Analysis of Ozone in Cloudy Versus Clear Sky Conditions

Sarah Strode, Anne Douglass, Jerry Ziemke
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.
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 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

Single Day  

\[ dO3_{\text{dynamics}} \]  

\[ dO3_{\text{physics}} \]  

\[ dO3_{\text{chemistry}} \]  

Avg. over many days  

\[ dO3_{\text{dynamics}} \]  

\[ dO3_{\text{physics}} \]  

\[ dO3_{\text{chemistry}} \]
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 $O_3$ 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