The Impact of Marine Organic Emissions on Global Climate and Coastal Air Quality

Contact Information
Dr. Nicholas Meskhidze
nmeskhidze@ncsu.edu

Nicholas Meskhidze[1], Jun Xu[1], Yang Zhang[1], Brett Gantt[1], Annmarie Carlton[2], Steve Ghan[3], Athanasios Nenes[4], Xiaohong Liu[3], Richard Easter[3] and Rahul Zaveri[3]

1. North Carolina State University, Raleigh, NC 2. U.S. EPA - Office of Research and Development, Research Triangle Park, NC 3. Pacific Northwest National Laboratory, Richland, WA
4. Georgia Institute of Technology, Atlanta, GA

Introduction

Marine aerosols contribute considerably to the global aerosol load, are emitted from a large surface area, and have an ability to strongly influence reflective properties and lifetime of marine stratiform clouds. As cloud properties are most sensitive to the addition of particles when the background concentration is low (Platnick and Twomey, 1994), marine aerosols play crucial role in our understanding of the cloud-mediated effects of aerosols on climate. Hoose et al. (2009) suggest that marine aerosol number concentration prescribed/diagnosed in global climate models (GCMs) could be the single most important parameter affecting model predicted magnitude of indirect forcing. Since model predictions are used for developing the planet's energy economy strategies, marine aerosols, their number, size distribution and chemical composition need to be better constrained.

Despite the crucial role, the source strength, emission mechanism and chemical composition of marine aerosols remain poorly understood. Sea-salt and dimethyl sulfide (DMS) have been established as the main contributors to marine aerosol; though, recent studies suggest that emissions of primary organic matter (POM) of marine origin, and secondary organic aerosol (SOA) from phytoplankton-produced volatile organic compounds can also lead to considerable changes in marine aerosol composition and size distribution.

Today there is no agreement on relative contribution of marine organic carbon (OC) aerosols to total aerosol mass and number distribution over the oceans and GCMs are often tuned with the existing marine aerosol to represent current climate. Therefore, instead of the attempting to reproduce Earth's contemporary climate, we will examine the range of uncertainty in radiative forcing associated with marine organic aerosols. Here we consider:

i) Effect of marine organic aerosols on coastal air quality

ii) Effect of marine organic aerosols on cloud radiative forcing

Model	CMAQ V. 4.7
Time Period	June-August 2005
Domain	Western US, Pacific coast
Horizontal Resolution	12 x 12 km^2
Vertical Resolution	14 layers from the surface to 100mb
Emissions	Anthropogenic: 2005 NEI; Natural: BEIS
Meteorology	MM5
Chemistry	CB05
Simulations	1) Baseline without marine emissions 2) "Bottom-up" (with measured plankton isoprene emission rates) 3) "Top-down" (with predicted isoprene and monoterpene emission rates from field measurements of Colomb et al. (2009)

CAM-MAM

- Primary emissions: size-resolved
- Microphysics: Morrison & Gettelman (2007)
- Aerosol activation: Abdul-Razzak and Ghan (AR-G)(default) and Fountoukis and Nenes (FN)
- New particle nucleation: ternary homogeneous (Merikanto et al., 2007)
- Condensation: mass transfer theory
- Coagulation: Binkowski & Shankar (1995)
- Water uptake: Köhler theory
- Cloud chemistry: Hoffmann and Calvert (1985) & Lind and Kok (1986)

Model Configurations

- Horizontal Resolution: 1.9° x 2.5°
- Vertical Resolution: 26 layers
- Aerosol: 5 and 2 super-micron modes
- Simulation: 10 years
- Spin up period: 3 months

Emissions

- Aerosol InterComparison (AeroCom) project with Year 2000 as baseline (Dentener et al., 2006)
- Sub- and super-micron marine POM
- Marine SOA from isoprene (Gantt et al., 2009)

Simulation Design

- Default: CAM-MAM run using AR-G activation scheme
- [Chl-*a*] *number*: Default with marine OC emissions added as a number in accumulation mode based on surface ocean Chlorophyll *a* concentration
- [Chl-*a*] *mass*: same as above, but with marine OC emissions added as a mass
- [DOC] *number:* Default with marine OC added as a number in accumulation mode based on surface ocean dissolved organic carbon (DOC) concentration

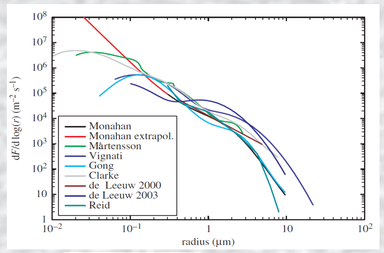
Marine Organic Aerosols in CAM-MAM

Sub-micron ← → Super-micron

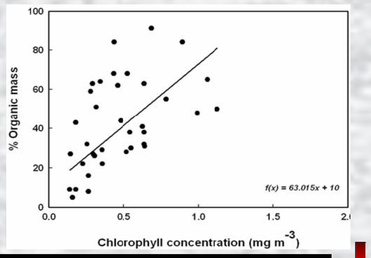
Mode	Accumulation	Atiken	Primary Carbon	Sea salt	Fine Soil Dust	Coarse Sea salt	Coarse Soil Dust
Aerosol component	Sulfate, ammonium, POM, SOA, BC, Sea salt	Sulfate, ammonium, SOA, Sea salt	POM, BC	Sea salt, sulfate, ammonium	Dust, sulfate, ammonium	Sea salt, sulfate, ammonium	Dust, sulfate, ammonium

Sub-micron marine POM — Marine SOA — Super-micron marine POM

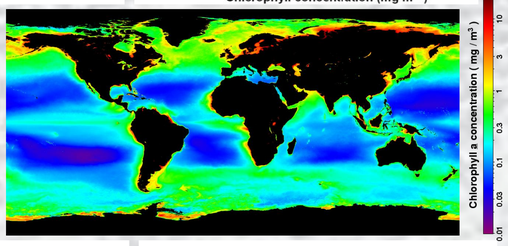
Marine Emissions (Primary Organic Aerosols)

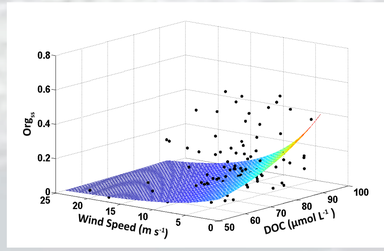


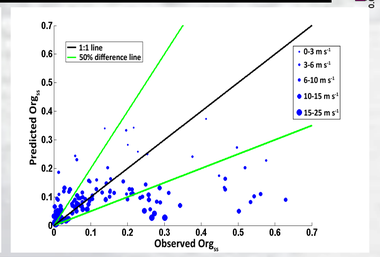
O'dowd et al., 2007; 2008



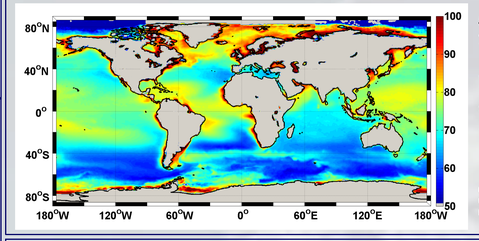
[Chl-*a*] based







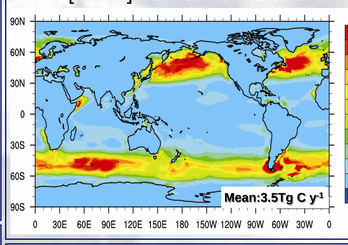
Gantt and Meskhidze, in review



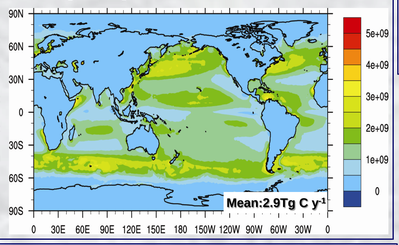
[DOC] based

Sub-micron Marine POM Emission (unit: C molecules/cm^2/s)

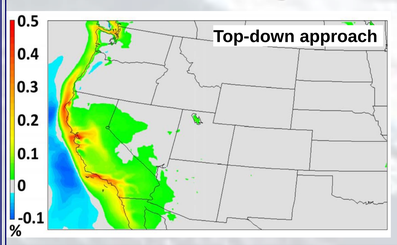
[Chl-*a*] *number* simulation

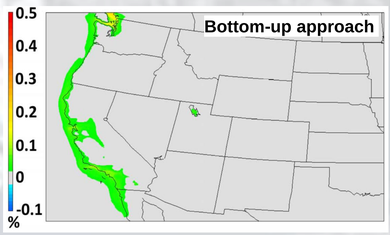


[DOC] *number* simulation



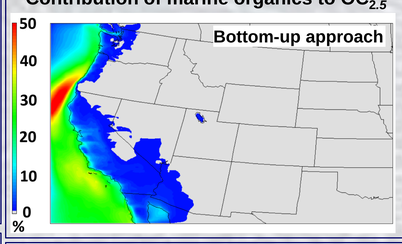
Effect of Marine Organics on Coastal Ozone



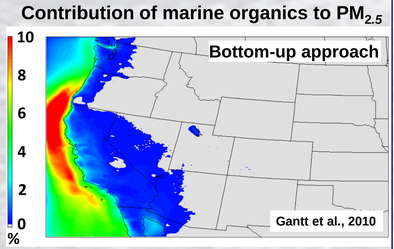


Effect of Marine Organics on Coastal Aerosol

Contribution of marine organics to $OC_{2.5}$

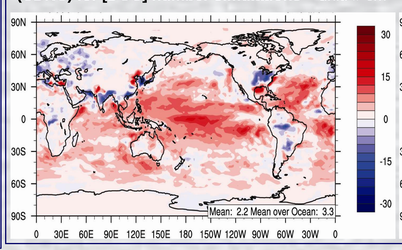


Contribution of marine organics to $PM_{2.5}$

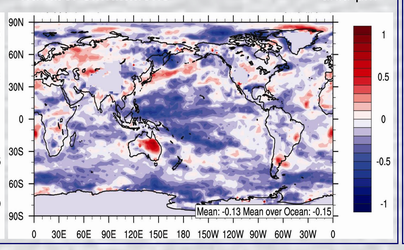


Effect of Marine Organics on shallow cloud (<850 mb)

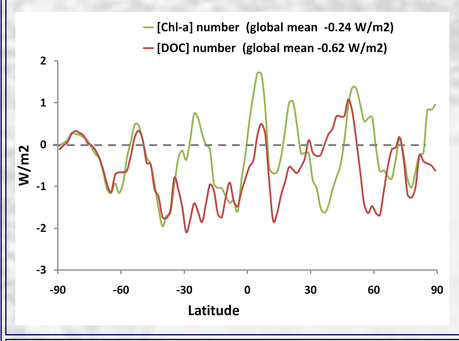
Change in in-cloud droplet number concentration (CDNC) for [DOC] number simulations unit: # cm^{-3}



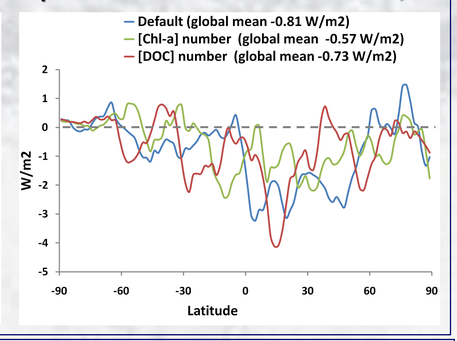
Change in droplet effective radius (r_e) for [DOC] number simulations unit: μm



Δ Shortwave Cloud Forcing (SWCF) (with marine *OC* – without Wm^{-2})



Indirect Effect (present – preindustrial SWCF Wm^{-2})



Summary

✓ **New marine primary organic aerosol emission function** based on **[DOC]** and **wind speed** has been developed

- Addition of marine OC aerosols increases **coastal $PM_{2.5}$** mass by **0.1- 0.3 μgm^{-3}** (up to **5%**) and **coastal $OC_{2.5}$** concentration up to **15%**
- Small changes (**0.2 ppb**, **0.5%**) are predicted in O_3 concentration over coastal urban areas in the Top-down approach; changes in Bottom-up approach was trivial

[Chl-*a*] *mass* simulation compared to Default: No considerable change in shallow cloud microphysical properties is predicted when marine OC aerosols are added as **mass** to a**c**cumulation mode aerosols

[Chl-*a*] *number* simulation compared to Default:

⇒Increased shallow cloud **CDNC** by **6.5%** over the global oceans and by **10%** over the Southern Ocean (SO)
⇒Increased **LWP** by **1.5%** over the global ocean and by **1.7%** over the SO
⇒Decreased cloud top r_e by **0.20 μm** over the global ocean
⇒Increased global mean **SWCF** by **- 0.24 W/m^2**

[DOC] *number* simulation compared to Default:

❖ Increased shallow cloud **CDNC** by **8.5%** over the global oceans and by **23%** over the equatorial waters (EW)
❖ Increased **LWP** by **1.8%** over the global ocean and by **4.4%** over the EW
❖ Decreased cloud top r_e by **0.19 μm** over the global ocean
❖ Increased global mean **SWCF** by **-0.62 W/m^2**

Predicted reduction of indirect effect due to background marine OC aerosol 0.0 to 0.20 W/m^2

Simulated CDNC in Different Ocean Parts

	In-cloud CDNC at 970mb over the ocean (unit: #/cm^3)					Global mean vertically integrated CDNC (#/m^2)
	North Pacific	North Atlantic	Southern Ocean	Equatorial Pacific	Global Ocean	
Default	50.3	53.0	47.5	43.1	43.2	3.27e+10
[Chl-*a*] number	57.5	59.0	56.1	45.5	47.5	3.34e+10
[DOC] number	54.5	56.1	52.9	57.9	49.1	3.36e+10

Simulated Global Mean Clouds Properties and Precipitation§

	LWP (g/m^2)	IWP* (g/m^2)	r_e-top (μm)	COT	Precipitation (mm/day)	SWCF (W/m^2)
Default	66.5/56.2	33.5/30.2	9.60/9.45	32.2/30.5	2.62/2.25	-64.0/-54.6
[Chl-*a*] number	67.5/56.7	33.7/30.3	9.40/9.24	33.4/31.4	2.63/2.25	-64.6/-54.9
[DOC] number	67.7/57.0	33.6/30.3	9.35/9.14	33.6/31.5	2.63/2.25	-65.0/-55.2

§ Over the ocean/global mean; * Ice water path (IWP)

Future Work

✓ Finish implementation of new SOA production mechanism for terrestrial isoprene
✓ Conduct long-term climate simulations for 2001-2010 and 2050-2059 (IPCC A1) with different model configurations

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