How ozone air pollution makes itself worse by damaging vegetation: simulating ozone-vegetation interactions in the Earth system

Mehliyar Sadiq, Amos P. K. Tai, Danica Lombardozzi and Maria Val Martin
Background: ozone damage

- **Stratospheric ozone** prevents damaging ultraviolet light from reaching the Earth’s surface – beneficial
  - Tropospheric ozone has detrimental effects on human health with its strong oxidizing ability – air pollutant
    - Annual burden of $0.7 \pm 0.3$ million respiratory mortalities [Anenberg et al., 2010]
  - Tropospheric ozone severely damages forest and agricultural productivity:
    - Elevation of $[O_3]$ suppresses photosynthetic $\text{CO}_2$ uptake by 11% and stomatal conductance by 13% [Wittig et al. 2007]
Background: vegetation -> ozone

Vegetation’s effects on tropospheric ozone

Chemical production

NOx

OH

VOC emission: mainly isoprene

Dry deposition

Stoma

Boundary layer meteorology

Transpiration
Research question

- What are the possible Earth system feedbacks of these ozone-vegetation interactions on present day ozone air quality?
Methods: model configs + O$_3$ effects

Resolution:
1.9°*2.5°*26

- Fully coupled CAM4 + CLM4.0 (CN mode with dynamic LAI)
- Ozone damage scheme [Lombardozi et al., 2015]: cumulative ozone uptake affects photosynthesis and conductance:
  \[ F_{pO3} = a_p \times CUO + b_p, \]
  \[ F_{cO3} = a_c \times CUO + b_c, \]
- Dry deposition scheme [Val Martin et al., 2014]: coupling stomatal resistance to LAI
- 20-year simulations, averaging JJA values over last 15 years
Results: ozone changes and attribution

With ozone damage

Ozone damages conductance alone

Ozone damages photosynthesis alone

Left: Differences in mean JJA surface ozone

[Sadiq et al., 2017, ACP]
Ozone damage in CAM-Chem-CLM4.5BGC

Surface ozone changes

Dry deposition changes

Leaf Area Index changes

Isoprene emission changes \( *10^{-11} \text{ kg m}^{-2} \text{ s}^{-1} \)
Changes in hydrometeorology

Canopy transpiration (W m\(^{-2}\))

Latent heat flux (W m\(^{-2}\))

Surface temperature (K)

Precipitation ( \(* 10^{-6}\) m s\(^{-1}\))
• Simulated ozone concentration is higher by up to 6 ppb over Europe and 5 ppb over North America with ozone-vegetation interaction, representing a strong positive feedback.

• Ozone damage -> stomatal conductance↓ -> dry deposition↑ -> ozone↑

• Ozone-vegetation interactions should be considered in future model developments.

• Hydrometeorology (temperature, precipitation) is also modified by ozone damage.

Thanks!