

---

**Effect of Terrestrial and Marine Organic Aerosol on Regional and Global Climate: Model Development, Application, and Verification with Satellite Data**

**Final Project Report for the period** 12/15/2007 to 12/14/2011  
*U.S. Department of Energy, Grant No: DE-FG02-08ER64508*  
Grant ID: ER64508-1031104-0013943

---

Principal investigator: Meskhidze, Nicholas  
Assistant Professor  
Marine Earth and Atmospheric Sciences  
North Carolina State University  
Tel: (919) 515-7243

Co-PIs: Zhang, Yang                      Marine, Earth & Atmospheric Sciences  
          Kamykowski, Daniel          Marine Earth & Atmospheric Sciences

## **1. Introduction**

In this DOE project the improvements to parameterization of marine primary organic matter (POM) emissions, hygroscopic properties of marine POM, marine isoprene derived secondary organic aerosol (SOA) emissions, surfactant effects, new cloud droplet activation parameterization have been implemented into Community Atmosphere Model (CAM 5.0), with a seven mode aerosol module from the Pacific Northwest National Laboratory (PNNL)'s Modal Aerosol Model (MAM7). The effects of marine aerosols derived from sea spray and ocean emitted biogenic volatile organic compounds (BVOCs) on microphysical properties of clouds were explored by conducting 10 year CAM5.0-MAM7 model simulations at a grid resolution  $1.9^{\circ} \times 2.5^{\circ}$  with 30 vertical layers. Model-predicted relationship between ocean physical and biological systems and the abundance of CCN in remote marine atmosphere was compared to data from the A-Train satellites (MODIS, CALIPSO, AMSR-E). Model simulations show that on average, primary and secondary organic aerosol emissions from the ocean can yield up to 20% increase in Cloud Condensation Nuclei (CCN) at 0.2% Supersaturation, and up to 5% increases in droplet number concentration of global maritime shallow clouds. Marine organics were treated as internally or externally mixed with sea salt. Changes associated with cloud properties reduced (absolute value) the model-predicted short wave cloud forcing from  $-1.35 \text{ Wm}^{-2}$  to  $-0.25 \text{ Wm}^{-2}$ . By using different emission scenarios, and droplet activation parameterizations, this study suggests that addition of marine primary aerosols and biologically generated reactive gases makes an important difference in radiative forcing assessments.

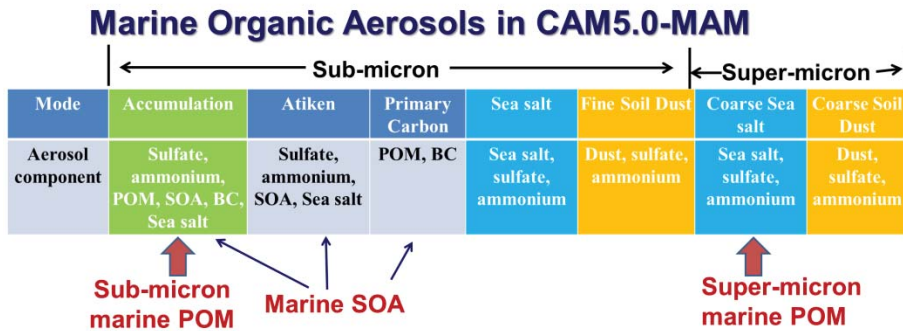
All baseline and sensitivity simulations for 2001 and 2050 using global-through-urban WRF/Chem (GU-WRF) were completed. The main objective of these simulations was to evaluate the capability of GU-WRF for an accurate representation of the global atmosphere by exploring the most accurate configuration of physics options in GWRF for global scale modeling in 2001 at a horizontal grid resolution of  $1^{\circ} \times 1^{\circ}$ . GU-WRF model output was evaluated using observational datasets from a variety of sources including surface based observations (NCDC and BSRN), model reanalysis (NCEP/ NCAR Reanalysis and CMAP), and remotely-sensed data (TRMM) to evaluate the ability of GU-WRF to simulate atmospheric variables at the surface as well as aloft. Explicit treatment of nanoparticles produced from new particle formation in GU-WRF/Chem-MADRID was achieved by expanding particle size sections from 8 to 12 to cover particles with the size range of 1.16 nm to 11.6  $\mu\text{m}$ . Simulations with two different nucleation parameterizations were conducted for August 2002 over a global domain at a  $4^{\circ}$  by  $5^{\circ}$  horizontal resolution. The results are evaluated against field measurement data from the 2002 Aerosol Nucleation and Real Time Characterization Experiment (ANARChE) in Atlanta, Georgia, as well as satellite and reanalysis data.

We have also explored the relationship between “clean marine” aerosol optical properties and ocean surface wind speed using remotely sensed data from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board the CALIPSO satellite and the Advanced Microwave Scanning Radiometer (AMSR-E) on board the AQUA satellite. Detailed data analyses were carried out over 15 regions selected to be representative of different areas of the global ocean for the time period from June 2006 to April 2011. We show that for very low (less than  $4 \text{ m s}^{-1}$ ) and very high (more than  $12 \text{ m s}^{-1}$ ) wind speed conditions the mean CALIPSO-derived aerosol optical depth (AOD) has little dependency on the surface wind speed. For an intermediate (between  $4$  and  $12 \text{ m s}^{-1}$ ) marine AOD was linearly correlated with the surface wind speed values, with a slope of  $0.0062 \text{ s m}^{-1}$ . Results of our study suggest that considerable

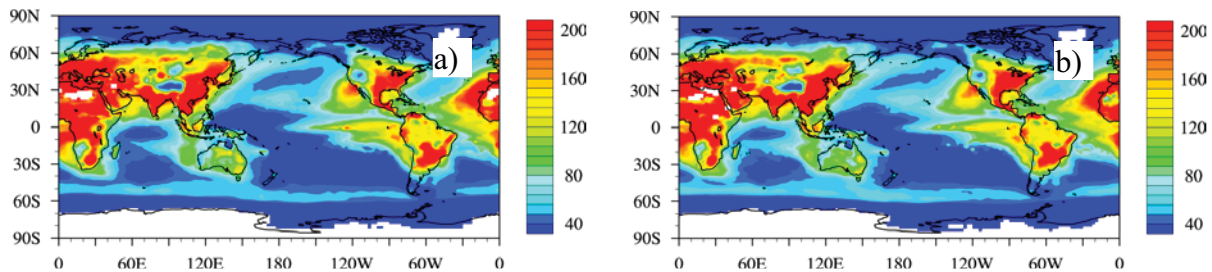
improvements to both optical properties of marine aerosols and their production mechanisms can be achieved by discriminating “clean marine” aerosols (or sea salt particles) from all other types of aerosols present over the ocean.

## 2. CAM5 Model Development

Several new/improved modules have been developed and implemented into the CAM5 model to allow better quantification of aerosol-cloud interaction and assessments of the effects of marine aerosols on clouds. Aerosol activation/droplet nucleation parameterization of Fountoukis and Nenes (2005) was implemented in a manner consistent with the existing Abdul-Razzak and Ghan (2000) aerosol activation parameterization to facilitate the direct model intercomparison. To quantify radiative effects of marine aerosols in the overlying atmosphere, prognostic emissions mechanism for marine OC aerosol (Gantt et al., 2011 and Gantt et al., 2011) were implemented. The marine OC emission module considers contributions from both sub- and super-micron marine POM aerosols and ocean derived SOA from the oxidation of phytoplankton-emitted isoprene. Figure 1 shows schematic diagram for the implementation of marine organic aerosols in seven-modal version of CAM5. Over most of the oceans total mass OC of marine origin was primarily driven by POM emissions, with smaller contribution from SOA derived from phytoplankton produced BVOCs.



**Figure 1.** Schematic diagram for the implementation of marine organic aerosols in seven-modal version of CAM5.0-MAM7.

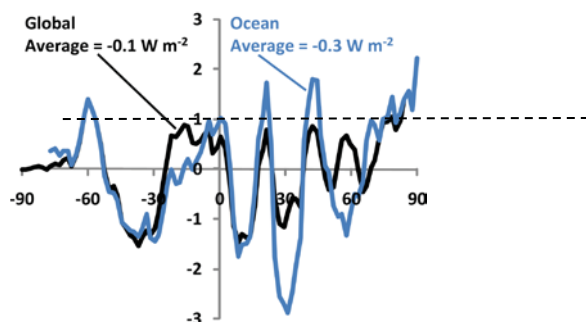


**Figure 2.** Model predicted in-cloud droplet number concentration ( $\text{cm}^{-3}$ ) from 940-985 mb for without a) and with b) marine organic carbon aerosol.

Analysis of model simulations show considerable effects of marine organic aerosols on the shallow cloud droplet concentration (CDNC), liquid water content (LWC), effective radii ( $r_e$ ) and liquid cloud fraction (CF). Fig. 2 shows model predicted in-cloud droplet number

concentration ( $\text{cm}^{-3}$ ) from 940-985 mb for the default (no marine emissions) and with marine organic carbon aerosol included.

CAM5 model simulations (see Fig. 3) show considerable differences in model-simulated indirect effect (present - preindustrial shortwave cloud forcing (SWCF) in  $\text{Wm}^{-2}$ ) with default simulations and simulations with marine OC emissions. Model estimated 10-year mean increase in SWCF is  $\sim -0.1 \text{ Wm}^{-2}$  for different emissions scenarios. Our model simulations indicate that marine emissions of primary and secondary organic aerosol may influence current assessments of aerosol indirect effect.

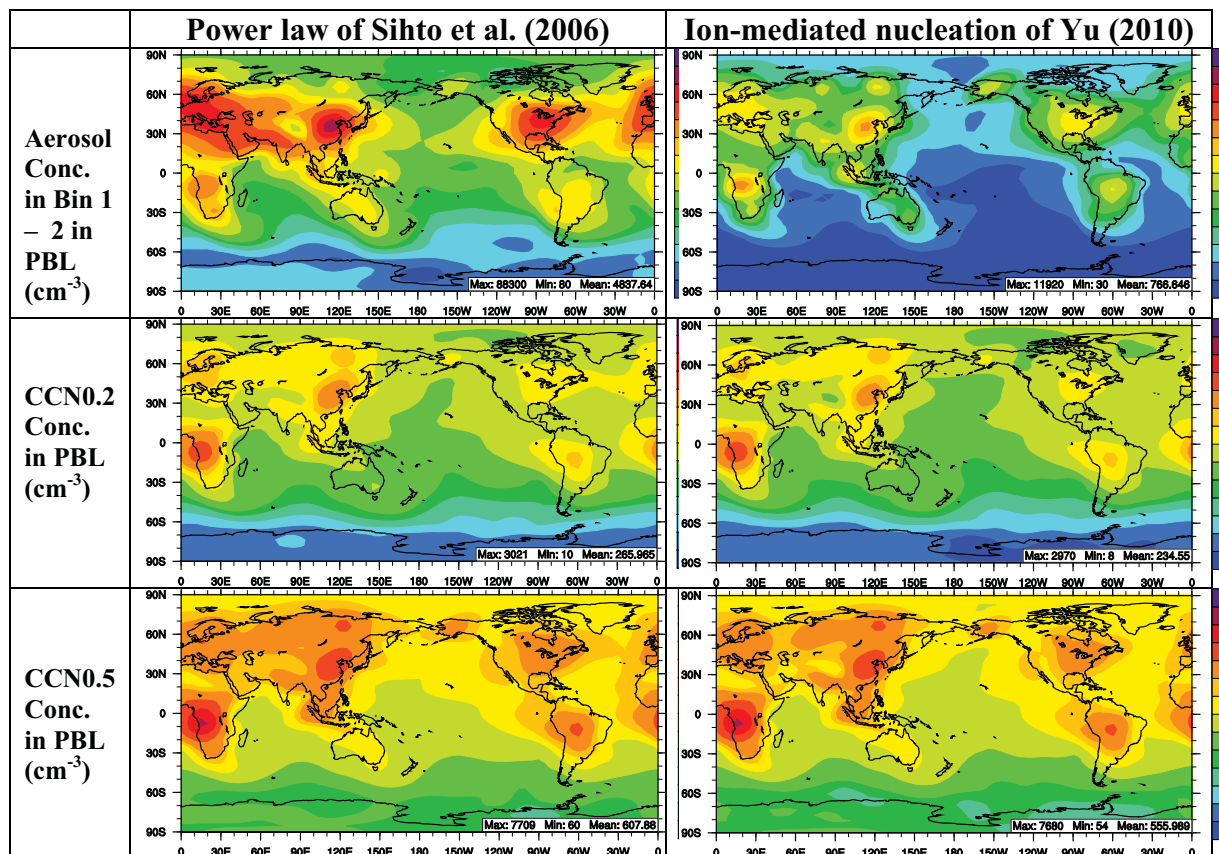


**Figure 3.** Model predicted difference in the shortwave cloud forcing ( $\text{W m}^{-2}$ ) for simulations without and with marine organic carbon aerosols.

### 3. GU-WRF/Chem Model Development

#### 3.1 New Particle Formation Algorithm for GU-WRF/Chem

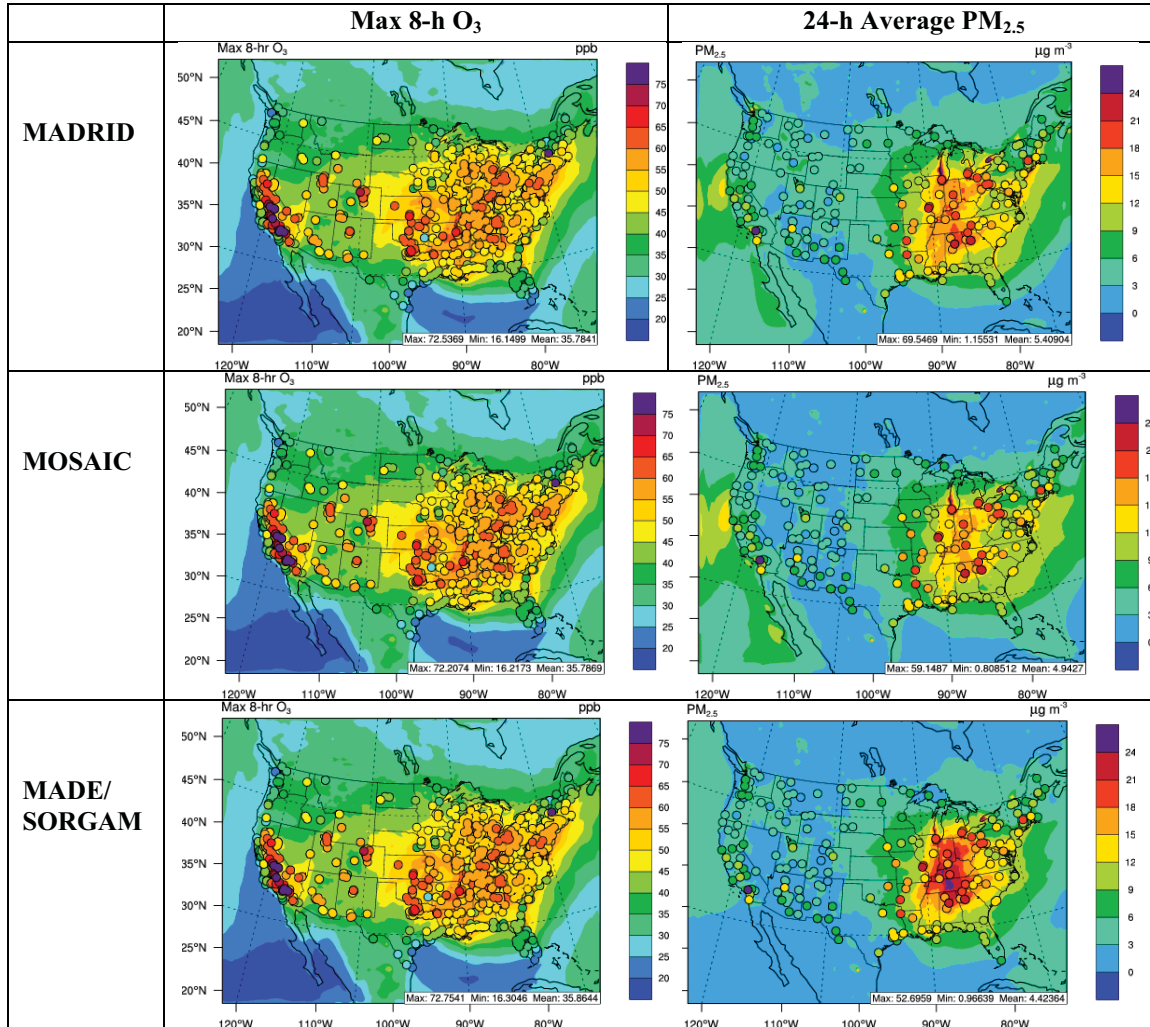
GU-WRF/Chem-MADRID (Zhang et al., 2011) uses a default sectional structure with 8 size bins over the size range of 25 nm - 11.6  $\mu\text{m}$ . New particles formed from homogeneous nucleation are injected into the first size bin based on mass balance, which introduces some uncertainties. To overcome this limitation and explicitly treat nanoparticles produced from new particle formation, we expand particle size sections from 8 to 12 to cover particles with the size range of 1.16 nm to 11.6  $\mu\text{m}$  for the global version of WRF/Chem. Simulations with two nucleation parameterizations, the power law of Sihto et al. (2006) and ion-mediated nucleation of Yu (2010) were conducted for August 2002 over a global domain at a  $4^\circ \times 5^\circ$  horizontal resolution. The results are evaluated against field measurement data from the 2002 Aerosol Nucleation and Real Time Characterization Experiment (ANARChE) in Atlanta, Georgia, as well as satellite and reanalysis data. Figure 4 shows simulated surface level PM number concentrations in Bins 1-3 (1.16 – 10 nm) and cloud condensation nuclei (CCN) in the planetary boundary layer (PBL) from Sihto et al. (2006) and Yu (2010). As shown, Sihto et al. (2006) gives much higher aerosol number concentrations than Yu (2010), leading to higher CCN at a supersaturation of 0.2% but similar CCN at a supersaturation of 0.5%.



**Figure 4.** Simulated monthly-mean aerosol number concentrations in size bins 1-3 (1.16 – 10 nm) and cloud condensation nuclei at a supersaturation of 0.2% (CCN0.2) and 0.5% (CCN0.5) from GU-WRF/Chem for August 2002.

Simulated meteorological variables (e.g., temperature and relative humidity at 2-m (T2 and RH2, respectively)), concentrations of precursors for homogeneous nucleation (e.g., SO<sub>2</sub> and NH<sub>3</sub>), and PM number concentrations in the size ranges of 3-11.6 nm and 11.6-116 nm were consistent with the observations from ANARChE at Jefferson street (JST), Atlanta, Georgia. Even at a very coarse grid resolution, the model is able to capture the diurnal variation of T2 and RH2, despite overpredictions of daily maximum T2 and underpredictions of daily minimum RH2. Larger biases exist in concentration predictions of SO<sub>2</sub> and NH<sub>3</sub>. The model is incapable of capturing extreme concentration values of SO<sub>2</sub> (either very high or very low values) and high levels of NH<sub>3</sub> at this coarse grid resolution. In addition to a very coarse grid resolution, uncertainties in their emissions may contribute to the model biases. The inaccuracies in the precursors are propagated into aerosol number concentrations, leading to a net underprediction for both simulations. The power law of Sihto et al. (2006) predicts surface PM number conc. in aerosol size bins 1-3 (1.16 – 10 nm) higher by factors of 8 – 10 and differing in diurnal variation patterns as compared with ion-mediated nucleation of Yu (2010), likely because the former does not account for the dependence of nucleation rates on temperature and surface areas of aerosols whereas the latter does. Neither parameterizations can reproduce observed PM number concentrations between 3 and 11.6 nm at JST, although the simulation with the power law of Sihto et al. (2006) gives PM number concentrations and temporal variations that are closer to observations. Likely causes for such discrepancies include the coarse grid resolution used in the

simulations, uncertainties associated with both nucleation parameterizations, and the model inputs and treatments of major processes affecting model predictions. Model sensitivity simulations at a grid resolution of 4-km may help diagnose the reasons and reduce the biases.



**Figure 5.** Overlay of observations and simulated O<sub>3</sub> and PM<sub>2.5</sub> concentrations from WRF/Chem simulations with three aerosol modules: MADRID, MOSAIC, and MADE/SORGAM. The cycle symbols represent available observations from various networks in the U.S

### 3.2 Coupling of CB05 with MADE/SORGAM in WRF/Chem

We have completed the coupling of CB05 with MADE/SORGAM in meso-scale WRF/Chem and conducted some test simulations using meso-scale WRF/Chem with three aerosol modules including MADRID, MOSAIC, and MADE/SORGAM over continental U.S. (CONUS) (Zhu and Zhang, 2011). Figure 5 shows contour plots for max 8-hr average O<sub>3</sub> and 24-hr average PM<sub>2.5</sub> concentrations over CONUS in July 2001. Three simulations have similar performance for O<sub>3</sub> predictions. However, larger differences exist in the predicted PM<sub>2.5</sub>

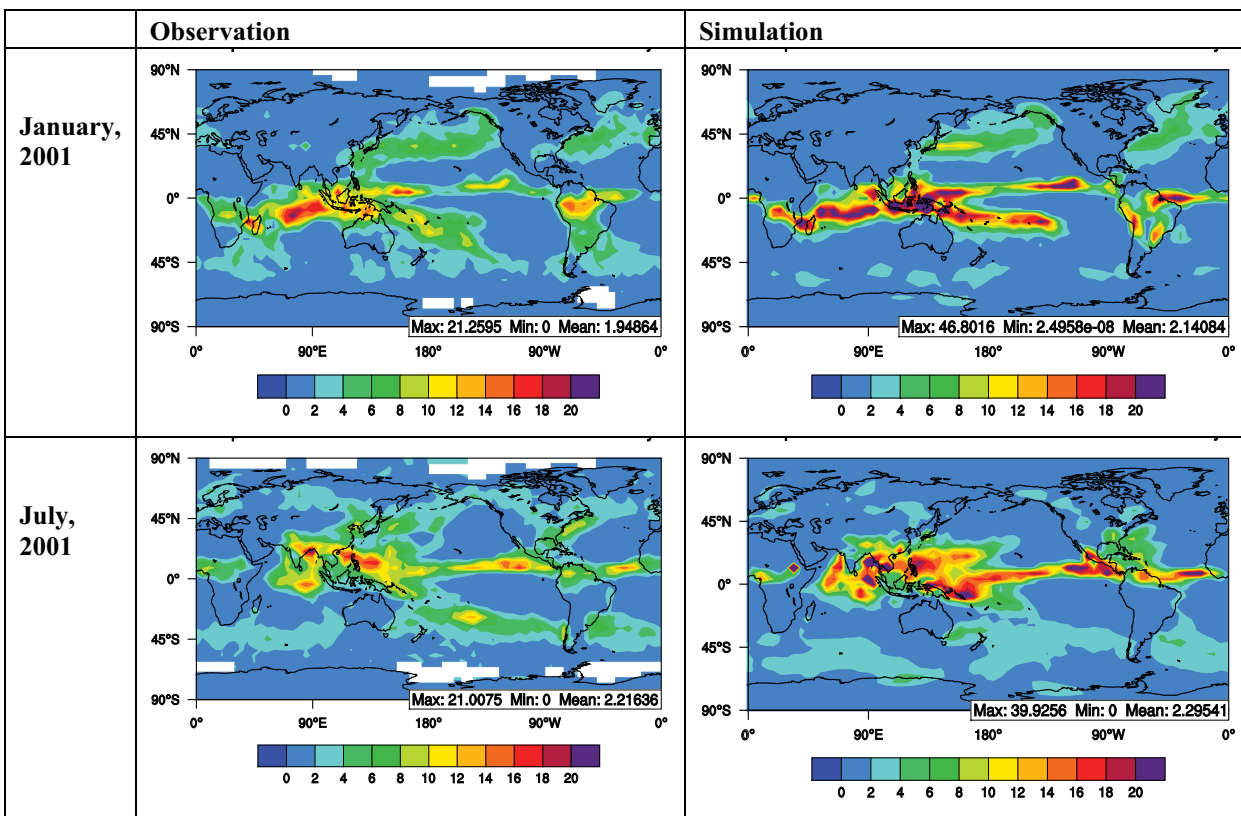
concentrations by the three simulations. Such differences are caused by different treatments and parameters used in these aerosol modules. For example, MOSIAC does not simulate SOA. MADRID includes a more advanced SOA than MADE/SORGAM, as it treats more SOA precursors (25 vs. 8 species). MADRID therefore gives the highest concentrations of SOA and thus organic matter (OM). Different PM<sub>2.5</sub> predictions result in different CCN and CDNC (see Figure 5).

### *3.3 Incorporation of marine primary organic matter (POM) and isoprene emissions into GU-WRF/Chem*

We have incorporated marine POM and isoprene emission modules of Gantt et al. (2011) developed for the CAM5 in this project into GU-WRF/Chem, which will allow the simulation of SOA from marine sources and the examination of their impacts on total aerosol direct and indirect radiative forcings. We conducted GU-WRF/Chem simulations with and without marine emissions and compare model predictions of aerosol number concentrations, CCN, and CDNC to estimate such impacts. One possible development is to consider the potential contributions of secondary condensable organics from terrestrial and marine sources to new particle formation via ternary nucleation. While such parameterizations are not yet available for 3-D model incorporation, a correction factor may be implemented in the existing H<sub>2</sub>SO<sub>4</sub>-H<sub>2</sub>O binary nucleation parameterization to estimate the co-nucleation effect of H<sub>2</sub>SO<sub>4</sub> and secondary condensable organics, following an approach similar to the work of Fan et al. (2006). These results are being compared with results from CAM5.0-MAM to examine the relative importance of marine emissions and resulting SOA in affecting aerosol radiative forcing over the ocean and the global scale. We plan to publish one paper on this work.

### *3.4 GU-WRF/Chem Model Applications: (1) Current Year Simulations*

GU-WRF/Chem has been applied to global-through-urban nested domains for January and July 2001 to study aerosol direct, semi-direct and indirect effects. These model simulation results are evaluated using in-situ ground - based and satellite observational dataset over the continental U.S. and satellite/reanalysis dataset. Fig. 6 compares simulated and observed precipitation. The observed precipitation was obtained from the CPC Merged Analysis of Precipitation (CMAP). The model is able to reproduce the synoptic spatial distribution of observed precipitation in both months, despite some overpredictions over some areas. Figure 6 shows the overlay of observed and simulated surface maximum 8-hr O<sub>3</sub> mixing ratios and 24-hr average PM<sub>2.5</sub> concentrations in July 2001 over CONUS domain. The model simulation gives overall good predictions of maximum 8-hr O<sub>3</sub> mixing ratios (with the normalized mean biases (NMBs) of -12.4%) and 24-hr average PM<sub>2.5</sub> concentrations (with NMBs of 7.9-18.2%).



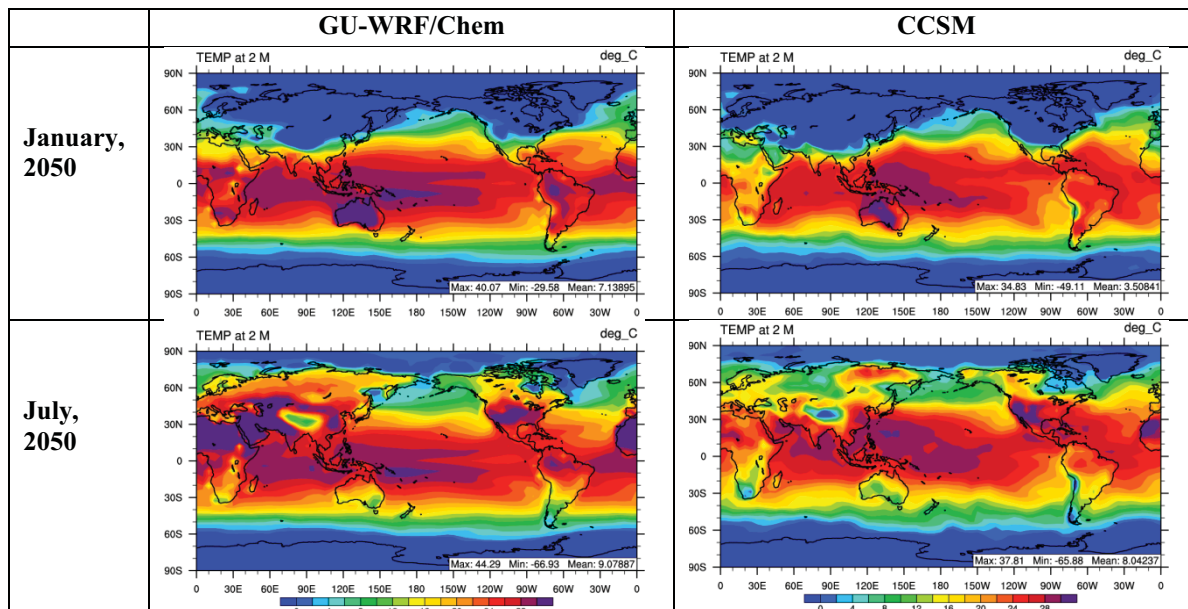
**Figure 6.** Observed and simulated daily total precipitation in January and July 2001. The observations were obtained from CMAP.

### 3.5 GU-WRF/Chem Model Applications: Future Year Simulations

GU-WRF/Chem has been applied to simulate air quality and climate, as well as their interactions in future years. Fig. 7 shows simulated monthly-mean temperatures at 2-m in January and July 2050 and their comparison with 10-year average monthly-mean temperatures during 2045-2054 simulated using the NCAR's Community Climate System Model (CCSM). Driven with CCSM's 10-year average sea surface temperature (SST) profiles, GU-WRF/Chem is able to provide spatial distributions of near surface temperatures that are similar to those simulated with CCSM, although GU-WRF/Chem gives higher surface temperatures than CCSM. Relative to summer 2001, model predicts  $\sim 1.1$  °C increase in the global mean T2 and  $\sim 0.03$  mm day<sup>-1</sup> decrease in total precipitation for summer 2050. Such changes coupled with changes in anthropogenic and biogenic emissions will lead to changes in air quality, radiation, and cloud variables. Sulfate concentrations are predicted to increase in most of the domain in responses to higher T2 and projected increased SO<sub>2</sub> emissions. AOD and CCN are predicted to increase in most of the domain in response to changes in aerosol concentrations, and CDNC tends to increase over ocean but decrease over most continents (except for a few areas such as south Asia and eastern U.S. where increases in CDNC occur) in summer 2050. GU-WRF/Chem simulates changes in CDNC due to major atmospheric processes including droplet nucleation/aerosol activation, advection of droplets from adjacent grid cells droplet loss from evaporation, collision/coalescence, collection by rain, ice, and snow, and freezing to form ice crystals following the parameterization of Ghan et al. (1997). The increase in the number of droplet



nucleated dominates over the ocean and the decrease in CDNC due to other processes such as advection and collision/coalescence dominates over most continents, leading to net changes in different signs in different areas.

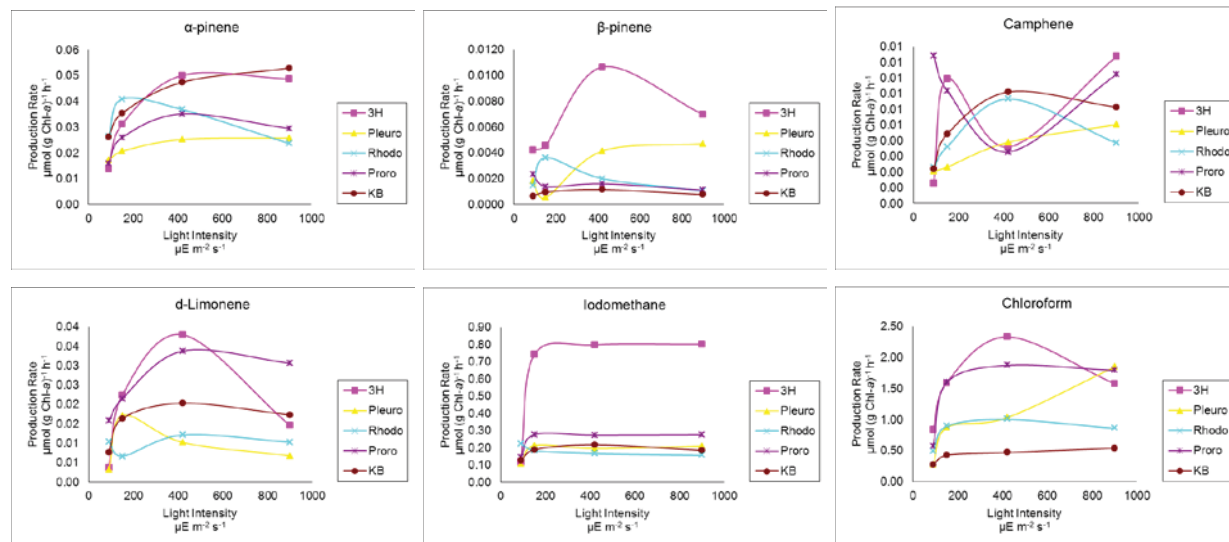


**Figure 7.** Simulated 2-m temperatures in January and July 2050 from GU-WRF/Chem vs. simulated 10-year (2046-2055) monthly-mean 2-m temperatures in January and July from CCSM

### New Laboratory Data for BVOC Emissions from Phytoplankton and Estuarine Samples

Emission rates of 40 different hydrocarbons (in addition to isoprene) were quantified for lab-grown non-axenic phytoplankton monocultures and ambient samples collected at the Pamlico-Neuse Estuary, NC. The samples were grown and maintained in 9.5L Pyrex bottles at climate controlled room. BVOCs accumulated in the water and headspace above the water were measured by passing the sample through a gas chromatography/mass spectrometry (Varian 220 GC-MS) system equipped with a sample pre-concentrator (CDS 8000). Inside the preconcentrator the compounds were trapped on a sorbent material, heated, and backflushed into the GC-MS that contains a CP-PoraBOND Q Fused Silica column. A split/splitless injection was used, with an initial splitless mode for 0.75 minutes, followed by a split ratio of 100:1 for 2.25 minutes, and then kept at a 20:1 split ratio for the remainder of the analysis. The column oven was maintained at 50°C for 2 minutes, followed by an increase of 6°C/min until 250°C (total of 35.33 minutes). The preconcentrator/GC-MS system gave at least 1000 times magnification of the sample concentrations, allowing detection of low ppt levels of hydrocarbons. Diatoms *Thalassiosira weissflogii* and *Thalassiosira pseudonana*, prymnesiophyte *Pleurochrysis carterae*, cryptophyte *Rhodomonas salina*, and dinoflagellates *Karina brevis* and *Procentrum minimum*, as well as Neuse River samples were subjected to differential light regimes to assess the photoproduction of different BVOCs. To make results widely usable, all the emissions were normalized to Chlorophyll-*a* concentration [Chl-*a*] and cell counts. The measurements showed that diatoms had the highest isoprene production rate of 2.8  $\mu\text{mol} (\text{g Chl-}a)^{-1} \text{h}^{-1}$  with ranges

between 1.4 and 3.6  $\mu\text{mol}(\text{g Chl-}a)^{-1} \text{h}^{-1}$  at light levels between 90 and 900  $\mu\text{E m}^{-2} \text{s}^{-1}$ , respectively. The prymnesiophyte and dinoflagellate species had isoprene production rates of  $1.3 \pm 0.4 \mu\text{mol}(\text{g Chl-}a)^{-1} \text{h}^{-1}$  with a similar light dependency as diatoms. Field samples had comparable isoprene production rate of  $3.5 \mu\text{mol}(\text{g Chl-}a)^{-1} \text{h}^{-1}$  with ranges between 0.6 and 4.1  $\mu\text{mol}(\text{g Chl-}a)^{-1} \text{h}^{-1}$  for similar light levels and temperatures between 18 to 30°C. Three monoterpenes detected were  $\alpha$ -pinene, camphene, and d-limonene. Diatoms had the highest  $\alpha$ -pinene and d-limonene production rates of  $0.045 \mu\text{mol}(\text{gChl-}a)^{-1} \text{h}^{-1}$  and  $0.015 \mu\text{mol}(\text{gChl-}a)^{-1} \text{h}^{-1}$ , respectively. The prymnesiophyte species had the highest camphene production of  $0.021 \mu\text{mol}(\text{gChl-}a)^{-1} \text{h}^{-1}$ . Production rates of d-limonene and camphene did not show a well-defined light dependency, but both isoprene and  $\alpha$ -pinene showed an increase in terpene production with increasing light intensities. Field samples show  $\alpha$ -pinene, d-limonene, and camphene production rates of  $0.05 \mu\text{mol}(\text{gChl-}a)^{-1} \text{h}^{-1}$ ,  $0.02 \mu\text{mol}(\text{gChl-}a)^{-1} \text{h}^{-1}$  and  $0.018 \mu\text{mol}(\text{gChl-}a)^{-1} \text{h}^{-1}$ , respectively. Field samples acclimated at 26°C had the highest terpene production rates. This is the first study that study tabulates (in a consisten manner) a large number of BVOC emission rates for various phytoplankton species under diverse environmental conditions. Remotely-sensed [Chl-*a*] in conjunction with laboratory measurements of BVOCs can be used to generate unique emission inventories for the large number of ocean emitted biogenic trace gases. Figure 8 shows some of the measured BVOC emissions for lab-grown phytoplankton monocultures.

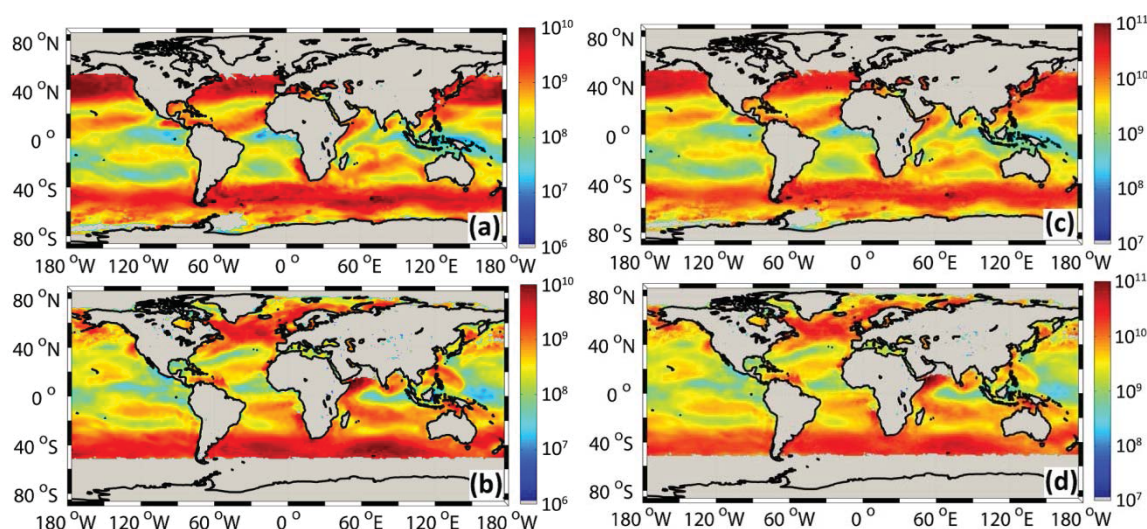


**Figure 8.** BVOC emissions for lab-grown non-axenic phytoplankton monocultures *Thalassiosira weissflogii* (3H) and *Rhodomaonas salina* (Rhodo), *Pleurochrysis carterae* (Pleuro), *Karina brevis* (KB) and *Procentrum minimum* (Proro).

## Global Marine Primary Organic Aerosol Emissions

In light of current evidence that organic aerosols can enter marine atmosphere through direct emissions of biogenic organic matter (OM) by the bubble bursting process, our project team considered generating input files for sub- and super-micron primary marine organic matter. Chemical analyses of marine aerosols show that OC residing in the sub- and super-micron modes of sea-spray particles has considerably different water solubility (Facchini et al., 2008). While

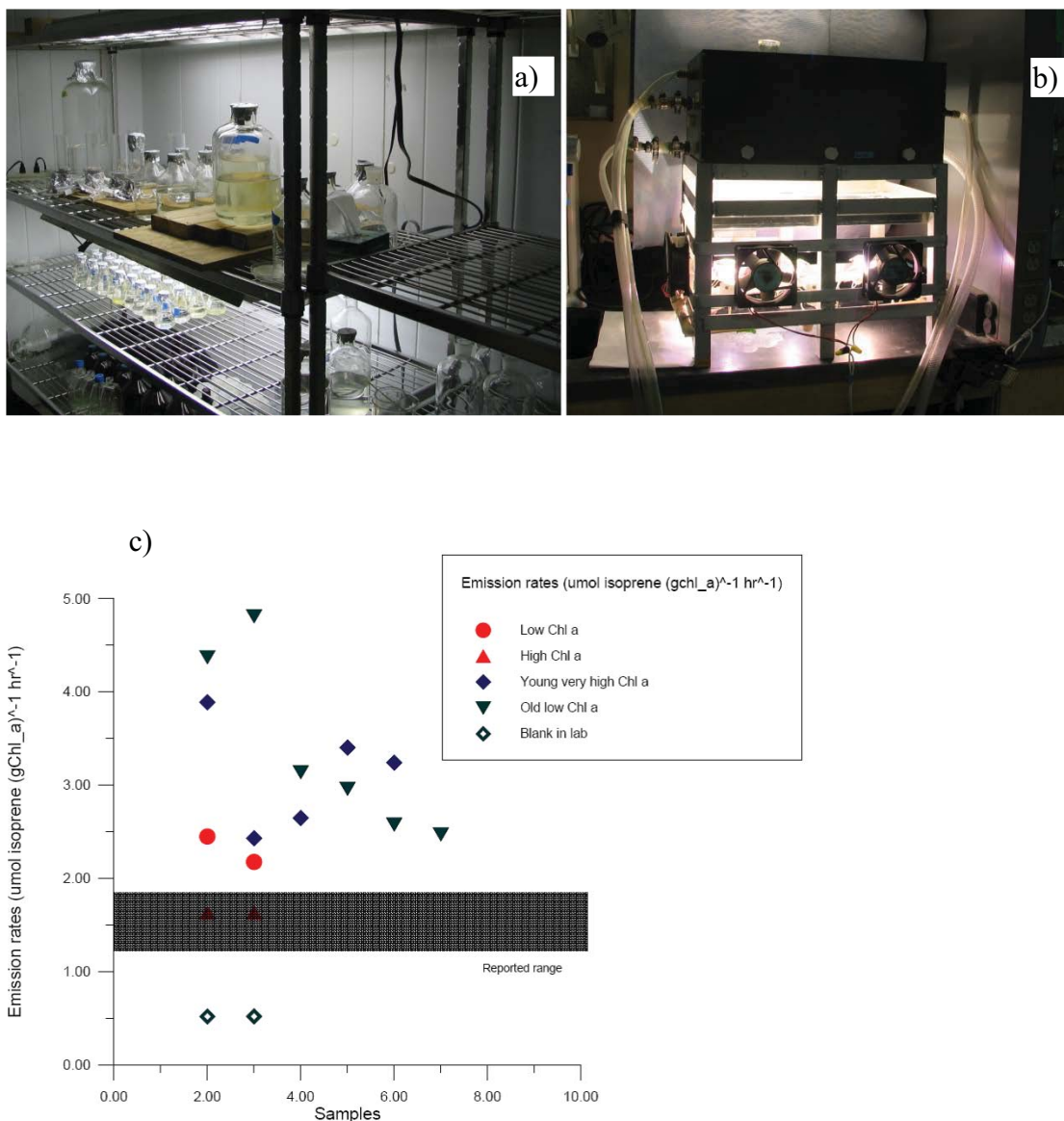
water-insoluble organic carbon (WIOC) comprises the major portion ( $94\pm 4\%$ ) of sub-micron OC particles, water soluble organic carbon (WSOC) contributes more than one third ( $33\pm 3\%$ ) of total carbon in the coarse size fraction of marine aerosols (Facchini et al., 2008). The global marine primary OC emissions were estimated separately in sub- and super-micron range. Over the productive regions of the oceans, the sub-micron marine aerosol mass was shown to be dominated by insoluble organics, while the super-micron aerosols were dominated by sea-salt (Facchini et al., 2008). The sub-micron mass emission rate of marine primary organic aerosols is obtained by multiplying the mass emission rate of marine particles less than  $1\mu\text{m}$  in diameter from Ceburnis et al. (2008) while the super-micron primary organic mass emission rate is calculated using a Gong-Monahan function (Gong, 2003). More details can be found in Gantt et al. (2009). The sub- and super-micron primary OC emission rates for January and July 2001 are shown in Figure 9a-d.



**Figure 9.** Monthly-average sub- and super-micron primary OC emission rate ( $\text{molecules C cm}^{-2} \text{s}^{-1}$ ) for January (a, c) and July (b, d) 2001..

### Laboratory Measurements of Isoprene Emissions

The project team has made multiple experiments for isoprene emissions from different plankton species using headspace gas chromatography. To obtain isoprene emission rates for phytoplankton species characteristic to the world ocean, we have purchased different algal cultures and grew them in an incubation chamber (Figure 10a). To assess the effect of changing incoming solar radiation for isoprene production, the plankton was exposed to various levels of light intensity. The ambient conditions were imitated by using light intensities between  $100$  and  $1000 \text{ W m}^{-2}$ . Based on our lab experiments, the isoprene production rates for different species were determined using exponential relationship with the light intensity. Figure 10c shows isoprene emission rates for different phytoplankton species and different light regimes. To assure the accuracy of our measurements, we have calibrated our GC against Dr. Jose Fuentes's PT-RMS (Proton Transfer Reaction Mass Spectrometry) during extensive field campaign at the University of Virginia.



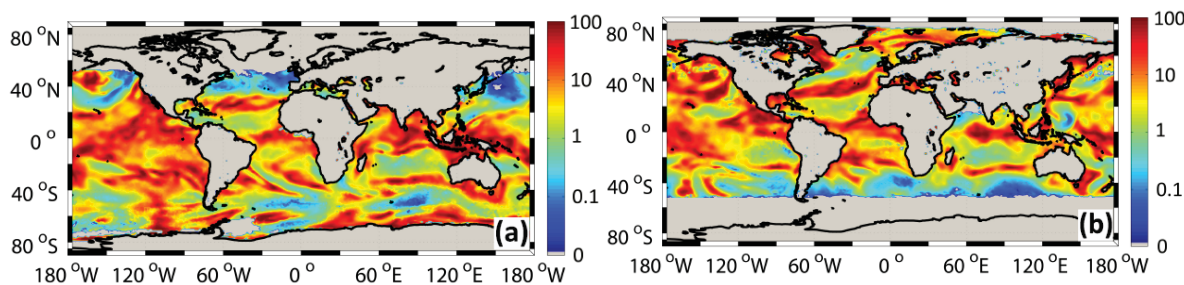
**Figure 10.** a) Phytoplankton growth chamber with variable light capability and temperature control; b) Typical configuration used for measuring isoprene emission from different phytoplankton species under different light and temperature conditions, c) Isoprene emission rates for different plankton species and different light regimes.

#### 4. Results from project-related peer-reviewed papers

##### 4.1 The Major Achievements of *Gantt et al. (2009)* Study

The relative contribution of SOA from marine isoprene to the total marine organic aerosol burden has been a topic of discussion in several recent papers. Dynamic, physically-based emission mechanisms for both primary OC and marine isoprene used in this study allow us to evaluate spatial and temporal distribution of the percentage contribution of marine isoprene

SOA to the total simulated marine organic aerosol emissions. Here we focus on total sub-micron OC aerosols (sub-micron primary OC + marine isoprene SOA) because of their potential influence on CCN activation of marine aerosols (O'Dowd *et al.*, 2004). Figure 11 shows that the localized percentage contributions of marine isoprene SOA to the total sub-micron marine OC emissions approach 50%, even in areas with low monthly-averaged values (i.e., mid-latitude regions). Because emissions of marine isoprene and primary OC aerosols are primarily driven by solar radiation and surface wind speed respectively, the local meteorology plays a large role in determining the percentage contribution of marine isoprene SOA to total OC. Therefore, Fig. 11 shows that marine isoprene emissions at much higher temporal resolution (with a time step on the order of an hour) may be required in order for the global models to correctly simulate radiative effect of marine OC aerosols.

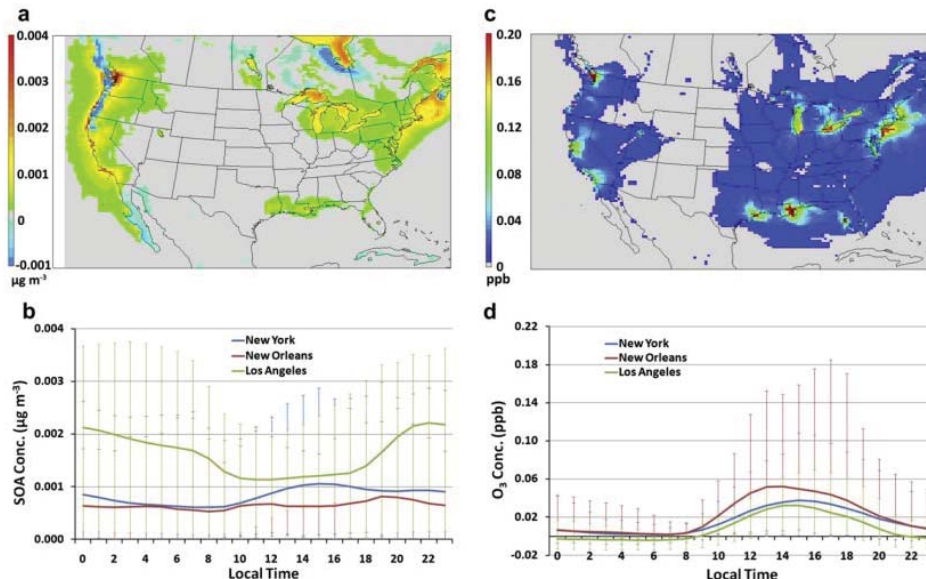


**Figure 11.** Percentage contribution of daily maximum marine isoprene SOA to corresponding total (primary and secondary) sub-micron marine OC emissions for (a) 1 January and (b) 1 July 2001.

#### 4.2 The Major Achievements of Gantt *et al.* (2010a) Study

The impact of marine isoprene emissions on summertime surface concentrations of isoprene, secondary organic aerosols (SOA), and ozone ( $O_3$ ) in the coastal areas of the continental United States is studied using the U.S. Environmental Protection Agency regional-scale Community Multiscale Air Quality (CMAQ) modeling system. Marine isoprene emission rates are based on the following five parameters: laboratory measurements of isoprene production from phytoplankton under a range of light conditions, remotely sensed chlorophyll-*a* concentration ([Chl-*a*]), incoming solar radiation, surface wind speed, and sea-water optical properties. Model simulations show that marine isoprene emissions are sensitive to meteorology and ocean ecosystem productivity, with the highest rates simulated over the Gulf of Mexico. Simulated offshore surface layer marine isoprene concentration is less than 10 ppt and significantly dwarfed by terrestrial emissions over the continental United States. With the isoprene reactions included in this study, the average contribution of marine isoprene to SOA and  $O_3$  concentrations is predicted to be small, up to  $0.004 \text{ mgm}^{-3}$  for SOA and 0.2 ppb for  $O_3$  in coastal urban areas. The light-sensitivity of isoprene production from phytoplankton results in a midday maximum for marine isoprene emissions and a corresponding daytime increase in isoprene and  $O_3$  concentrations in coastal locations. The potential impact of the daily variability in [Chl-*a*] on  $O_3$  and SOA concentrations is simulated in a sensitivity study with [Chl-*a*] increased and decreased by a factor of five. Our results indicate that marine emissions of isoprene cause minor changes to coastal SOA and  $O_3$  concentrations. Comparison of model simulations with few available measurements shows that the model underestimates marine boundary layer isoprene concentration. This underestimation is likely due to the limitations in

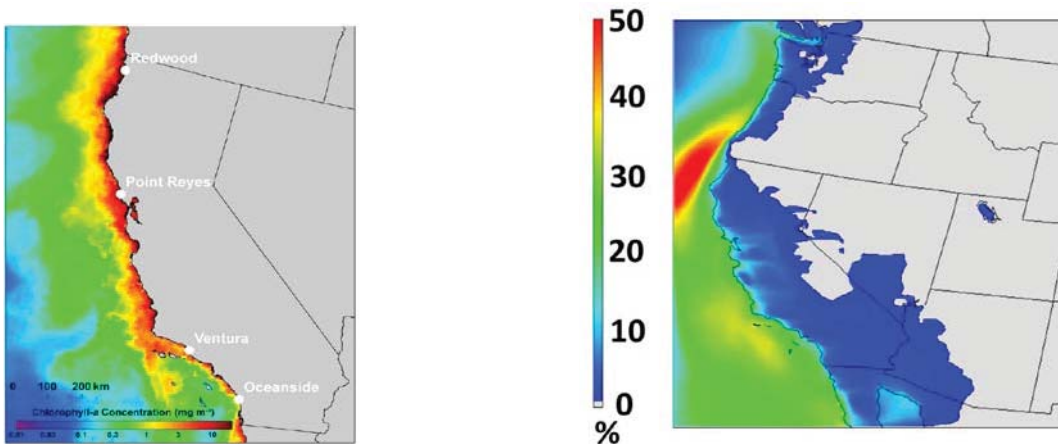
current treatment of marine isoprene emission and a coarse spatial resolution used in the model simulations.



**Figure 12.** Model predicted domain-wide monthly average marine isoprene-derived (a) SOA and (c) 8-h average O<sub>3</sub> concentrations in the MBL. Monthly average hourly values for (b) SOA and (d) O<sub>3</sub> are shown for New York, New Orleans, and Los Angeles for July, 2001. Error bars on Fig. 7b and 7d show the highest and lowest simulated values during the monthly time period.

### 4.3 The Major Achievements of Gantt et al. (2010b) Study

The contribution of marine organic emissions to the air quality in coastal areas of the western United States is studied using the latest version of the US Environmental Protection Agency (EPA) regional-scale Community Multiscale Air Quality (CMAQv4.7) modeling system. Emissions of marine isoprene, monoterpenes, and primary organic matter (POM) from the ocean are implemented into the model to provide a comprehensive view of the connection between ocean biology and atmospheric chemistry and air pollution. Model simulations show that marine organics can increase the concentration of PM<sub>2.5</sub> by 0.1–0.3  $\mu\text{g m}^{-3}$  (up to 5%) in some coastal cities such as San Francisco, CA. This increase in the PM<sub>2.5</sub> concentration is primarily attributed to the POM emissions, with small contributions from the marine isoprene and monoterpenes. When marine organic emissions are included, organic carbon (OC) concentrations over the remote ocean are increased by up to 50% (25% in coastal areas), values consistent with recent observational findings. This study is the first to quantify the air quality impacts from marine POM and monoterpenes for the United States, and it highlights the need for inclusion of marine organic emissions in air quality models.

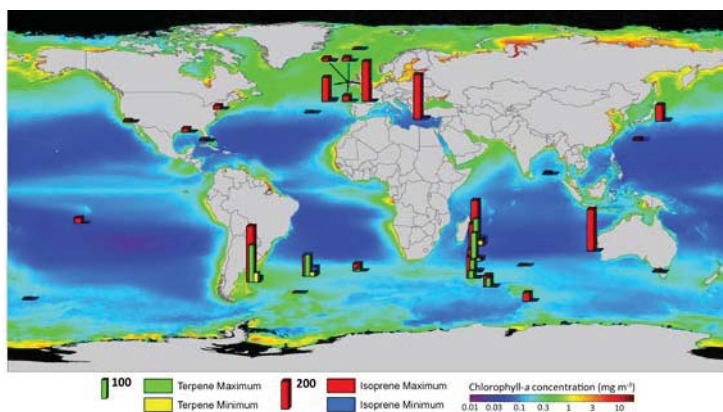


**Figure 13.** Locations of the IMPROVE and PAMS stations used in this study and the seasonally-averaged [Chl-*a*] concentrations for the summer of 2005.

**Figure 14.** Average percentage contribution of marine organics to surface OC<sub>2.5</sub> concentration for the bottom-up simulation from 1 June to 31 August 2005.

#### 4.4 The Major Achievements of Shaw et al. [2010] Study

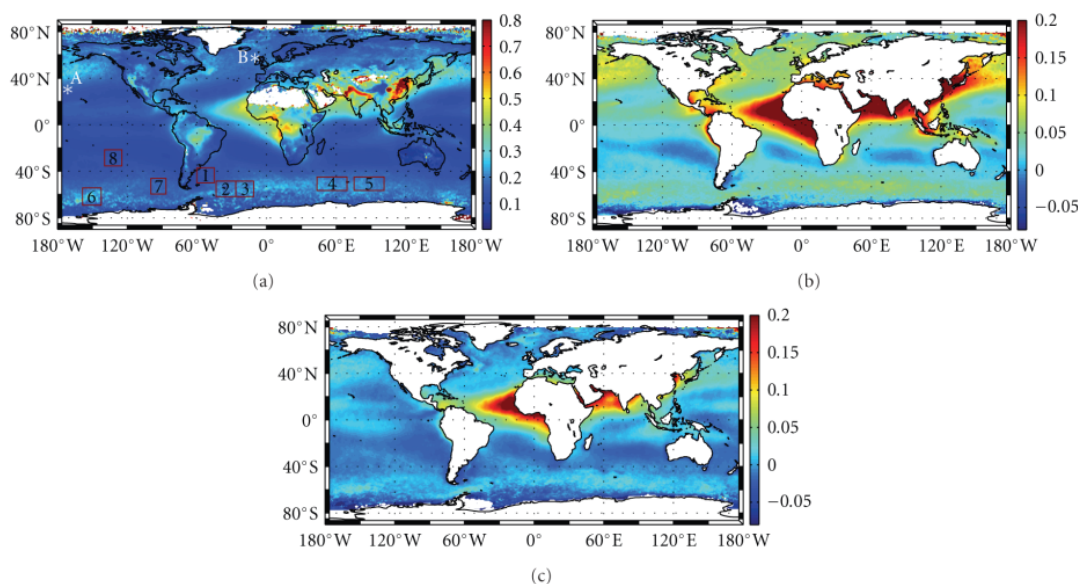
Terrestrial and marine photosynthetic organisms emit trace gases, including isoprene and monoterpenes. The resulting emissions can impact the atmosphere through oxidative chemistry and formation of secondary organic aerosol. Large uncertainty exists as to the magnitude of the marine sources of these compounds, their controlling factors, and contribution to marine aerosol. In recent years the number of relevant studies has increased substantially, necessitating the review of this topic. Isoprene emissions vary with plankton species, chlorophyll concentration, light, and other factors. Remote marine boundary layer isoprene mixing ratios can reach >300 pptv, and extrapolated global ocean fluxes range from <1 to >10 Tg C year<sup>-1</sup>. Modeling studies using surface chlorophyll concentration as an isoprene emissions proxy suggest variable atmospheric impacts. More information is needed, including emission fluxes of isoprene and monoterpenes from various biogeographical areas, the effects of species and nutrient limitation on emissions, and the aerosol yields via condensation and nucleation, in order to better quantify the atmospheric impacts of marine isoprene and monoterpenes.



**Figure 15.** Marine isoprene and monoterpene atmospheric mixing ratios (in pptv) overlaid over remotely sensed 2000-2009 averaged [Chl-*a*] map.

#### 4.5 The Major Achievements of Meskhidze and Nenes [2010] Study

Using satellite data for the surface ocean, aerosol optical depth (AOD), and cloud microphysical parameters, we show that statistically significant positive correlations exist between ocean ecosystem productivity, the abundance of submicron aerosols, and cloud microphysical properties over different parts of the remote oceans. The correlation coefficient for remotely sensed surface chlorophyll *a* concentration ([Chl-*a*]) and liquid cloud effective radii over productive areas of the oceans varies between  $-0.2$  and  $-0.6$ . Special attention is given to identifying (and addressing) problems from correlation analysis used in the previous studies that can lead to erroneous conclusions. A new approach (using the difference between retrieved AOD and predicted sea salt aerosol optical depth,  $AOD_{diff}$ ) is developed to explore causal links between ocean physical and biological systems and the abundance of cloud condensation nuclei (CCN) in the remote marine atmosphere. We have found that over multiple time periods, 550nm  $AOD_{diff}$  (sensitive to accumulation mode aerosol, which is the prime contributor to CCN) correlates well with [Chl-*a*] over the productive waters of the Southern Ocean. Since [Chl-*a*] can be used as a proxy of ocean biological productivity, our analysis demonstrates the role of ocean ecology in contributing CCN, thus shaping the microphysical properties of low-level marine clouds.



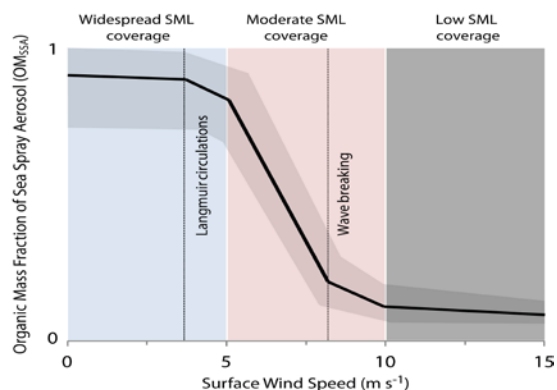
**Figure 16.** Seven-year (2002–2008) averaged daily data for (a) MODIS AOD at 550nm and the differences between MODIS AOD and parameterized ss-AOD at (b) 550nm and (c) 1020 nm. The ss-AOD is calculated using Smirnov et al. (2003) regression. Red boxes on Fig. 13 (a) indicate seven regions where time series analyses are carried out. Letters A and B denote locations of previous study areas of Smirnov et al. (2003) at Midway Islands (28.2°N and 177.4°W) and Mulchay et al. (2008) at the Mace Head station (53.3°N, 9.9°W), respectively.

#### 4.6 The Major Achievements of Gantt et al. (2011) Study

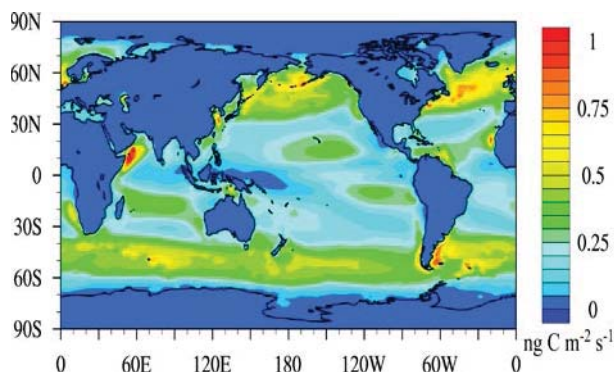
We proposed that organic enrichment at the air-sea interface, chemical composition of seawater, and the aerosol size are three main parameters controlling the organic mass fraction of sea spray aerosol ( $OM_{SSA}$ ). To test this hypothesis, we developed a new marine POA emission function based on a conceptual relationship between the organic enrichment at the air-sea



interface and surface wind speed. We considered the effect of the surface microlayer (SML) on sea spray enrichment by organics as being in three different regimes based on sea surface wind speed: 1) high enrichment occurs under the conditions when biogenic SML covers the majority of the sea surface, 2) moderate enrichment when SML only covers a portion of the sea surface often appearing as visible slicks or streaks, and 3) low enrichment when SML coverage is strongly reduced due to wave action. Fig. 17 shows our interpretation of the relationships between the organic fraction of sea spray aerosol, SML coverage (Gantt et al., 2011).



**Figure 17.** Conceptual relationship between the organic mass fraction of sea spray aerosol and surface wind speed.



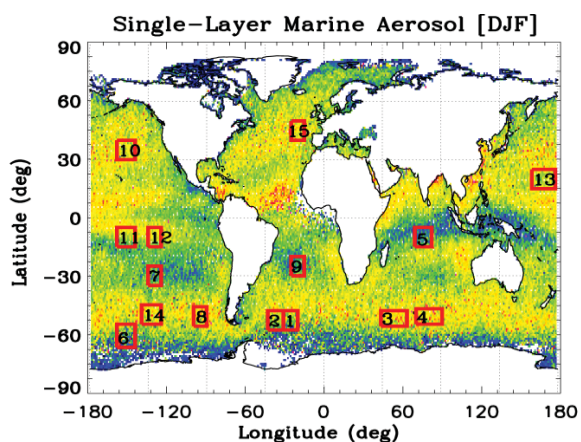
**Figure 18.** Annual average submicron marine POA emission rate in units of  $\text{ng C m}^{-2} \text{s}^{-1}$  using the Mårtensson et al. (2003) sea spray function, monthly average climatological [Chl-*a*] from SeaWiFS, modeled  $U_{10}$  from the CAM5 “current climate”.

The resulting parameterization was explored using aerosol chemical composition and surface wind speed from Atlantic and Pacific coastal stations, and satellite-derived ocean concentrations of chlorophyll-*a*, dissolved organic carbon, and particulate organic carbon. Of all the parameters examined, a multi-variable logistic regression revealed that the combination of 10 meter wind speed and surface chlorophyll-*a* concentration ([Chl-*a*]) are the most consistent predictors of sea spray aerosol organic fraction. This relationship, combined with the published aerosol size dependence of organic fraction, resulted in a new parameterization for the organic mass fraction of sea spray (Gantt et al., 2011). The estimated global marine POA emissions range from 15.9 to 18.7 Tg C yr<sup>-1</sup> with 2.8 to 5.6 Tg C yr<sup>-1</sup> emitted in the submicron mode (see Fig. 18).

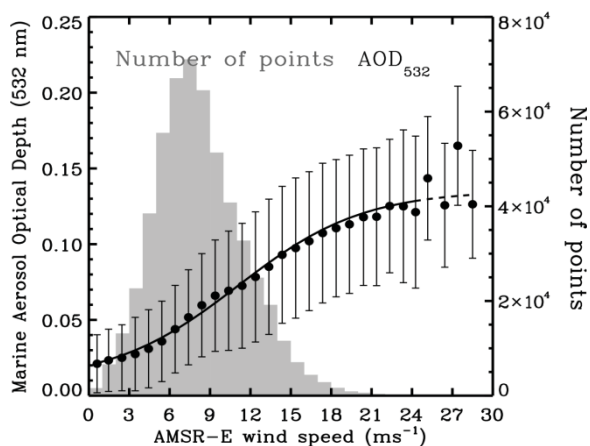
#### 4.7 The Major Achievements of Kiliyanpilakkil and Meskhidze (2011) Study

We have expanded upon previous satellite remote sensing analyses by introducing a novel approach that allowed an explicit distinction of “clean marine” aerosols properties from those of other aerosol subtypes through the use of the CALIPSO satellite. Due to its unique capabilities, such as accurate determination of the vertical location of aerosols, retrieval of aerosol properties during the night as well as the day, CALIPSO can give new insight into the marine aerosol wind relationship. Unlike passive imagers that typically have highest relative error at low optical depth values, uncertainty in CALIPSO optical depth retrieval is lowest at low AOD, making it suitable instrument for exploring optical properties of aerosols under clean marine conditions. Daily surface wind speed data were obtained from the AMSR-E. Detailed data analyses were carried out over 15 regions selected to be representative of different areas of the global oceans

for the time period from June 2006 to April 2011 (Fig. 19). Derived logistic regression between CALIPSO-retrieved AOD and AMSR-E wind speed (see Fig. 20) indicates weak relationship at low wind speed values. This result is consistent with previous studies, suggesting that AOD at surface wind speed  $\leq 4 \text{ m s}^{-1}$  can be viewed to be representative of background maritime aerosol with little dependence on surface wind speed. At an intermediate wind speed values, the derived logistic regression relationship between clean marine aerosol and surface wind speed has a constant slope. At high wind speed values analysis of CALIPSO-retrieved AOD and AMSR-E wind speed values suggests that for sea spray generation via mechanical disruption of wave crests aerosol effects on optical turbidity of atmosphere appear to level off, indicating the existence of some finite maritime AOD values.



**Figure 19.** Global distribution of  $1^\circ \times 1^\circ$  degree averaged CALIPSO level 2 version 3.01 mean AOD for “clean marine” single-layer aerosols. Layer optical depths are averaged for June 2006 to April 2011. Areas surrounded by solid red line in illustrate the regions selected for the detailed analysis.

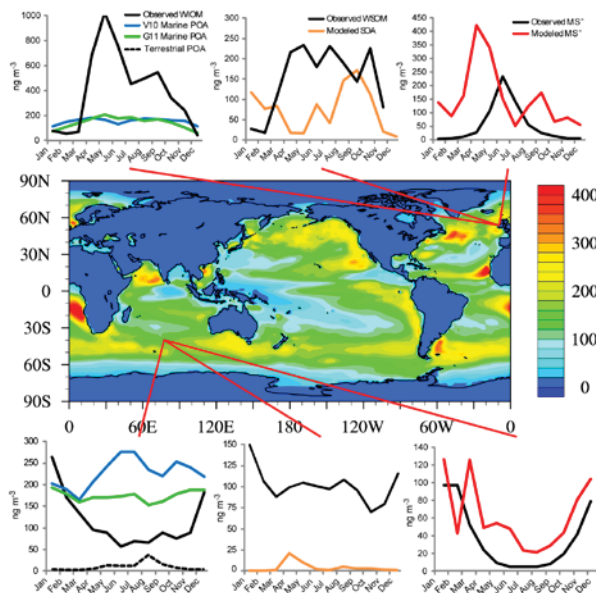


**Figure 20.** The relationship between CALIPSO AOD and AMSR-E wind speed. The analysis is based on a total 539,549 collocated data points of AOD and wind speed. The number of available data points for each wind speed bin is plotted at the background in grey color.

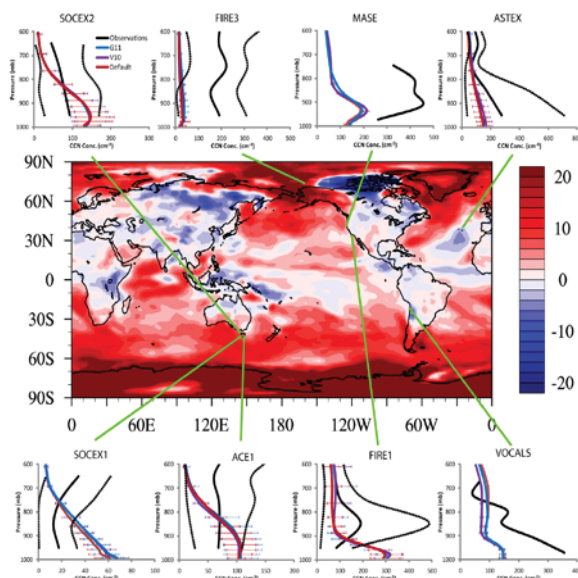
#### 4.8 The Major Achievements of Meskhidze et al. (2011) Study

Marine organic emissions were implemented in CAM5 by adding two different online emission parameterizations of marine primary organic aerosol (POA) and offline productions of marine secondary organic aerosol (SOA) and methane sulfonate ( $\text{MS}^-$ ), derived from phytoplankton-emitted biogenic volatile organic compounds (BVOCs). The estimated annual total submicron marine POA emissions are  $9.4 \text{ Tg yr}^{-1}$  and  $7.9 \text{ Tg yr}^{-1}$  using the Vignati et al. (2010) and Gantt et al. (2011) parameterizations, respectively. Over biologically productive surface ocean waters, model-predicted concentrations of submicron marine-source OM are estimated to be up to  $400 \text{ ng m}^{-3}$ . Fig. 21 shows that over most of the oceanic regions surface concentrations of submicron marine POA are between  $50 - 200 \text{ ng m}^{-3}$  (with maximum of  $250 \text{ ng m}^{-3}$ ). Marine SOA from phytoplankton-derived isoprene and monoterpenes contributes to a relatively small fraction (up to 20%) of the surface concentration of marine-source OM. Extreme scarcity of ground-based long-term measurements of marine organic aerosols does not allow effective evaluations of marine-source surface OM concentrations predicted by the Vignati

et al. (2010) and Gantt et al. (2011) emission mechanisms. Nevertheless, comparisons of model-predicted marine-source POA concentrations with observations of WIOM at the Northern and Southern Hemispheric coastal sites show (Fig 21) that the Gantt et al. (2011) emission parameterization yields a more accurate representation for the seasonal cycle of marine organic aerosol mass concentrations. Our model simulations show that, when only the terrestrial emissions of POA are accounted for, CAM5 significantly under-predicts organic aerosol mass concentration over the remote ocean.



**Figure 21.** Annual average total marine OM concentrations in units of  $\text{ng m}^{-3}$  with the top and bottom charts comparing the monthly average concentrations of water insoluble organic matter (WIOM), water soluble organic matter (WSOM), and methane sulfonate ( $\text{MS}^-$ ) concentrations with the modeled POA, SOA and  $\text{MS}^-$ .



**Figure 22.** Annual average percentage change in surface CCN (0.2% S) due to marine organics. The inserts with charts are comparing the observed vertical distribution of CCN from various remote ocean and coastal field campaigns.

Although the global model-predicted surface CCN (at a  $S = 0.2\%$ ) concentration is shown to be relatively insensitive to the addition of marine organic aerosols, marine emissions of organics are shown to influence surface CCN concentration over the localized regions of the remote ocean. Fig. 4.6 shows that the largest increases (up to 20%) in yearly-averaged CCN concentration are obtained over biologically productive ocean waters when marine organic aerosol is assumed to be externally mixed with sea-salt. The addition of internally-mixed marine organics provides diverse results, often with reductions of CCN concentration over biologically productive parts of the ocean. Based on the experimental evidence for the increased CCN concentration during the periods of higher [Chl-*a*] levels, our study suggests that it is unlikely that marine organic aerosols are emitted only as an internal mixture with sea-salt, without changing aerosol number.

## 5. a) Peer- reviewed Publications

1. Meskhidze, N., A. Sabolis, J. Trueblood, R. Reed, D. Kamykowski, (2011b), Quantifying marine emissions of trace gases using laboratory and field measurements, manuscript in preparation.
2. Kamykowski, D. (2012), 20<sup>th</sup> century variability of Atlantic Meridional Overturning Circulation: Planetary wave influences on world ocean surface phosphate utilization and synchrony of small pelagic fisheries, *Deep-Sea Research I*, doi:10.1016/j.dsr.2012.03.005.
3. Gantt B., J. Xu, N. Meskhidze, Y. Zhang, A. Nenes, S. J. Ghan, X. Liu, R. Easter, and R. Zaveri, Global distribution and climate forcing of marine organic aerosol - Part 2: Effects on cloud properties and radiative forcing, *Atmos. Chem. Phys. Discussion*, Atmos. 12, 7453–7474, doi:10.5194/acpd-12-7453-2012.
4. Meskhidze, N., J. Xu, B. Gantt, Y. Zhang, A. Nenes, S. J. Ghan, X. Liu, R. Easter, and R. Zaveri (2011), Global distribution and climate forcing of marine organic aerosol – Part 1: Model improvements and evaluation, *Atmos. Chem. Phys.*, 11, 11689–11705, doi:10.5194/acp-11-11689-2011.
5. Kiliyanpilakkil, V. P. and N. Meskhidze (2011), Deriving the effect of wind speed on clean maritime aerosol optical properties using the A-Train satellites, *Atmos. Chem. Phys.*, 11, 11401-11413, doi:10.5194/acp-11-11401-2011.
6. Sabolis A., N. Meskhidze, G. Curci, P. I. Palmer and B. Gantt (2011), Interpreting elevated space-borne HCHO columns over the Mediterranean Sea using the OMI and SCIAMACHY sensors, *Atmos. Chem. Phys.*, 11, 12787–12798, doi:10.5194/acp-11-12787-2011.
7. Ghan, S.J., H. Abdul-Razzak, A. Nenes, Y. Ming, X. Liu, M. Ovchinnikov, N. Meskhidze, J. Xu, and X. Shi (2011), Droplet Nucleation: Physically-Based Parameterization and Comparative Evaluation, *J. Adv. Model. Earth Syst.*, 3, M10001, 33 pp, doi:10.1029/2011MS000074.
8. Gantt, B. and N. Meskhidze, M. C. Facchini, M. Rinaldi, D. Ceburnis, and C. O’Dowd (2011), Wind speed dependent size-resolved parameterization for the organic enrichment of sea spray, *Atmos. Chem. Phys.*, 11, 8777–8790, doi:10.5194/acp-11-8777-2011.
9. Chen, Y.-S. and Y. Zhang (2011) Impacts of Nucleation Algorithms on Simulated Aerosol and Cloud Properties and Aerosol Direct and Indirect Effects, manuscript in preparation.
10. Zhang, Y., Y.-S., Chen, P. Karamchandani, D. G. Streets, and W. C. Skamarock (2011), Development and Initial Application of the Global-Through-Urban WRF/Chem, manuscript in preparation.
11. Zhang, Y., Y.-C. Chen, G. Sarwar, and K. Schere (2011), Impact of Gas-Phase Mechanisms on WRF/Chem Predictions: Mechanism Implementation and Comparative Evaluation, *J. Geophys. Res.*, 117, D01301, doi: 10.1029/2011JD015775.
12. Zhang, Y., J. Hemperly, and N. Meskhidze (2011), The Application and Evaluation of the Global Weather Research and Forecasting (GWRF) Model: Model Evaluation and Sensitivity Studies, manuscript in review.
13. Zhu, S. and Y. Zhang (2011), Sensitivity of Simulated Chemical Concentrations and Aerosol-Meteorology Interactions to Aerosol Treatments in WRF/Chem, manuscript in preparation.
14. Shaw, S.L., B. Gantt, and N. Meskhidze (2010), Marine Isoprene and Monoterpene Production and Emissions: A Review, *Advances in Meteorology*, Article ID 408696, doi:10.1155/2010/408696.

15. Meskhidze N. and A. Nenes (2010), Effects of ocean ecosystem on marine aerosol-cloud interactions, *Advances in meteorology*, Article ID 239808, doi:10.1155/2010/239808, <http://www.hindawi.com/journals/amet/2010/239808.html>.
16. Kamykowski, D. (2010), Atlantic meridional overturning circulation and phosphate-classified bottom-up control of Atlantic pelagic ecosystems through the 20<sup>th</sup> century, *Deep-Sea Research I*, 57, 1266-1277.
17. Gantt, B., N. Meskhidze, and A. G. Carlton (2010), The impact of marine organics on the air quality of the western United States, *Atmos. Chem. Phys.*, 10, 1–9. <http://www.atmos-chem-phys.net/10/7415/2010/acp-10-7415-2010.pdf>.
18. Gantt, B., N. Meskhidze, Y. Zhang, and J. Xu (2010), The effect of marine isoprene emissions on secondary organic aerosol and ozone formation in the coastal United States, *Atmos. Environ.*, 44, 115–121, doi:10.1016/j.atmosenv.2009.08.027.
19. Gantt, B., N. Meskhidze, and D. Kamykowski (2009), A new physically-based quantification of isoprene and primary organic aerosol emissions from the world's oceans, *Atmos. Chem. Phys.*, 9, 4915-4927.

### 5b) Non-Peer reviewed Publication

1. Meskhidze, N., C. R. McClain, M. D. Petters, E. Vignati, O. Stetzer, C. Osburn, and D. J. Kieber, (2011), Marine Aerosol-Cloud-Climate Interaction, Editorial, *Advances in Meteorology*, 2010, Article ID 250896, doi:10.1155/2010/250896.
2. Sabolis, A. (June, 2010): Quantifying marine emissions of biogenic volatile organic compounds using laboratory measurements, field measurements and remote sensing data, Master's Thesis, NCSU, available at: <http://www.lib.ncsu.edu/resolver/1840.16/6473>.
3. Hemperly, J. J. (July, 2009), The Application and Evaluation of the Global Weather Research and Forecasting Model, M.S. thesis, NCSU, Raleigh, NC.
4. Gantt, B. (May, 2009), Marine Organic Aerosols and Their Implication to Air Quality, M.S. thesis, NCSU, Raleigh, NC (<http://www.lib.ncsu.edu/theses/available/etd-03272009-132432/unrestricted/etd.pdf>).

### 5c) Presentations

1. Meskhidze, N., B. Gantt, M. S. Johnson, *Sea Spray Aerosols and Climate Assessments*, American Meteorological Society (AMS) 92<sup>nd</sup> annual meeting, January 22 - 26, 2012, New Orleans, LA.
2. Meskhidze, N., B. Gantt, Jun Xu, *Evaluating the potential impact of marine organic aerosols on climate assessments*, poster presentation, American Geophysical Union (AGU) Fall Meeting, December 5 – 9, 2011, San Francisco, CA.
3. Meskhidze, N., B. Gantt, M. Wilbanks, *Evaluating the impact of marine carbonaceous aerosols on clouds and climate assessments*, invited oral presentation, 242<sup>nd</sup> ACS National Meeting & Exposition, Denver, CO, August 28-September 1, 2011.
4. Gantt, B., M. Johnson, and N. Meskhidze, *Evaluation of marine Primary Organic Aerosol Emission Schemes*, poster presentation at Goldschmidt2011, Prague, Czech Republic, August 14-19, 2011,.

5. Meskhidze, N., J. Xu and B. Gantt, *Evaluating the Impact of Marine Organic Aerosols on Climate*, oral presentation at Goldschmidt2011, Prague, Czech Republic, August 14-19, 2011.
6. Meskhidze, N., B. Gantt, M. Wilbanks, and J., Xu, *Effect of Marine Biogenic Aerosols on Clouds: A Community Atmosphere Model (CAM) Study*, poster presentation at DOE ASR meeting, San Antonio, Texas, March 28-April 1, 2011.
7. Meskhidze, N., *Marine Primary and Secondary Organic Aerosol: Their Emission Rates and Potential Effects on Cloud Microphysical Properties*, invited seminar at AEROCENTER Forum - NASA-Goddard Space Flight Center, Greenbelt, MD, February 21, 2011.
8. Chen, Y.-S. and Y. Zhang, *Evaluation of Nucleation Algorithms and Their Impacts on Simulated Aerosol Number and Size Distributions and Cloud Properties*, poster presentation at the 13<sup>th</sup> Conference on Atmospheric Chemistry /the 91<sup>st</sup> AMS Annual Meeting, Seattle, Washington, January 23-27, 2011.
9. Glotfelty, T., Y.-S. Chen, and Y. Zhang, *Impact of Future Climate and Emissions on Air Quality*, poster presentation at the 6<sup>th</sup> Annual NC State University Graduate Student Research Symposium, McKimmon Center, Raleigh, NC, March 21, 2011.
10. Zhang, Y., *Modeling Transport, Chemistry, and Climatic Impacts of Particulate Matter at Regional and Global Scales: Model Capabilities, Deficiencies, and Uncertainties*, invited keynote speech at the 2011 Bouyoucos Conference on Synchrotrons for Soils, Estes Park, CO, August 1 -2.
11. Zhang, Y., Y.-S. Chen, and Tim Glotfelty, *Impact of Future Climate and Emission on Climate-Air Quality Interactions*, oral presentation at the 3<sup>rd</sup> Symposium on Aerosol-Cloud-Climate Interactions/the 91<sup>st</sup> AMS Annual Meeting, Seattle, Washington, January 23-27, 2011.
12. Zhang, Y., L. R. Leung, and J.-W. Fan, *Towards Improved Aerosol-Cloud-Precipitation Representations in a Coupled Climate-Aerosol Model: Some Preliminary Results*, poster presentation at the DOE's 2011 Climate Modeling Meeting, Washington, D.C., September 19-22, 2011.
13. Zhu, S. and Y. Zhang, *Sensitivity of Simulated Chemical Concentrations and Aerosol-Meteorology Interactions to Aerosol Treatments in WRF/Chem*, poster presentation at the European Geosciences Union General Assembly 2011 and oral presentation at the COST Action ES1004: 'EuMetChem' scientific meeting, Vienna, Austria, April 3-8, 2011.
14. Meskhidze, N., B. Gantt, J. Xu, A. Sabolis, E. Morris, M. Petters, *Marine Primary and Secondary Organic Aerosols and Their Effect on Indirect Radiative Forcing*, oral presentation at the 12<sup>th</sup> Conference on Atmospheric Chemistry/the 91<sup>st</sup> AMS Annual Meeting, Seattle, Washington, January 23-27, 2010.
15. Chen, Y.-S. and Y. Zhang, 2010, *Evaluation of Nucleation Algorithms and Their Impacts on Simulated Aerosol Number and Size Distributions and Cloud Properties*, submitted for presentation at the 12<sup>th</sup> Conference on Atmospheric Chemistry /the 91<sup>st</sup> AMS Annual Meeting, Seattle, Washington, January 23-27, 2010.
16. Gantt, B., E. Morris, M. D. Petters, N. Meskhidze, *Isolating factors that determine the organic enrichment of sea spray*, submitted for presentation at the 2010 AGU Fall meeting, San Francisco, CA, December 13-17, 2010.
17. Sabolis, A.W., N. Meskhidze, D. Kamykowski, R. E. Reed, *Quantifying Marine Emissions of Biogenic Volatile Organic Compounds Using Laboratory Measurements of Plankton Monocultures and Field Samples*, submitted for presentation at the at the 2010 AGU Fall meeting, San Francisco, CA, December 13-17, 2010.

18. Meskhidze, N. and B. Gantt, *A Novel Parameterization of the Marine Primary Organic Aerosol Emission for Regional and Global Models*, poster presentation at the 9<sup>th</sup> Annual CMAS Conference at the Friday Center, UNC-Chapel Hill, October 11-13, 2010.
19. Gantt, B. N. Meskhidze and A.G. Carlton, *The Contribution of Marine Organic Emissions to Coastal Air Quality*, oral presentation at the 9th Annual CMAS Conference at the Friday Center, UNC-Chapel Hill, October 11-13, 2010.
20. Meskhidze, N, J. Xu, J and B. Gantt, *The Impact of Marine Organic Emissions on Global Climate*, poster presentation at Goldschmidt 2010, Earth Energy and the environment, Knoxville, TN, June 13 – 18, 2010.
21. Hemperly, J., Y. Zhang, and N. Meskhidze, 2010, *The Sensitivity of the Global Weather Research and Forecasting Model to Physical Parameterization*, poster presentation at the Consequences of Global Change for Air Quality Progress Review Meeting, Research Triangle Park, North Carolina, October 4,
22. Gantt, B. and N. Meskhidze, *Rethinking the Organic Sea Spray Function*, poster presentation at Goldschmidt 2010, Earth Energy and the environment, Knoxville, TN, June 13 – 18, 2010.
23. Sabolis, A. and N. Meskhidze, *Quantifying Marine Emissions of Volatile Organic Compounds Using Laboratory and Field Measurements from North Carolina Estuarine System*, poster presentation at Goldschmidt 2010, Earth Energy and the environment, Knoxville, TN, June 13 – 18, 2010.
24. Gantt, B. and N. Meskhidze, *Measuring and modeling marine biogenic volatile organic compounds*, invited oral presentation in the early career session, 5th Biogenic Hydrocarbons & The Atmosphere Gordon Research Conference, Les Diablerets, Switzerland, May 23-28, 2010.
25. Meskhidze, N., J. Xu, Y. Zhang, B. Gantt, A. Carlton, S. Ghan, A. Nenes, X. Liu, R. Easter, and R. Zaveri, *The Impact of Marine Organic Emissions on Global Climate and Coastal Air Quality*, poster presentation at DOE ASR meeting, Washington, DC, March 15 – 18.
26. Meskhidze, N., J. Xu, Y. Zhang, B. Gantt, A. G. Carlton, S. J. Ghan, A. Nenes, X. Liu, R. C. Easter, R. A. Zaveri, *The Impact of Marine Organic Emissions on Coastal Air Quality and Climate*, poster presentation at AGU 2010 Ocean Sciences Meeting, Portland, OR, Feb. 22-26, 2010.
27. Sabolis, A. W., N. Meskhidze, D. Kamykowski, and R. E. Reed, *Quantifying Marine Emissions of Biogenic Volatile Organic Compounds Using Laboratory and Field Measurements from North Carolina Estuarine System*, poster presentation at AGU 2010 Ocean Sciences Meeting, Portland, OR, Feb. 22-26, 2010.
28. Gantt, B., N. Meskhidze, A. G., Carlton, *The Impact of Marine Organic Emissions on Coastal Air Quality of the Western US.*, poster presentation, AGU Fall 2009, San Francisco, CA, Dec. 14 – 18.
29. Johnson, M. S., N. Meskhidze, S. Gassó, F. Solmon, *Quantifying the Impact of Mineral Dust and Dissolved Iron Deposition on Marine Biological Activity*, poster presentation, AGU Fall 2009, San Francisco, CA, Dec. 14 – 18.
30. Xu, J., N. Meskhidze, Y. Zhang, B. Gantt, S. J. Ghan, A. Nenes, X. Liu, R. C. Easter, R. A. Zaveri, *Climatic Effects of Marine Organic Aerosols*, poster presentation, AGU Fall 2009, San Francisco, CA, Dec. 14 – 18.

31. Meskhidze, N., J. Xu, B. Gantt, Connecting Oceanic Emissions, Aerosols, and Maritime Clouds: What do we know and where do we go? oral presentation, AGU Fall 2009, San Francisco, CA, Dec. 14 – 18.
32. Meskhidze, N., Connecting Oceanic Emissions of Trace Gases, Aerosols, and Maritime Clouds, oral presentation, IAMA 2009, Dec. 9 – 11, UC Davis, CA.
33. Xu, J, N. Meskhidze, Y. Zhang, B. Gantt, S. Ghan, A. Nenes, X. Liu, R. Easter, & R. Zaveri, 2009, *The Effect of Marine Biogenic Organic Aerosols on Stratiform Clouds: A 10-Year Global Simulation with Coupled GCM-Aerosol Model*, AAAR 2009 Annual conference, Hyatt Regency Minneapolis, Minneapolis, MN, October 26 – 30.
34. Gantt, B., N. Meskhidze, A. M. Carlton, *The Impact of Marine Organic Aerosols on Coastal Air Quality of the Western US*, AAAR 2009 Annual conference, Hyatt Regency Minneapolis, Minneapolis, MN, October 26 – 30.
35. Hemperly, J.J., X.-Y. Wen, N. Meskhidze, and Y. Zhang, *The Evaluation of the Global Weather Research and Forecasting (GWRf) Model with Surface-Based and Remotely-Sensed Observations*, The 4<sup>th</sup> Annual NC State University Graduate Research Symposium, March 18th, 2009, Raleigh, NC.
36. Hemperly, J.J., X.-Y. Wen, N. Meskhidze, and Y. Zhang, *Retrospective Application and Evaluation of the Global Weather Research and Forecasting (GWRf) System*, The 7<sup>th</sup> Annual Community Modeling and Analysis (CMAS) Meeting, October 6-8, 2008, Chapel Hill, NC.
37. Meskhidze, N., J. Xu, Y. Zhang, B. Gant, S. Ghan, A. Nenes, X.Liu, R. Easter, and R. Zaveri, *Marine Organic Aerosols and Clouds: From Emissions to Climate Change*, oral presentation, Goldschmidt2009, Davos, Switzerland, June 21 – 26.
38. Meskhidze, N., Y. Zhang, B. Gantt, J. Hemperly, D. Kamykowski, and X.-Y. Wen, 2009, *Effect of Terrestrial and Marine Organic Aerosol on Regional and Global Climate: Work Plan and Some Preliminary Results*, oral presentation at the Department of Energy Atmospheric Science Program FY 2009 Science Team Meeting, Annapolis, MD, 25 - 27 February.



## References

- Abdul-Razzak, H. and S. Ghan (2000), A parameterization of aerosol activation 2. Multiple aerosol types, *J. Geophys. Res.*, 105, 6837–6844.
- Chen, Y.-S. and Y. Zhang, 2011, Evaluation of Nucleation Algorithms and Their Impacts on Simulated Aerosol Number and Size Distributions and Cloud Properties, poster presentation at the 13<sup>th</sup> Conference on Atmospheric Chemistry /the 91<sup>st</sup> AMS Annual Meeting, January 23-27, 2011, Seattle, Washington, USA.
- Fan, J., R. Zhang, D. Collins, and G. Li, 2006, Contribution of secondary condensable organics to new particle formation: A case study in Houston, Texas, *Geophys. Res. Lett.*, 33, L15802, doi:10.1029/2006GL026295.
- Fountoukis, C. and A. Nenes (2005), Continued development of a cloud droplet formation parameterization for global climate models, *J. Geophys. Res.*, 110(D11212), doi:10.1029/2004JD005 591.
- Ghan, S. J., L. R. Leung, R. C. Easter, and H. Abdul-Razzak, 1997, Prediction of cloud droplet number in a general circulation model, *J. Geophys. Res.*, 102(D18), 21,777– 21,794.
- Karamchandani, P., Y. Zhang, S.-Y. Chen, and R. Balmori-Bronson, 2011, Development and Testing of an Extended Chemical Mechanism for Global-Through-Urban Applications, *Atmospheric Pollution Research*, in press, doi: 10.5094/APR.2011.047, Available online 05 May.
- Randall, D. A., R. A. Wood, S. Bony, R. Colman, T. Fichet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R. J. Stouffer, A. Sumi, and K.E. Taylor (2007), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Climate Models and Their Evaluation*, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Sihto, S., M. Kulmala, V. Kerminen, M. Dal Maso, T. Petäjä, I. Riipinen, H. Korhonen, F. Arnold, R. Janson, and M. Boy, 2006, Atmospheric sulphuric acid and aerosol formation: Implications from atmospheric measurements for nucleation and early growth mechanisms, *Atmos. Chem. Phys.*, 6, 4079-4091.
- Yu, F., 2010, Ion-mediated nucleation in the atmosphere: Key controlling parameters, implications, and look-up table, *J. Geophys. Res.*, 115, D03206, doi:10.1029/2009JD012630.
- Yu, F., G. Luo, T. S. Bates, B. Anderson, A. Clarke, V. Kapustin, B. Yantosca, Y.-X. Wang, and S.-L. Wu, 2010, Spatial distributions of particle number concentrations in the global troposphere: Simulations, observations, and implications for nucleation mechanisms, *J. Geophys. Res.*, doi:10.1029/2009JD013473, in press.
- Zhang, Y., P. Liu, X.-H. Liu, M.Z. Jacobson, P. McMurry, F. Yu, S.-C. Yu, and K. Schere, 2010, A Comparative Study of Homogeneous Nucleation Parameterizations, Part II. 3-D Model Application and Evaluation, *J. Geophys. Res.*, in press.
- Zhang, Y., P. McMurry, F. Yu, and M.Z. Jacobson, 2010, A Comparative Study of Homogeneous Nucleation Parameterizations, Part I. Examination and Evaluation of the Formulations, *J. Geophys. Res.*, in press.

Zhang, Y., Y. Pan., K. Wang, J. D., Fast, and G. A. Grell, 2010, WRF/Chem-MADRID: Incorporation of an Aerosol Module into WRF/Chem and Its Initial Application to the TexAQS2000 Episode, *J. Geophys. Res.*, 115, D18202, doi:10.1029/2009JD013443.

Zhang, Y., Y.-S., Chen, P. Karamchandani, D. G. Streets, and W. C. Skamarock, 2011, Development and Initial Application of the Global-Through-Urban WRF/Chem, manuscript in preparation.