Coupling dry deposition to vegetation phenology in CESM: Implications for surface O$_3$ simulations

Maria Val Martin (CSU), Colette L. Heald (MIT) and Steve Arnold (Leeds)

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CESM has a large positive bias in summertime surface $O_3$ over eastern US and Europe

Summertime positive bias is a persistent, well-known issue in some chemical models [e.g., Murakaki and Hess, 2006, Fiore et al., 2009, Lapina et al. 2014]
Linking the dry deposition velocity code to vegetation

Parameterization based on Wesely, (1989) multiple resistance approach

Calculation takes place in CLM for each PFT, and the weighted-mean velocity is then transferred to CAM-Chem

Standard Scheme

\[ R_s = r_s \left\{ 1 + \frac{1}{[200(G + 0.1)]^2} \right\} \left\{ \frac{400}{T_s(40 - T_s)} \right\} \frac{D_{H_2O}}{D_x} \]

Corrected Scheme

\[ \frac{1}{r_s} = m \frac{A e_s}{c_s e_i} P_{atm} + b \]

for sunlit (\( r_{s\text{sun}} \)) and shaded leaves (\( r_{s\text{sha}} \))

Scaled to the bulk canopy

\[ R_s = \frac{f_{\text{sun}} \times r_{s\text{sun}}}{LAI} + \frac{(1 - f_{\text{sun}}) \times r_{s\text{sha}}}{LAI} \]

[Wesely, 1989]

[Collatz et al., 1991; Sellers et al, 1996]
Linking the dry deposition velocity code to vegetation

Parameterization based on Wesely, (1989) multiple resistance approach
Calculation takes place in CLM for each PFT, and the weighted-mean velocity is then transferred to CAM-Chem

Standard Scheme

Corrected Scheme

\[
R_lu = \frac{r_{lu}}{10^{-5} H + f_o}
\]

\[
R_lu = \frac{r_{lu}}{LAI} \times \frac{r_{lu}}{(10^{-5} H + f_o)}
\]

Scaled to the bulk canopy

[Wesely, 1989]  [Baldocchi et al., 1987; Gao and Wesely, 1995]
Significant changes in dry deposition velocity and surface O$_3$ when the scheme is coupled to LAI
The dry deposition scheme substantially overestimates daytime stomatal resistance.

Daytime Rs is overestimated by a factor of 5

[Val Martin et al., GRL 2014]
O₃ dry deposition velocity is very sensitive to Rs in densely vegetated regions.
**O₃ Vd** is significantly improved with the LAI-dependence over densely vegetated regions

Seasonal cycle of midday (9:00-15:00) O₃ dry deposition velocity

Seasonal cycle of LAI

Observations from Wu et al. [2011], Padro et al. [1991, 1992, 1994], Finkelstein et al. [2000], Meyers et al. [1998] and Gao and Wesely [1995]
LAI-coupled simulations improve surface O$_3$, yet it is still overestimated over relatively polluted sites.

Simulated versus observed summertime surface O$_3$
.. and also over remote sites

Simulated versus observed surface $O_3$ over remote sites

American and Asian Baseline Sites

European Baseline Sites

Measured (monthly average ppb)

Modeled (monthly average ppb)

[Courtesy of Dr. David Parrish (NOAA)]
Evaluating the dry deposition code in CLM4.5

Significant changes between CLM4.0 and CLM4.5 [Bonan et al., 2011, Oleson et al., 2013]

- New rubisco kinetics scheme (effect on net leaf photosynthesis)
- Updated radiative transfer scheme (effect on sunlit and shaded LAI)
- New canopy integration (effect on the maximum rate of carboxylation)
- Different surface map (effect on LAI)
- Etc, etc

Simulated versus observed summertime surface O$_3$ over polluted sites

Eastern US

Original: +30 ppb
Opt CLM40: +14 ppb
Opt CLM45: +16 ppb

Europe

Original: +13 ppb
Opt CLM40: +5 ppb
Opt CLM45: +4 ppb
But, the stomata resistances differ from CLM4.0!
A few final notes....

- Coupling the dry deposition to vegetation improves significantly surface $O_3$ over densely vegetated regions.
- The effect of changes in the dry deposition code in other species and above 900 hPa is small.
- Further work is needed to understand the causes in the Rs bias in CLM4.0 and CLM4.5 and implications to the hydrological and carbon cycles.