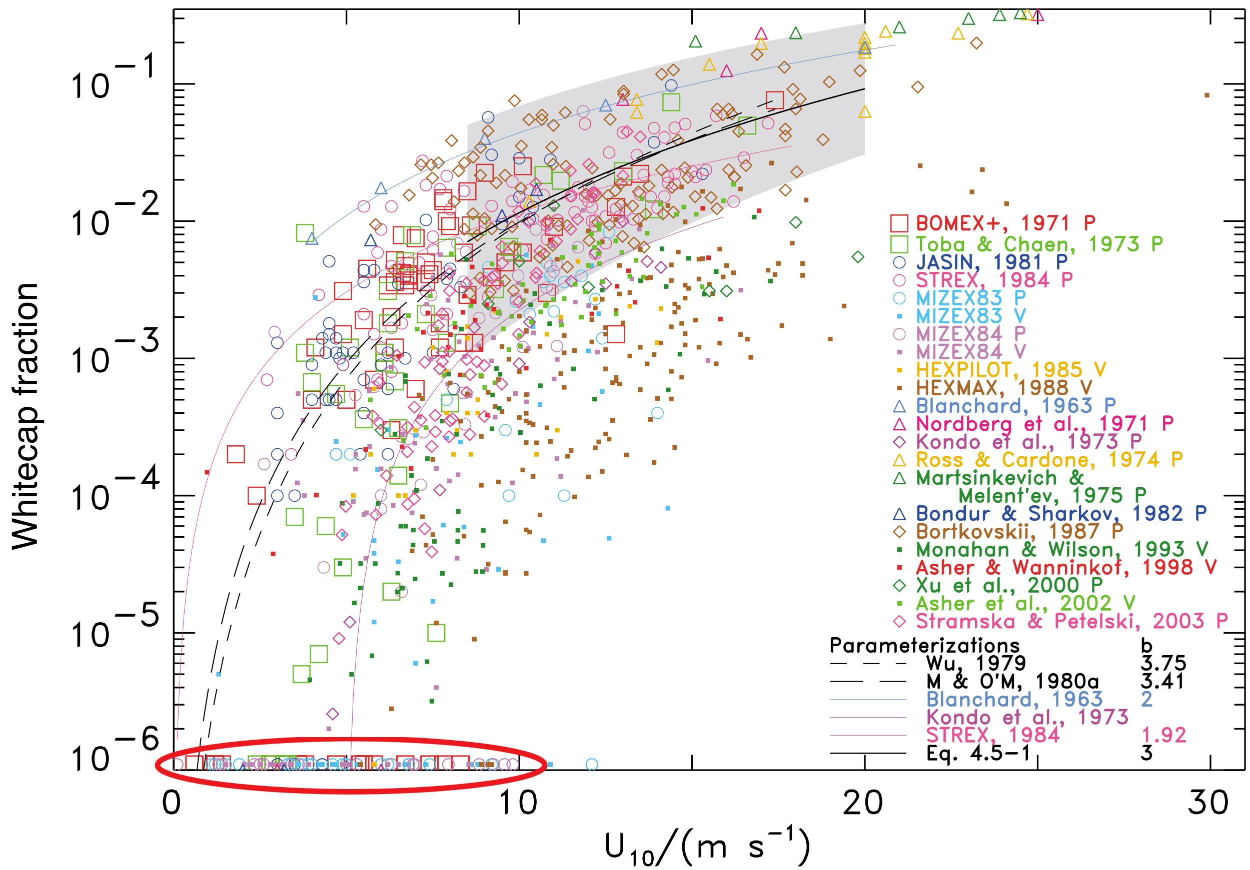
Flux per white area determined by lab experiment or field observation

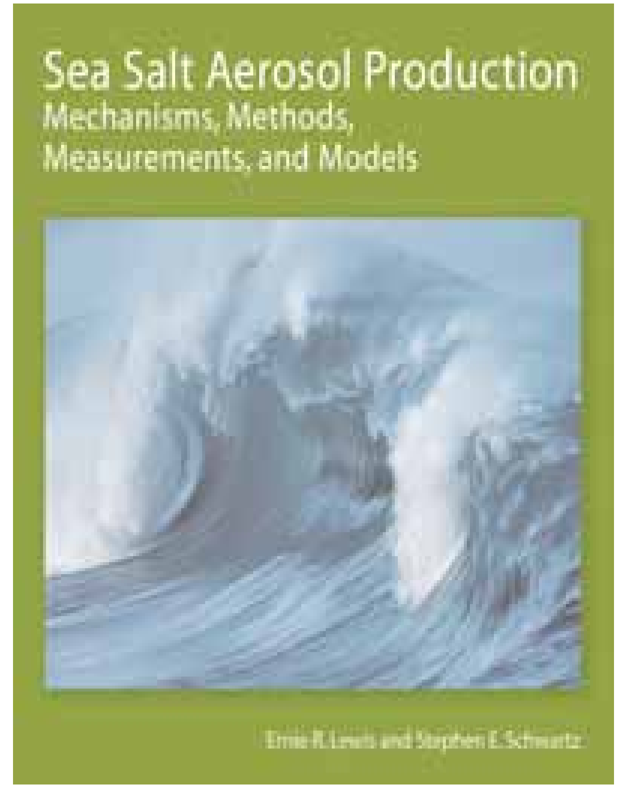
The whitecap method assumes that the flux per white area is constant, independent of conditions.

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





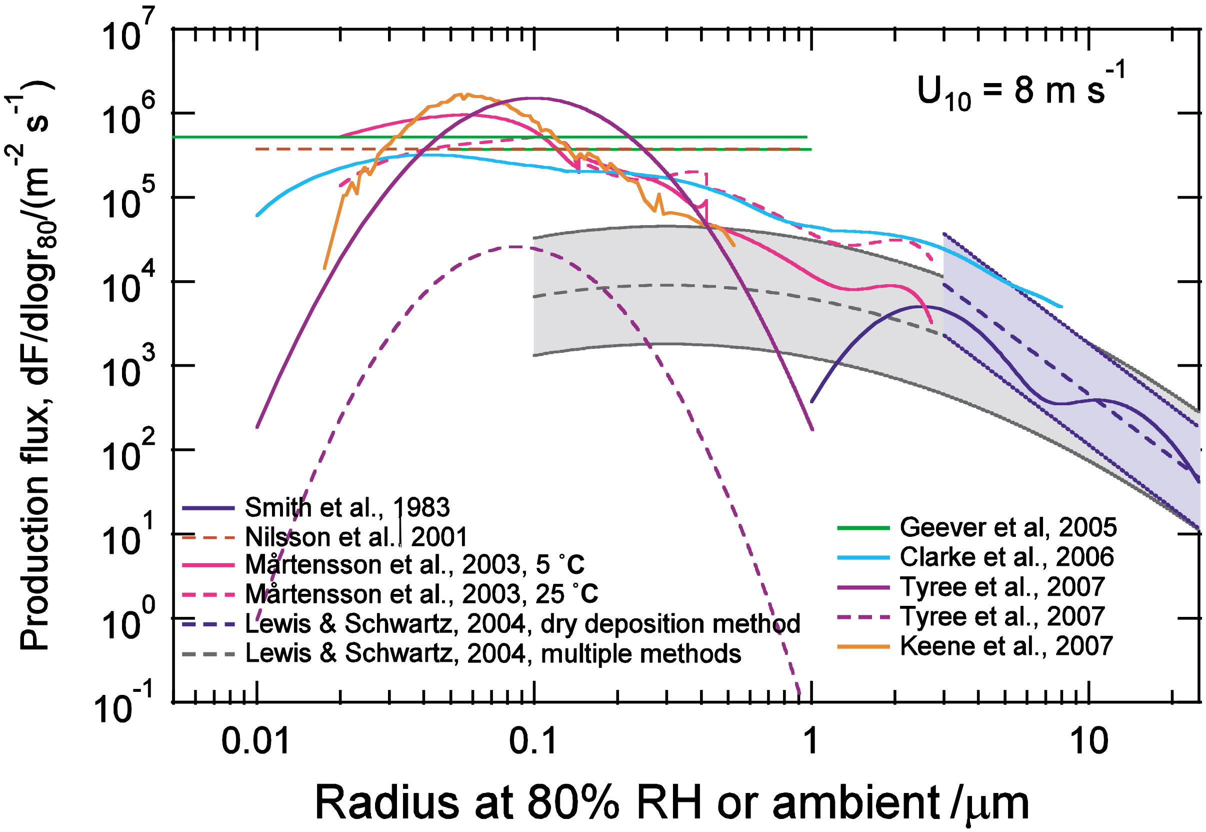
Large symbols, photographic; small symbols, video. Note many zero's.

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.

SEA SPRAY AEROSOL PRODUCTION FLUX

Measurements and estimates circa 2010



De Leeuw, Fairall, Andreas, Anguelova, Lewis, O'Dowd, Schulz, Schwartz, in preparation

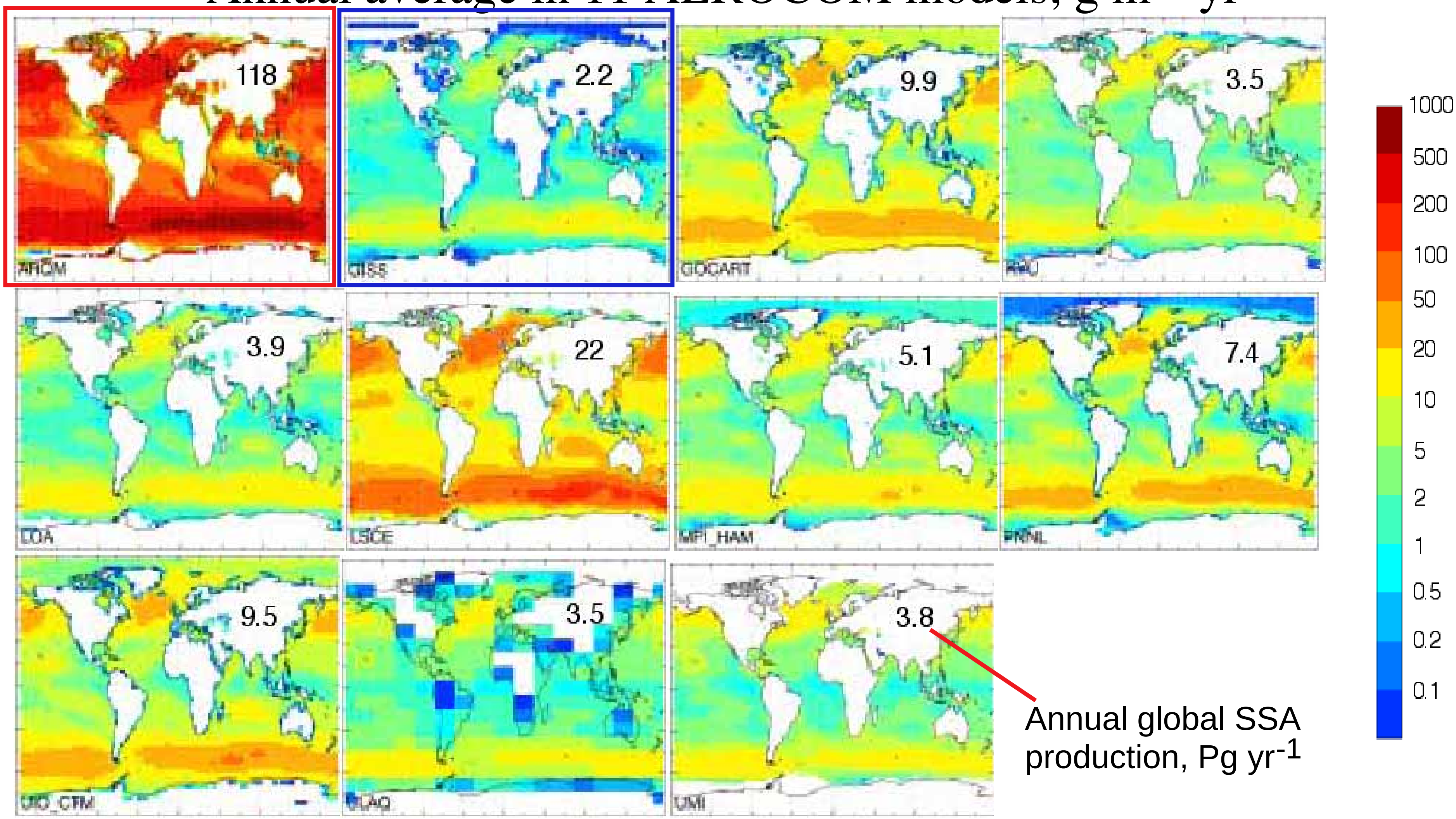
New eddy correlation measurements (Geever, not size resolved) and surf-zone measurements (Clarke) indicate high flux at low r_{80}.

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}



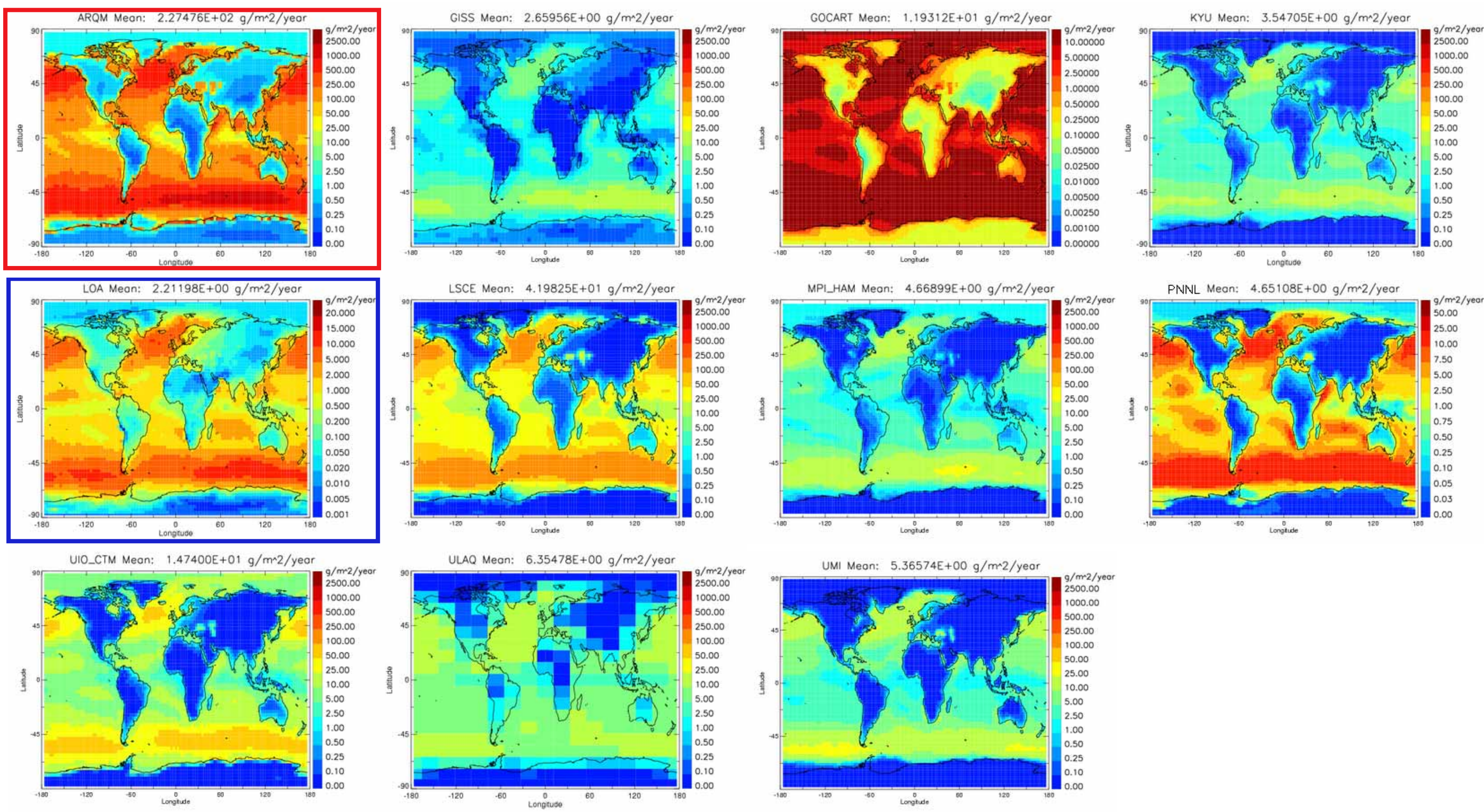
Textor et al., ACP 2006; courtesy, Michael Schulz

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

Range of global annual mean is a ***factor of 50***.

SEA SALT AEROSOL SEDIMENTATION AND DRY DEPOSITION

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

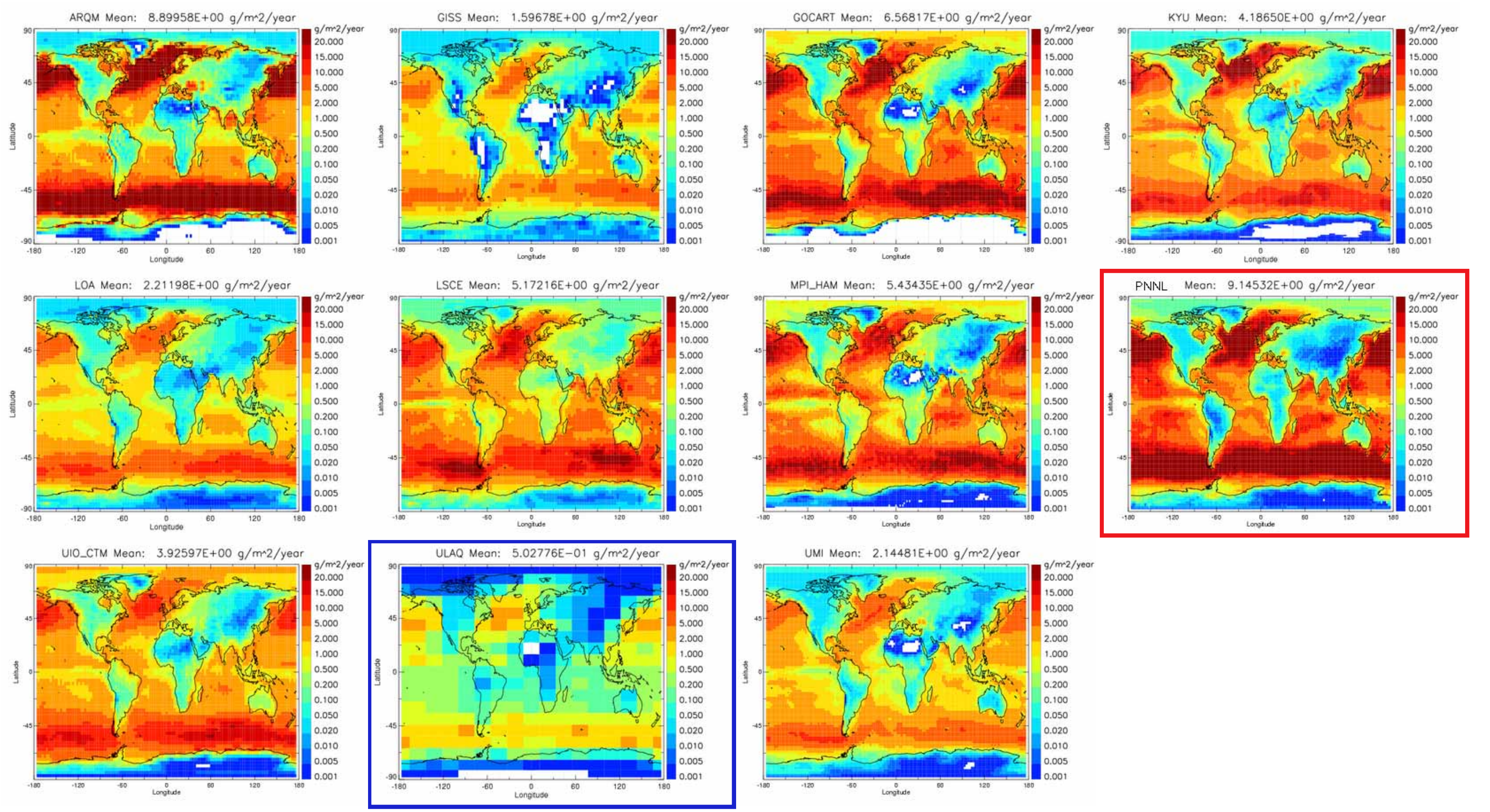


http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

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}

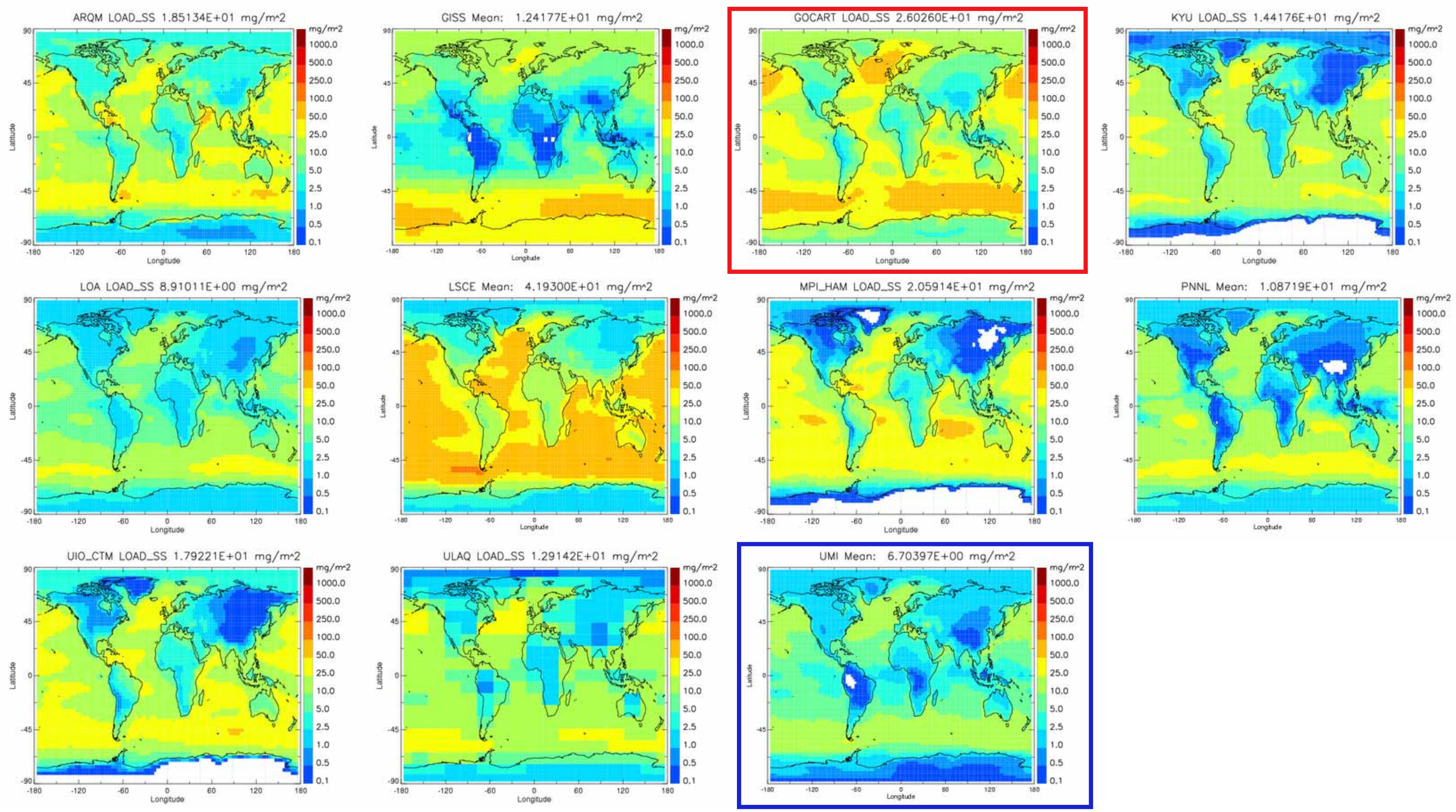


http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

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}

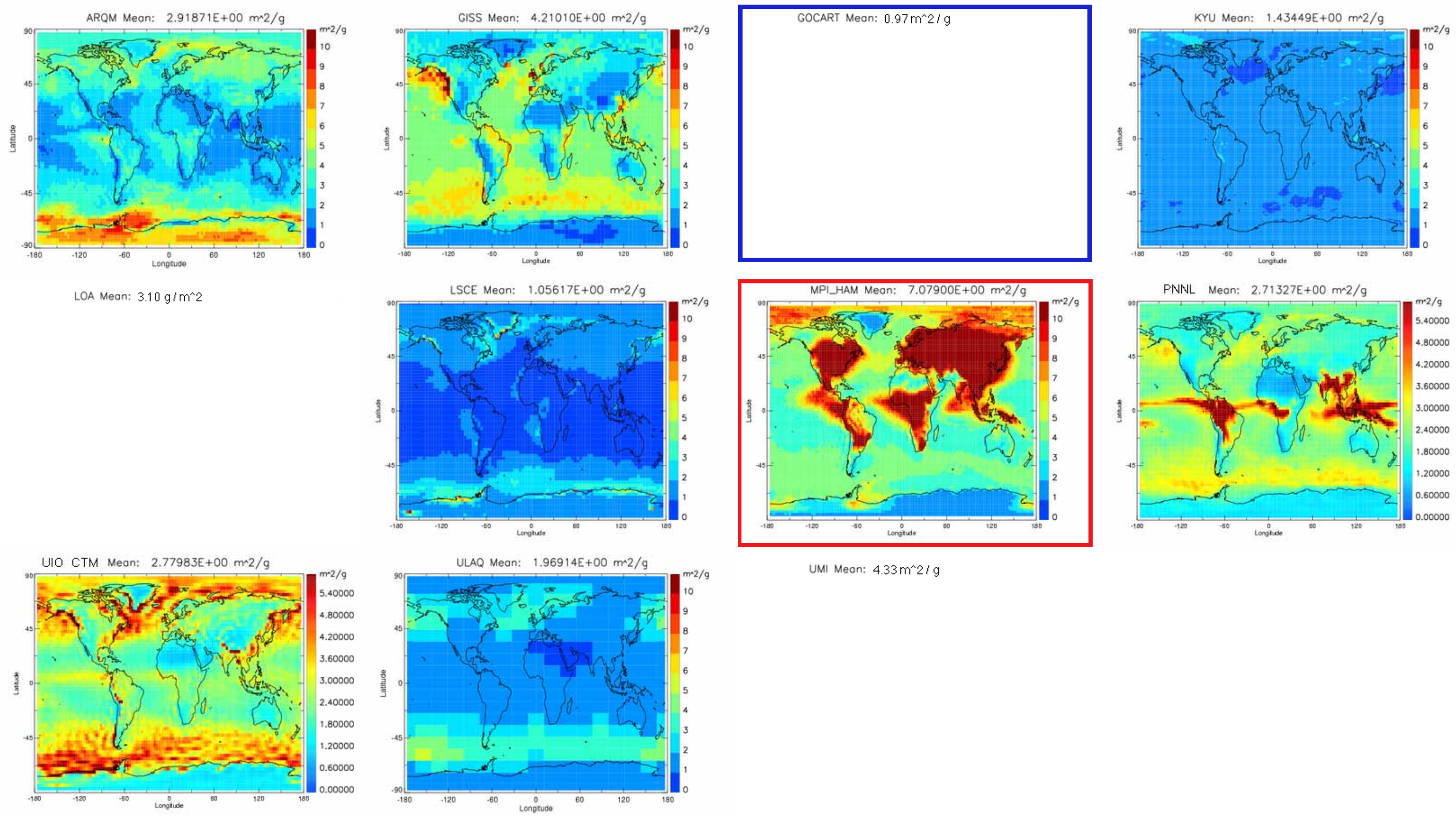


http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

Range of global annual mean is a ***factor of 3.9***.

SEA SALT AEROSOL
MASS SCATTERING EFFICIENCY

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

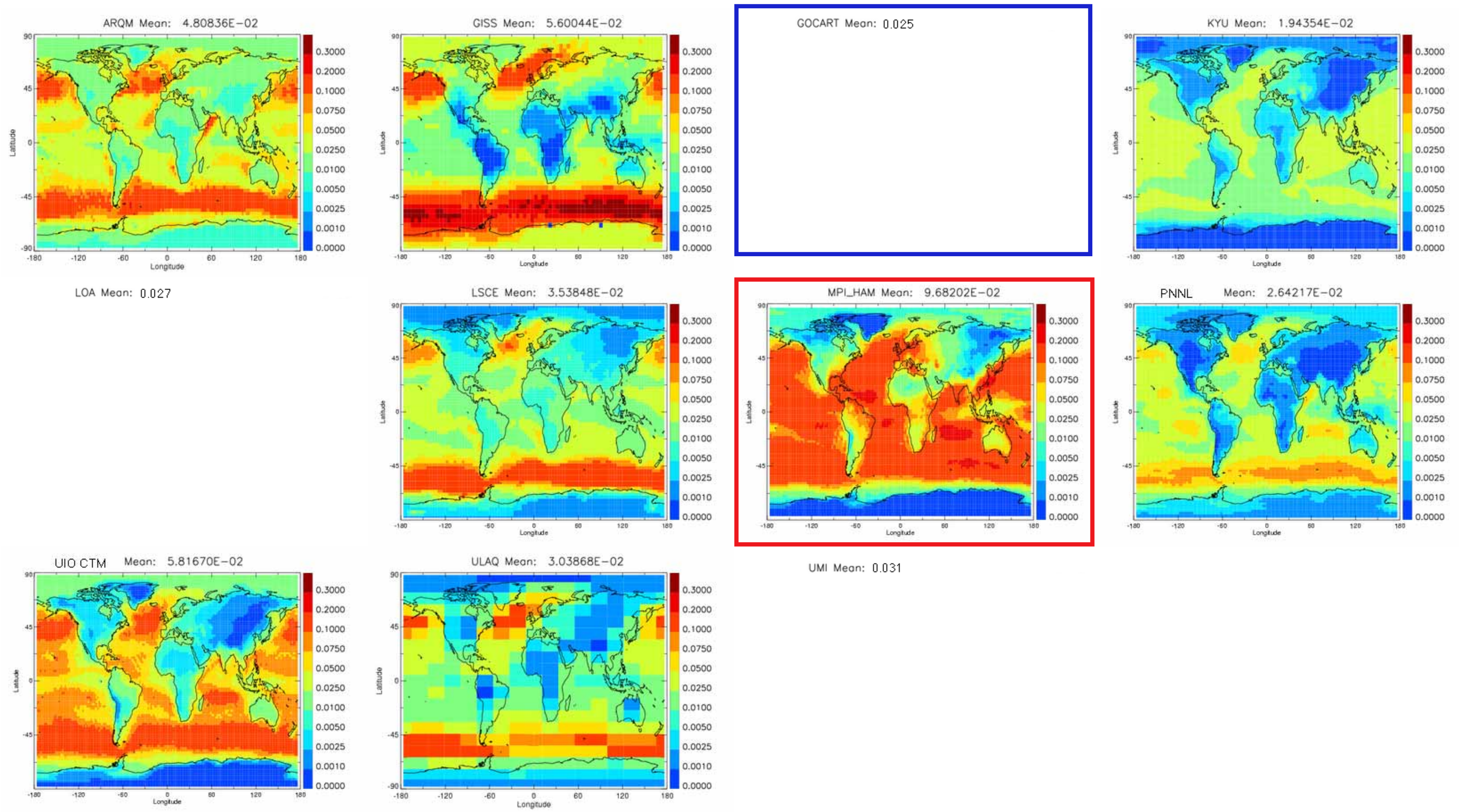


http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

Range of global annual mean is a ***factor of 7***.

SEA SALT AEROSOL CONTRIBUTION TO OPTICAL DEPTH

Annual average in 11 AEROCOM models

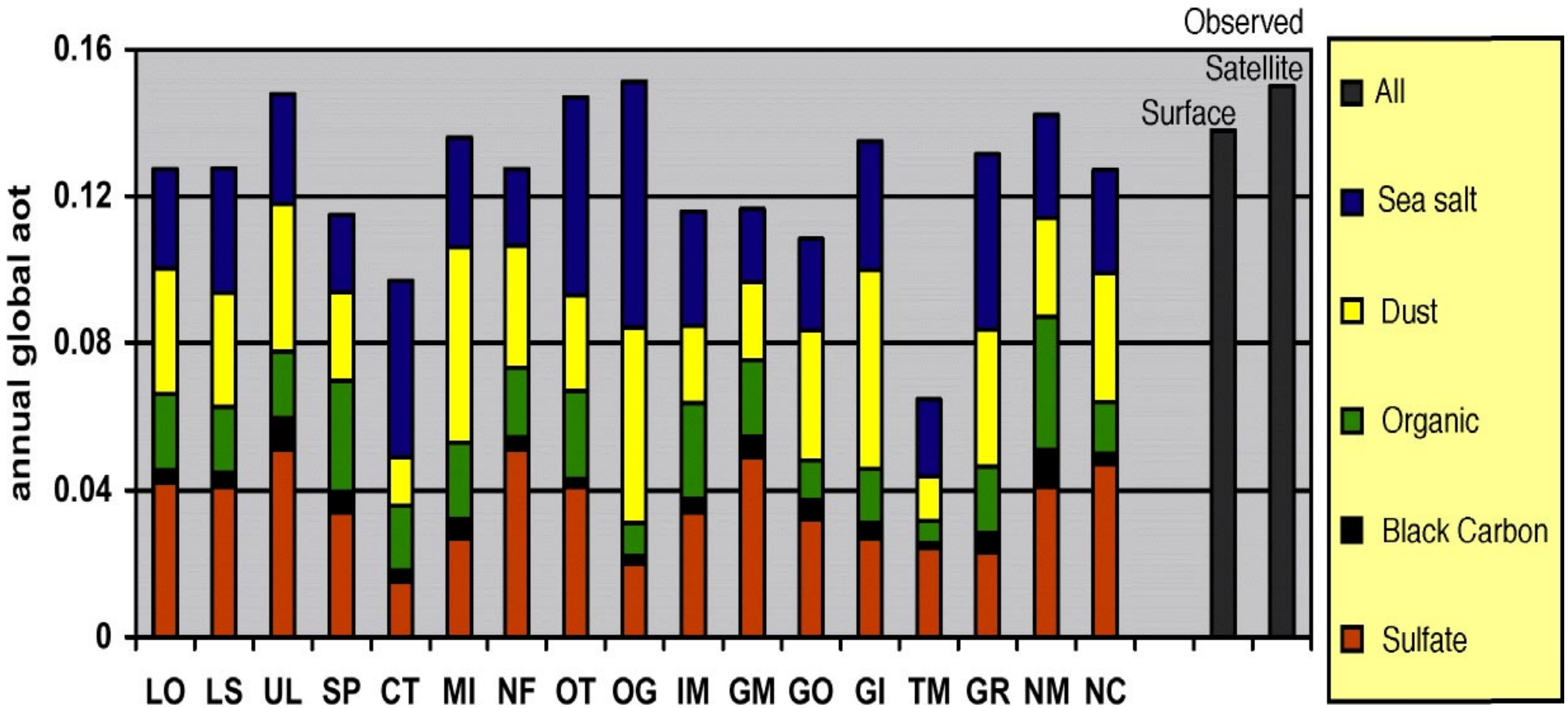


http://dataipsl.ipsl.jussieu.fr/cgi-bin/AEROCOM/aerocom/aerocom_work_annualrs.pl

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

AEROSOL OPTICAL DEPTH IN 17 MODELS (AEROCOM)

Comparison also with surface and satellite observations



Kinne et al., ACP, 2006

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***.