Using WRF-Chem to understand interactions between synoptic and microphysical variability during VOCALS

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Motivation

$N_d =$ droplet concentration

Colored contours:
Mean albedo (observed $N_d$)
Mean albedo (remote $N_d$)

White contours:
$\Delta$(reflected solar flux) in W m$^{-2}$

- Aerosol Indirect Effects (AIEs) remain a large source of uncertainty in the anthropogenic contribution to climate change
-Fractional composite difference plots of MODIS fields on index of the strength of the Subtropical High, 2001-2008. (George and Wood 2009)

**To what extent are these associations due to**

- aerosol effects on clouds and aerosol transport
- direct dynamical mechanisms independent of aerosol changes?

More was done, and more could be done with satellite data alone, but fundamental problem of attributing causality to physical mechanisms and separating meteorology from aerosol impacts remains.
Goals (not for today)

• Run a regional model that can reproduce the mean and variability of meteorology (easy), clouds (hard), and aerosols (hard) seen in satellite and VOCALS flight data.

• Determine dominant mechanisms influencing cloud microphysical and macrophysical variability, including radiatively relevant quantity albedo.

• Ultimately attempt to constrain indirect effect in SEP
WRF-CHEM Model Specs used

• Simulation domain 60 -110 ° W, 0-50 ° S, dt = 3 minutes, data saved every 2 hours, dx=0.5°, 27 vertical levels ~10-12 in the boundary layer
• Forced with NCEP FNL meteorological data
• Lin et al. microphysics scheme
• Implemented UW PBL scheme from CAM (modified code from Xin-Zhong Liang)
• Regional Acid Deposition Model, 2nd generation (RADM2) chemical mechanism
• Modal aerosol scheme (aitken, accumulation, coarse modes) [MADE/SORGAM aerosols]
• Some aqueous reactions- cloud chemistry, wet scavenging, Fast-J photolysis, subgrid convective transport
• Emissions: VOCA Emissions inventory compiled by Scott Spak and Marcelo Mena
• MOZART4 initial and boundary conditions (Emmons et al. 2010)
• Sea salt only Na and Cl (no DMS)
UW PBL vs YSU PBL vs MODIS
CF=cloud fraction

Mean 10/16/2008-10/20/2008
UW PBL vs YSU PBL vs MODIS
LWP=Liquid Water Path

Mean 10/16/2008-10/20/2008
UW PBL vs YSU PBL vs MODIS

\[ N_d = \text{droplet concentration} \]
UWPBL scheme

- More mixing than most other schemes $\rightarrow$ vertical diffusivity coefficient ($K$) large $\rightarrow$ maximum subgrid vertical velocity always used for activation

- $TKE = \frac{1}{2} (u''^2 + v''^2 + w''^2) \rightarrow \text{assume } u''^2 \sim v''^2 \sim w''^2 \rightarrow w''^2 = \sqrt{\frac{2}{3}} TKE$

- Redefine $w''^2 = K/dz = \text{lengthscale} \times \text{Stability function} \times \sqrt{TKE} / dz$

  to $w''^2 = \sqrt{\frac{2}{3}} TKE$

Mean over REx period

UWPBL modified activation

<table>
<thead>
<tr>
<th>$N_d [\text{cm}^{-3}]$</th>
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<tr>
<td>250</td>
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MODIS
LWP is somewhat low, though that is a common model issue...

Mean over REx period

UWPBL modified activation

MODIS

LWP [g m$^{-2}$]
Compare flight data from Allen et al. 2011 to REx mean WRF-Chem fields, binned via similar algorithm:
Offshore low SO2 and SO4 aerosol in MBL – no model DMS

Much larger SO2 near shore (grid box includes regions/times unsampled by aircraft, model lack of cloud nearshore-SO2 not processed fast enough?, error in emissions translation?)

In general encouraging result
Reasonable aerosol mass, $N_d$ (at 20S), but very low CCN
- Not limited to this model (VOCA)
- Possibly CCN definition, assumed size of mode, missing DMS, etc.
- Mean CCN loss rate (coalescence scavenging)?
Precipitation over the VOCALS region

- **CloudSat**
  Attenuation and Z-R methods

- **VOCALS**
  Wyoming Cloud Radar and in-situ cloud probes

![Graph showing mean precipitation rate](Image)

**VOCALS Region, 17.5-22.5°S**

- **Mean precipitation rate [mm day⁻¹]**
- **Longitude [W]**

- **Oct-Nov 06-09**
- **Oct-Nov 08**

**Slide from Robert Wood**

WCR data courtesy Dave Leon

**Significant drizzle at 85°W**

**Very little drizzle near coast**
- $N_d$ variability over VOCAL Rex seems reasonable → model microphysical response to synoptic forcing is encouraging – WRF-Chem should be a good tool for interpreting meteorological versus aerosol effects.
Summary
- WRF-Chem is a useful tool for investigating Aerosol Indirect Effects
- The UWPBL scheme written for CAM improves representation of cloud properties such as LWP and CF, but work is still needed on microphysical effects
- Along 20S averaged over the REx time period aerosol, and chemical species agree to an extent with flight measurements.
- Precipitation rate, CCN loss rate to coalescence scavenging, and the amount of rain liquid water versus cloud liquid water are consistent at 20S with observations – thus are useful tools for investigating aerosol/precip/cloud processes.
- Nd variability consistent with satellite/flight data
Future Work

- Resolve/explain remaining model mysteries (e.g. low CCN, large amount of aerosol and activation 0-10S near coast, PM2.5 boundary conditions, too much SO2)
- Use the model for good: investigate aerosol indirect effects
  - Impact of sulfate/anthropogenic influence
  - Role of precipitation in aerosol effects (with great model fields to explore—3D precip rate, CCN loss rate, etc)
  - Identify role of meteorology – are cloud changes associated with the synoptic high due to aerosol impacts and aerosol transport, or thermodynamic/dynamic mechanisms?
A snapshot in time to take with a grain of salt...

LWC g m$^{-3}$

$N_d$ cm$^{-3}$

SO4 aerosol ug m$^{-3}$

81-82 W during RF03, 10-21-2008