Mesoscale Modeling of Marine Stratocumulus and Cloud-Aerosol Interactions

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What are the effects of aerosol chemistry on the evolution of stratocumulus clouds downwind of large anthropogenic point sources along the coast of Chile?

What is the relative importance of natural and anthropogenic sources of primary particulates and particulate precursors on cloud-aerosol interactions?

Integrate VOCALS measurements with WRF predictions to examine how particulate properties and aerosol indirect effects evolve.
PreVOCA: Predicted Effective Radius

October 2006 Average at 18 UTC

Full Chemistry Simulation

Prescribed Aerosol # Simulation

Mean MODIS Cloud Droplet Effective Radius October 2006
from Matthew Wyant (UW)
Aircraft Observations

G-1 Flight on October 22

- Cloud altitude higher farther from coast.
- LWC > 0.01 g cm⁻³.
- Aerosols highest near coast.
- Droplet # highest near coast.

Do models replicate this? If not, why?
Configuration of WRF

Weather Research and Forecasting (WRF) Model

Our goal is to “get the right answer for the right reasons”, therefore:

- Examine sensitivity of predicted marine stratocumulus to key PBL, microphysics, and scale issues first (phase 1)
- Then, include cloud-aerosol interactions (phase 2)

Phase 1

- **Boundary Layer schemes**: 5 - YSU, MYJ, MYNN5, MYNN6, ACM
- **Microphysics schemes**: 4 - Lin, Thompson, Morrison, WDM5, default droplet # set to 250 cm$^{-3}$
- **Boundary Conditions**: Meteorology and SST from GFS

Phase 2:

- **Chemistry**: CBM-Z photochemistry + MOSAIC aerosols
- **Aerosol-Cloud-Radiation Interactions**: methodology similar to GCMs
Results: Meteorology
Example Radisonde Profiles

0330 UTC October 28

Microphysics: Lin

Boundary Layer: ACM

sensitivity to boundary layer scheme

sensitivity to microphysics scheme
All Radisonde Profiles

Observed $\theta$: from RHB

$\Delta \theta = 2$ K

$306$ K

$288$ K

$z_i$

WRF $\theta$: ACM Boundary Layer, Thompson Microphysics

Observed height of $\theta = 296$ K

5 Boundary layer schemes

far from coast

close to coast
Spatial Distribution of LWP
Sensitivity to Microphysics Schemes

Observed LWP from GOES
18 UTC October 22

Simulated: ACM Boundary Layer, $\Delta x = 9$ km
Lin
Morrison
Thompson
WDM5

$too\ low,\ why?$
Monthly Averaged LWP
Sensitivity to Microphysics Schemes

Observed LWP from GOES
October 15 – November 15

Simulated: ACM Boundary Layer, $\Delta x = 9$ km

Lin Morrison

too high

Thompson WDM5
Diurnal LWP
Sensitivity to Microphysics Schemes

Domain Averaged LWP over Ocean (ACM Boundary Layer, $\Delta x = 9$ km)

- maximum: sunrise
- minimum: late afternoon

Cloudiness too small during day

Observed, Lin, Morrison, Thompson
Spatial Distribution of LWP
Sensitivity to Boundary Layer Schemes

Observed LWP from GOES
18 UTC October 22
Averaged to $\Delta x = 9$ km

Simulated: Thompson Microphysics, $\Delta x = 9$ km
YSU
MYJ
MYNN5
ACM
Monthly Averaged LWP
Sensitivity to Boundary Layer Schemes

Observed LWP from GOES
October 15 – November 15

Simulated: Thompson Microphysics, $\Delta x = 9$ km
YSU
MYJ
MYNN5
ACM
Diurnal LWP
Sensitivity to Boundary Layer Schemes

Domain Averaged LWP over Ocean (Thompson microphysics, $\Delta x = 9$ km)

- Maximum: sunrise
- Minimum: late afternoon

- Observed
- YSU
- MYJ
- MYNN5
- ACM
Spatial Distribution of LWP
Sensitivity to Spatial Resolution

Observed LWP from GOES, 18 UTC October 22

Simulated LWP: ACM boundary layer, Thompson microphysics

Δx = 81 km  Δx = 27 km  Δx = 9 km  Δx = 4 km

Δx = 81 km  Δx = 27 km  Δx = 9 km  Δx = 4 km
Cloud-Aerosol Interactions

\[
\frac{\partial N_k}{\partial t} = -(V \cdot \nabla)N_k + D_k - C_k - E_k + S_k
\]

Methodology similar to that used in CAM3

**Prescribed #**
150 & 600 cm\(^{-3}\) based on G-1 data

**Full Chemistry**
Variable aerosols

Coupled with Microphysics

- Lin (released v3.1)
- Thompson (currently testing)
- Morrison (currently testing)
Lin Microphysics + YSU Boundary Layer
Sensitivity to Prescribed Aerosols

Observed LWP from GOES

Vertical Cross Section of Droplet #

- Default
- Aerosol # = 600 cm⁻³
- Aerosol # = 150 cm⁻³

Highest peak values

Lowest peak values

Observed peak values
150 cm⁻³ (west) – 400 cm⁻³ (east)
Morrison Microphysics + YSU Boundary Layer
Sensitivity to Prescribed Aerosols

Default

Aerosol # = 600 cm⁻³

Aerosol # = 150 cm⁻³

Highest peak values

Lowest peak values

Observed LWP from GOES

vertical cross section of droplet #

peak values
40 – 60 cm⁻³

observed peak values
150 cm⁻³ (west) – 400 cm⁻³ (east)
Thompson Microphysics + YSU Boundary Layer
Sensitivity to Prescribed Aerosols

Default
Aerosol # = 600 cm⁻³
Aerosol # = 150 cm⁻³

Observed LWP from GOES
peak values
120 – 160 cm⁻³
observed peak values
150 cm⁻³ (west) – 400 cm⁻³ (east)

Vertical Cross Section of Droplet #
peak values
40 – 60 cm⁻³

Highest peak values
Lowest peak values
Diurnal LWP

Domain Averaged LWP over Ocean (YSU Boundary Layer, $\Delta x = 9$ km)

- Predicted LWP too low, but ...
- Prescribing constant aerosol # over the domain **not realistic**
- Simulations useful to check the sensitivity of cloud-aerosol interactions to microphysics scheme
- Sensitivity likely due to how autoconversion and collision/coalescence is treated
- Need to perform **full-chemistry** simulations next
Summary and Next Steps

- Results are preliminary - more statistics needed to assess predicted PBL structure and cloud properties using in situ and satellite data
- **On-going testing** of cloud-aerosol interactions coupled with Morrison and Thompson microphysics schemes
- **Differing sensitivity to aerosols** among microphysics schemes probably due to varying treatments of drizzle
- Effect of cloud-aerosol interactions on cloud properties as large as sensitivity to choice boundary layer and microphysics schemes
- Need to examine details of **vertical mixing within clouds**
  - Small changes in mixing can affect cloud-aerosol interactions
  - Exchange coefficients not yet available for all schemes
- Next steps: **Add full chemistry** to have realistic aerosol distributions
Related Research

- **New Project:** “Investigation of Multiple Aerosol-Cloud Equilibrium Regimes during VOCALS” funded by NOAA Atmospheric Composition & Climate Program, Principal Investigator: William Gustafson Jr.

Examine the plausibility of aerosol-cloud equilibrium states that preferentially lead to open and closed cellular convection and the ability of models to reproduce the resulting radiative effects from global to cloud-resolving scales.

- **Aerosol Modeling Testbed**
  - Methodology to systematically evaluate aerosol process modules
  - Tools to facilitate model evaluation using field campaign data
  - VOCALS data currently being ported into the testbed

http://www.pnl.gov/atmospheric/research/aci/aci_proj_testbed.stm