Analysis of Ozone in Cloudy Versus Clear Sky Conditions

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Introduction

• Convection
  – Lifts low ozone air from the marine boundary layer to the mid & upper troposphere
  – Contributes to S-shaped ozonesonde profiles in the tropics
  – Lifts NO$_x$ & hydrocarbons from the polluted boundary layer $\rightarrow$ O$_3$ production
  – Associated with lightning NO$_x$ emissions

• How important is O$_3$ production versus the O$_3$ transport due to convection?
• How has the impact of convection on upper tropospheric ozone changed over time?
OMI/MLS in-cloud O$_3$

- Observations of ozone under cloudy versus clear-sky conditions provide insight on how convection influences ozone.
- Ziemke et al. [2009] calculate O$_3$ inside tropical deep convective clouds by subtracting the MLS stratospheric column from the OMI above-cloud column.

Satellite observations give us broad spatial coverage over the tropics to extend our understanding of ozone under clear versus cloudy conditions.
Can we evaluate chemistry climate models (CCMs) with the OMI/MLS in-cloud ozone?

Can we use CCMs to interpret in-cloud ozone?

**Challenges:**
- Clouds in free-running CCM don’t align with the obs
- Model resolution (1 or 2 degree) much larger than a cloud, so gridbox isn’t completely cloudy

**Solution:**
- Bin model output according to a cloudiness threshold of 40% at 350-400hPa
- Composite July days over multiple years

**Examples from multi-year GEOS-5 CCM hindcasts, focusing on July**
Simulated ozone profiles are more vertically uniform under cloudy conditions, leading to lower concentrations in the mid-troposphere.

Use 400 hPa level to compare with obs since this is where separation is large.

Over polluted regions, CO profile shows lofting of pollution in cloudy conditions.

Tropical \( \text{O}_3 \)

African \( \text{O}_3 \)

African CO
All Sky vs. Cloudy O$_3$ Maps

- Cloudy O$_3$ lower than All Sky O$_3$ throughout tropics in both observations and model.
- East-West gradients in ozone well-simulated.
Dynamics, Convection, & Chemistry

- Model diagnoses $O_3$ tendency due to large-scale dynamics, physics (convection), & chemistry at 400 hPa:
  - Daily mean: dynamics dominates
  - Multi-July average: competition between terms
Distribution of Tendencies

- **all sky d03_physics**

- **all sky CMF**

- **all sky d03_chemistry**

- **all sky NOx**

- **cloudy d03_chemistry**

- **cloudy NOx**
Net Effect of Marine Convection

• Convection is localized and maps of convective mass flux are noisy
• CH$_3$I is a tracer of marine convection, gives smoother picture
• Cloudy vs. all-sky differences in simulated CH$_3$I anticorrelate ($r=-0.7$) with O$_3$ differences

\[ \Delta \text{CH}_3\text{I} = \text{cloudy} - \text{all sky} \]
\[ \Delta \text{O}_3 = \text{cloudy} - \text{all sky} \]
Pre-Industrial to Present Changes

- Simulation captures observed steep jump in cloudy-sky O$_3$ at the east coast of Africa
- All-sky & cloudy O$_3$ increased by comparable percentages since 1860s (larger absolute change in all-sky) in most regions
- Larger % increase in cloudy-sky O$_3$ over Africa where change in lightning NO$_x$ is large
Conclusions & Future Work

• Simulated 400 hPa O$_3$ for days with cloud fraction > 0.4 comparable to OMI/MLS in-cloud O$_3$
• Convection leads to lower ozone for “cloudy” days, but chemical production is enhanced for cloudy conditions over polluted regions
• Similar pre-industrial to present % increases in cloudy and all-sky O$_3$, with some regional differences

Future Work:
• Quantify role of lightning versus surface NO$_x$ emissions
• Calculate pre-industrial to present change in O$_3$ tendencies due to convection and chemistry