Revisiting dry deposition of particles in the atmosphere

Delphine K. Farmer¹, Ethan W. Emerson¹, Gavin McMeeking², Jeff Pierce³, Anna Hodshire³, Joshua Schwarz⁴, Joseph Katich⁴, Holly DeBolt¹, + many others

¹. Department of Chemistry, Colorado State University; ². Handix Scientific; ³. Department of Atmospheric Sciences, Colorado State University; ⁴. NOAA CSD
Deposition: An under-appreciated aspect of the aerosol life cycle?
Black Carbon is a tracer for studying wet vs dry deposition \(\rightarrow\) eddy covariance flux measurements at the Southern Great Plains site

Dry deposition accounted for 6 ± 4% of total BC deposition during BCADS*

Net BC lifetime: 7-11 days, dominated by wet deposition

*14 cm rainfall over ~6 weeks

Traditional view of particle dry deposition

\[ V_{dep} = V_{settling} + \frac{1}{R_{aerodynamic} + R_{surface}} \]

\[ E_{Brownian} = C_b S c^{-2/3} \]

\[ E_{Impaction} = C_{Im} \left( \frac{St}{a + St} \right)^\beta \]

\[ E_{Interception} = C_{In} \left( \frac{d_p}{A} \right)^\nu \]

[Zhang et al. 2001; Slinn, 1982]
We use two sets of size-resolved particle flux measurements

Manitou Forest, CO
4 seasons,

Southern Great Plains, OK
6 weeks,

Holly DeBolt
Gavin McMeeking
Ethan Emerson

Handix Scientific
Widely-used models fail to capture the observational data

Model: Zhang et al. [2001]
Widely-used models fail to capture the observational data
Sophisticated deposition models capture the observations (but widely used simpler ones generally do not)

• Can we develop a simple (yet accurate) model for global models?

• What underlying processes control particle dry deposition?

* Model shown is for forested terrain
We use the extensive observations to modify simple parameterization terms, using the sophisticated models as a framework.

\[ V_{\text{dep}} = V_{\text{settling}} + \frac{1}{R_{\text{aerodynamic}} + R_{\text{surface}}} \]

\[ E_{\text{Brownian}} = C_b S c^{-2/3} \]

\[ E_{\text{Impaction}} = C_{\text{Im}} \left( \frac{St}{\alpha + St} \right)^\beta \]

\[ E_{\text{Interception}} = C_{\text{In}} \left( \frac{d_p}{A} \right)^\nu \]
Our observations suggest current model overestimates of Brownian diffusion and underestimates of interception.
Revised vs standard parameterization for dry deposition captures data and has lower uncertainty.

[Emerson et al. In prep]
Parameterization holds for different land cover types, but data over oceans are limited

[Emerson et al. In prep]
Revised particle dry deposition parameterizations have a substantial effect on modeled aerosols...

*Collaboration with Anna Hodshire + Jeff Pierce (CSU); [Emerson et al. In prep]*
Dry deposition impacts size-resolved [particle], and thus the direct radiative effect – current models overestimate cooling effect over land.

IPCC AR5 non-cloud aerosol effect: \(-0.27 \, \text{W m}^{-2}\)

Global cooling, driven by deposition over ocean, which is highly uncertain due to lack of measurements.
Changing the dry deposition parameterization changes the aerosol indirect effect – current models underestimate cooling.

**Change in aerosol indirect effect**
- Global mean = -0.63 W m\(^{-2}\)
- Land mean = -0.13 W m\(^{-2}\)

**IPCC AR5 cloud-aerosol effect:** -0.55 W m\(^{-2}\)
Changing the dry deposition parameterization changes radiative forcings substantially – but is this real??

- Particle concentrations are the result of deposition AND emission AND chemistry
- Deposition processes are incorrectly captured in current models
- If we believe the model concentrations are right, then our emissions inventories are incorrect (generally overestimated for sub-micron aerosol)
- We aren’t necessarily getting particle concentrations and radiative forcing wrong in models – just right for the wrong reasons
We use the extensive observations to modify simple parameterization terms, using the sophisticated models as a framework.

For example, turbulence (and friction velocity $u^*$ in particular) plays a strong role in the size-dependent dry deposition.
Deposition velocity measures efficiency of removal

$V_{\text{dep}}$ (rBC Particle #)
Average: $0.3 \pm 0.2$ mm/s
Exclude upward fluxes: $1.6 \pm 0.3$ mm/s

$V_{\text{dep}}$ (rBC Particle Mass)
Average: $0.3 \pm 0.2$ mm/s
Exclude upward fluxes: $3.5 \pm 0.3$ mm/s

Comparable to model BC $V_{\text{dep,dry}}$
1 mm/s$^+$; 0.1-0.7 mm/s$^\ddagger$

$^+$ Reddy and Boucher (2004); Huang et al. (2010) $^\ddagger$ Liu et al (2011)

Compare to removal by wet deposition:
$V_{\text{dep, wet}} = 6-10$ mm/s