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 → 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.
Model Evaluation & Analysis

• 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
All Sky vs. Cloudy Profiles

• 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.
All Sky vs. Cloudy O₃ Maps

- Cloudy O₃ lower than All Sky O₃ throughout tropics in both observations and model
- East-West gradients in ozone well-simulated
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
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 O₃ at the east coast of Africa
- All-sky & cloudy O₃ increased by comparable percentages since 1860s (larger absolute change in all-sky) in most regions
- Larger % increase in cloudy-sky O₃ over Africa where change in lightning NOₓ 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