The impact of size-resolved aerosol microphysics on cloud properties and photochemistry in CESM

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2017-06-22
By scattering and absorbing solar radiation, clouds modify photochemistry reaction rate

COD used for CAM-Chem photochemistry (OldC)

\[ COD_{in} = \frac{3}{2} \frac{CWP}{\rho_{water} \cdot r_e} \quad \text{Slingo and Schrecker, 1982} \]

\[ COD_r = COD_{in} \cdot CF^{\frac{3}{2}} \quad \text{Briegleb, 1992} \]

The Biases are large

- Can we improve the agreement of COD by considering the impact of aerosol microphysics on cloud properties?
- How does it impact photochemistry and [OH]?
Incorporation of sectional aerosol microphysics in CESM

Provide a new method which can represent the relationships among aerosol, droplet, COD, and tropospheric photochemistry

1. On-line chemistry: MOZART + 2 product SOA scheme
2. Aerosol microphysics: the Advanced Particle Microphysics (APM)

Secondary particles (SP): 40 bins, composed of SO4, NIT, NH4, SOA
Black Carbon (BC): 15 bins
Primary OC (POC): 15 bins
Sea salt (SS): 20 bins
Dust: 15 bins
Particle formation, growth and contribution to CCN
3. Aerosol-cloud interaction

Aerosol
- Mass
- Number
- Size
- Mixing

Cloud
- Number
- Size
- CWC
- COD

CCN+IN

Cloud droplet activation

In-cloud scavenging

4. Cloud properties and impacts on atmospheric chemistry
   a. Cloud Water Content ⇒ aqueous chemistry
   b. Cloud Optical Depth ⇒ photolysis rate ⇒ SP precursors
Validation of Aerosol Mass
Validation of Ultra-fine Aerosol I: CN3 (Diameter > 3 nm)

Aircraft measurements: ~30,000 samples collected from GLOBE, ACE-1, PEM-Tropics A and B, TRACE-P, INTEX-A and B, NAMMA, TC-4, and ARCTAS
Validation of Ultra-fine Aerosol II: CN10 (Diameter > 10 nm)

Long-term ground-based measurements of CN10 at 21 sites:
Obs: 2177 # cm⁻³; Sim: 1756 # cm⁻³; R=0.8
Underestimated at rural region (P, U) and coast region (G, J, K, S)
Global mean = ~700 # cm⁻³
Ground-based measurements of CCN0.4 at 26 sites:
Obs: 947 # cm⁻³; Sim: 965 # cm⁻³; R=0.9
Underestimated at Arctic region (A, B, C, D)
Overestimated at Amazon (W, X, Y) and China (T)
Global mean = ~370 # cm⁻³
Characteristics of aerosol simulated by CAM-Chem/APM

40% of total particles are larger than CCN size

Tropics: 70-90%

Global aerosol number is dominated by SP: 73%

South Ocean: sea salt

Tropics: POC+BC
The Comparisons of COD: MODIS, OldC, NewC

Cloud Optical Depth

Aerosol Number $\Rightarrow$ Droplet Number $\Rightarrow$ Effective Radius + In Cloud Water Content $\Rightarrow$ COD

(a) MODIS: Annual, Mean=3.7

(b) OldC: Annual, Mean=6.8

(c) NewC: Annual, Mean=3.8

Zonal mean of COD
Impact on Photochemistry: Change OH Concentration

\[(\text{New C-Old C})/\text{Old C}: [\text{OH}] < 500 \text{m, Annual, Mean} = 4.7\%\]

\[(\text{New C-Old C})/\text{Old C}: [\text{OH}] < 500 \text{m, Jul, Mean} = 6.5\%\]
There are large biases of COD which are used for photochemistry in CAM-Chem.

By using cloud number and size predicted by the coupled aerosol and cloud microphysics, COD changes from 6.8 to 3.7 in CAM-Chem, which is closer to MODIS value of 3.6.

The reduced COD in CAM-Chem by using NewC:

a. enhances global average low layer [OH]
   - Annual: ~5%; Summer: ~7%
   - Regional changes can be high up to 10-40%

b. has large impact on CCN, CDNC, LWP, SWCF
Thank You!