Regional Modeling of Particulate Chemistry and its Effect on Cloud-Aerosol Interactions over the Southeastern Pacific Ocean

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Motivation

The Southeast Pacific Climate System

- Coupled atmosphere-ocean general circulation models do not adequately simulate marine stratocumulus clouds
- Affects global climate via teleconnections
- Indirect effect of aerosols on cloud-radiative properties not fully understood
- Limited in-situ data in this region
The VAMOS Ocean-Cloud-Atmosphere-Land Study

Lagrangian POC-drift

E-W cross-sections

pockets of open cells (POC)

buoy

buoy

land sites

85 W

75 W

Ronald H Brown

long-range

C-130

Jose Olaya

UK-146

UK-146

Arica

G-1

short-range

CIRPAS Twin Otter

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Objectives

Integrate extensive VOCALS measurements with WRF predictions to examine how particulate properties and aerosol indirect effects evolve in the region

- What are the effects of aerosol chemistry on the evolution of CCN and stratocumulus clouds downwind of large anthropogenic point sources along the coast of Chile?
- What is the relative importance of anthropogenic (copper smelters, power plants) and natural (DMS, volcanic) and sources on cloud-aerosol interactions?
- Do aerosols play a role on the evolution of POCs?

Because the field campaign will not be conducted until November 2008, we have run WRF-Chem for October 2006, a climatologically similar period, to “exercise” the code and participate in the Pre-VOCALS model assessment.
Model Configuration and Aerosol-Radiation-Cloud Interactions

- YSU boundary-layer scheme and Lin microphysics scheme
- CBM-Z photochemistry and MOSAIC aerosols
- Boundary conditions from GFS and MOZART models
- **Direct effect** (scattering and absorption) via Goddard shortwave radiation scheme
- **First & second indirect effects** (cloud albedo, cloud life cycle) via predicted CCN and cloud droplet number in modified Lin microphysics scheme

PNNL modules that couple aerosols, radiation, & clouds updated in version 3
Trace Gas and Particulate Emissions

Global 1 Degree Estimates of POA (AeroCom)
Reapportioned to $\Delta x = 45$ km


Reapportioned to $\Delta x = 15$ km

emissions “smeared” over many smaller model cells

Chilean scientists to develop higher resolution and more up-to-date emission estimates

(from Laura Gallardo Klenner)
### Simulations

<table>
<thead>
<tr>
<th>Run</th>
<th>Lin et al. Microphysics</th>
<th>$\Delta x$ (km)</th>
<th>Cloud-Aerosol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Default</td>
<td>45</td>
<td>no</td>
</tr>
<tr>
<td>1b</td>
<td>Default</td>
<td>45 &amp; 15</td>
<td>no</td>
</tr>
<tr>
<td>2a</td>
<td>Modified #</td>
<td>45</td>
<td>yes (prescribed aerosol)</td>
</tr>
<tr>
<td>2b</td>
<td>Modified #</td>
<td>45 &amp; 15</td>
<td>yes (prescribed aerosol)</td>
</tr>
<tr>
<td>3a</td>
<td>Full chemistry, modified</td>
<td>45</td>
<td>yes (complex)</td>
</tr>
<tr>
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</tbody>
</table>

Diagram showing 'clean' and 'polluted' cloud-aerosol interactions.
Critical assess the ability of global (7) and regional (6) models to predict conditions over the southeastern Pacific Ocean

Cloud Fraction at 20S 85W
Specific Humidity at 20S 85W

Models are currently being evaluated, primarily with satellite data

Analysis from Matthew Wyant and Roberto Mechoso
Regional Cloud Distribution

Simulated Cloud Optical Depth 12 UTC October 15, 2006

GOES Visible 18 UTC

Domain 2 ($\Delta x = 15$ km)

extent of SO$_2$ point source tracer plume
~ 1 km AGL
Sulfate and its Precursors

Vertical Cross Section of SO$_2$ Tracers (ppt)

Vertical Cross Section of SO$_4$ ($\mu$g m$^{-3}$) and DMS (ppt)
Elements of Aerosol Radiative Forcing

AOD (600 nm) 12 UTC October 15

CCN at 0.1% SS (# cm$^{-3}$)

particulates affect shortwave radiation via scattering & absorption

CCN activation affects cloud-aerosol interactions
Regional Liquid Water Path

LWP at 12 UTC October 15, 2006

Run 1: Default

Run 2: Prescribed Aerosol #

Run 3: Full Chemistry

- TRMM data aggregated to model domain
- Simulated distribution of LWP qualitatively similar to satellite measurements
- Subtle differences in LWP distribution and magnitude among 3 simulations
Evaluation – Liquid Water Path

**Mean & Peak LWP**

- Simulation 1
- Simulation 2
- Simulation 3

**Frequency of Liquid Water Path**

- Too high
- Too low

- Cloud-aerosol interactions reduce # of cells with similar LWP, except for very thin clouds
- Simulated mean LWP over domain too low
- Simulated peak LWP over domain better

Observed: TRMM satellite
Simulation 1 (no aerosol effects)
Simulation 2
Simulation 3

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Regional Cloudiness

MODIS Cloud Fraction

Prescribed Aerosol #

too much

too little

Full Chemistry

TMI Liquid Water Path

Prescribed Aerosols

Full Chemistry

analysis from Matthew Wyant and Roberto Mechoso
Evaluation - Cloudiness

Temporal Variation of # of Cloudy Cells

- Simulated diurnal variations similar to observed
- Cloud-aerosol interactions reduce cloudiness
- Influence of cloud-aerosol interactions larger during 2 periods
- Overall, “full-chemistry” and “prescribed aerosol” simulations similar
Summary and Next Steps

• Model performance is mixed, with room for much improvement
  - Is large-scale subsidence, boundary layer mixing, and low-level jet simulated adequately?
  - How important is high-resolution SST?
  - Which WRF microphysics scheme is most appropriate to simulate marine stratus?
  - Is the current simulated impact of aerosols too large?

• Even though extensive data will be collected during the VOCALS field campaign, evaluating predictions of aerosol chemistry and its effect on cloud-aerosol interactions will be very challenging