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Parametrizations of deposition velocity for particles

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Deposition velocity: model parameter

$$\text{Flux} = V_d(\text{particle}, \text{flow}, \text{surface}) \cdot \text{Concentration}$$

- V_d implies that flux is proportional to concentration
- V_d to be parameterized (experiments, mechanistic models etc.)
- Often u_* used to get velocity dimension for V_d

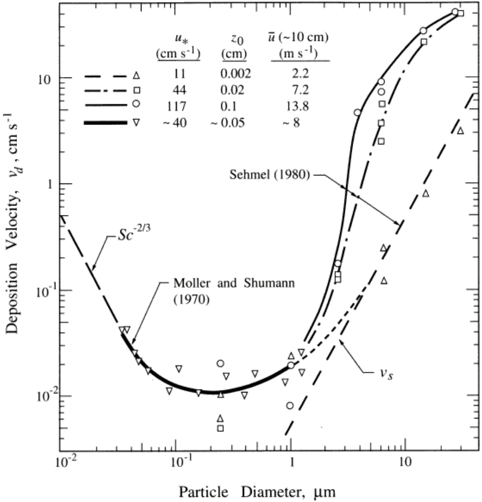
Direct method

- Observe concentration and deposited amount
- Require both measurements
- Laborious

Indirect method

- Observe concentration and in-air vertical flux
- Any flux measurements
- Assumption: vertical flux is deposition flux

Slinn, 1980



Slinn (1978), Fig. 9, after SP98

As in Seinfeld & Pandis, 1998

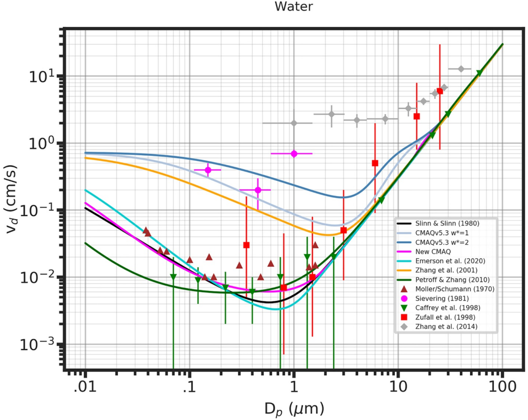
- Suggested by Slinn&Slinn (1980) for water surfaces
- Concepts of r_a, r_b and virtual resistance

$$v_d = \frac{1}{r_a + r_b + v_s r_a r_b} + v_s$$

- r_b accounts for diffusion and impaction
- No surface-specific parameters
- Very easy to implement
- Recommended by SP1998 for all surfaces
- Criticized by Venkatram and Pleim (1999)
- Much lower V_d than measured over nature

Zhang et al, 2001

- Resistance analogy
- Surface-dependent r_b
- Add interception term (Slinn, 1982)
- 4 parameters (3 deposition-specific)
- 15 LUC, 5 seasons
- x10 higher V_d than Slinn (1980)
- Recommended by SP2006, and SP2016



Pleim et al (2022), Fig. 6

LUC		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Z (m)	SC 1	0.8	2.65	0.85	1.05	1.15	0.1	0.1	0.04	0.03	0.1	0.03	0.01	$f(u)$	$f(u)$	1.0
	SC 2	0.9	2.65	0.85	1.05	1.15	0.1	0.1	0.04	0.03	0.1	0.03	0.01	$f(u)$	$f(u)$	1.0
	SC 3	0.9	2.65	0.80	0.95	1.15	0.05	0.02	0.04	0.03	0.1	0.02	0.01	$f(u)$	$f(u)$	1.0
	SC 4	0.9	2.65	0.55	0.55	1.15	0.02	0.02	0.04	0.03	0.1	0.02	0.01	$f(u)$	$f(u)$	1.0
	SC 5	0.8	2.65	0.60	0.75	1.15	0.05	0.05	0.04	0.03	0.1	0.03	0.01	$f(u)$	$f(u)$	1.0
A (mm)	SC 1	2.0	5.0	2.0	5.0	5.0	2.0	2.0	na	na	10.0	10.0	na	na	na	10.0
	SC 2	2.0	5.0	2.0	5.0	5.0	2.0	2.0	na	na	10.0	10.0	na	na	na	10.0
	SC 3	2.0	5.0	5.0	10.0	5.0	5.0	5.0	na	na	10.0	10.0	na	na	na	10.0
	SC 4	2.0	5.0	5.0	10.0	5.0	5.0	5.0	na	na	10.0	10.0	na	na	na	10.0
	SC 5	2.0	5.0	2.0	5.0	5.0	2.0	2.0	na	na	10.0	10.0	na	na	na	10.0
α		1.0	0.6	1.1	0.8	0.8	1.2	1.2	50.0	50.0	1.3	2.0	50.0	100.0	100.0	1.5
γ		0.56	0.58	0.56	0.56	0.56	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.50	0.50	0.56

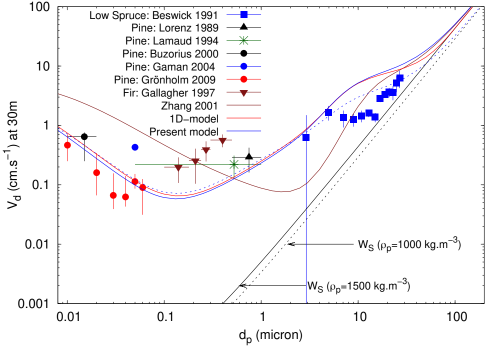
Note: $f(u)$ represents a function of wind speed (u) and na represents not applicable.

Zhang et al (2001), Table 3

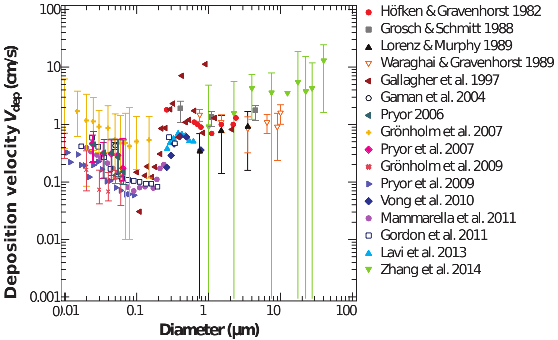
Petroff and Zhang, 2010

- “Exponential” form for aerodynamic layer
- Separate smooth surfaces, only diffusivity and settling
- 10 parameters (6 deposition-specific), 26 Land-Use Categories
- Better fits measurements

Deposition velocity on coniferous forests



Petroff and Zhang, 2010, Fig. 5



Farmer et al., 2021, Fig. 5

Recent schemes

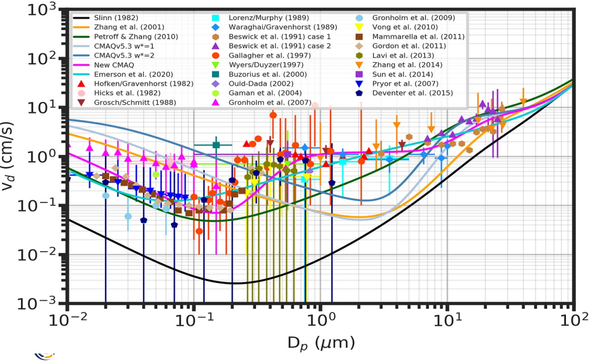
Emerson et al., 2020

- Driven by observations
- Zhang 2001 with adjusted parameters
- Interception $\sim (d_p/A)^{0.8}$ (Sic!)
- Shifts deposition minimum to $0.1\mu m$
- Cyan line

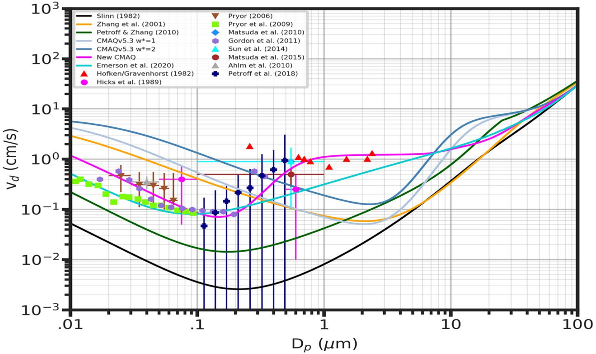
Pleim, 2022

- Two collector scales for impaction
- Impaction on leaf hairs (Slinn, 1982)
- Interception $\sim (d_p/A)^2$, but negligible
- Sharper deposition minimum $0.1\mu m$
- Magenta line

Evergreen Needleleaf Forest

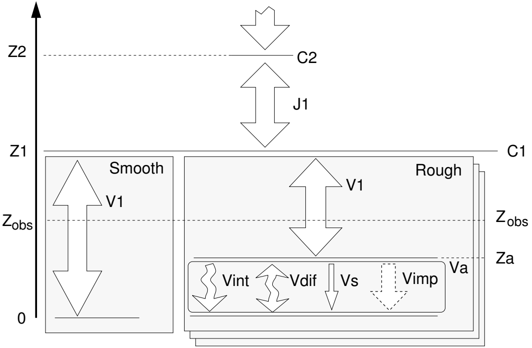


Deciduous Broadleaf Forest



Pleim et al. 2022), Fig. 2, Fig. 3

KS2012 scheme



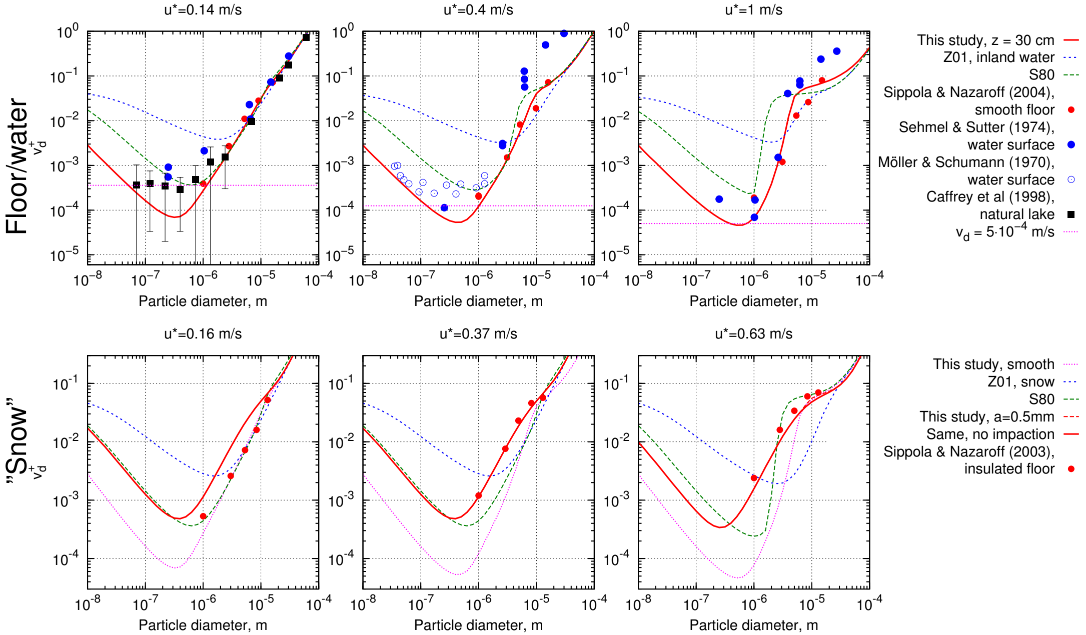
Kouznetsov & Sofiev 2012, JGR

- “Exponential” scheme for finite layers
- Pericles with D, d_p, τ rather than ’size’
- Asymptotic transition to gases
- Smooth/rough: roughness Reynolds number

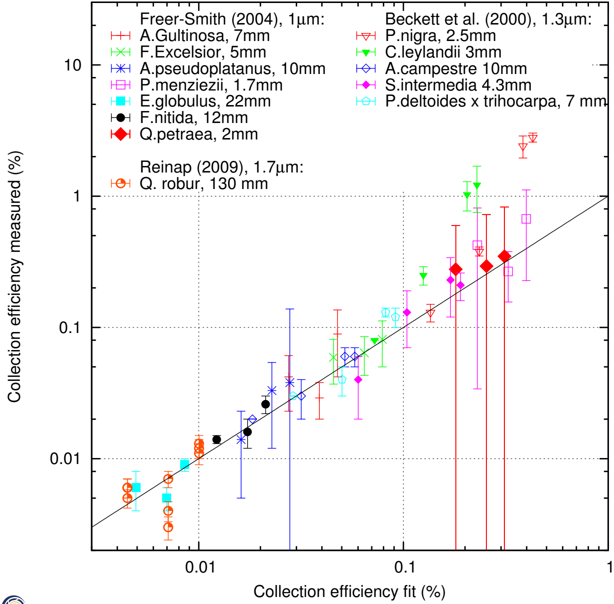
$$u_* z_0/\nu \sim 3$$

- Smooth surfaces
  - Rigorously derived scheme
  - Settling, turbophoresis, diffusion
  - No fitting parameters
- Rough surfaces
  - Filtration in canopy top
  - Particle vs momentum efficiency
  - Settling, impaction, interception, diffusion
  - One deposition-specific scale a
  - Can be calibrated with ’collectors’ rather than with ’canopy’
- Phoretic processes (thermophoresis so far)

Smooth surfaces and dynamic switch



Collector size from WT: trees/branches (slide from ITM 2013)



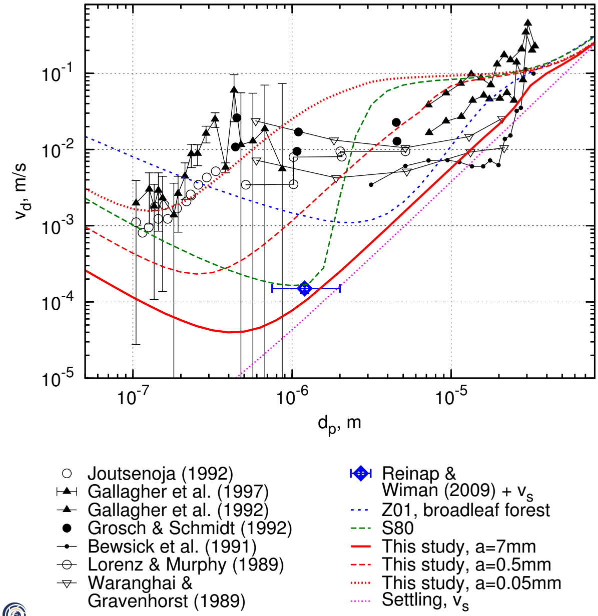
Courtesy of Walter Obermayer

Quercus Robur & Quercus petraea

Problems:

- Few studies
- Wide and uncertain particle size spectra

High vegetation (slide from ITM 2013)



Probable causes of discrepancies:

- Electricity?
  - Boltzmann charging: no sharp size dependence
  - Dipole charging: 10 orders of magnitude weaker
- Wrong measured size?
- Complex particle shapes?
- Humidity?
- Something else?

Black and white symbols Gallagher (1997)

Deposition on water

V_d for 1 µm particles

- Direct measurements: $V_d \sim 0.1\,\mathrm{mm/s}$
- Mechanistic models: Same
- Indirect measurements: $V_d \sim 10\,\mathrm{mm/s}$
- 2 orders of magnitude difference!

Experiments and parametrisations

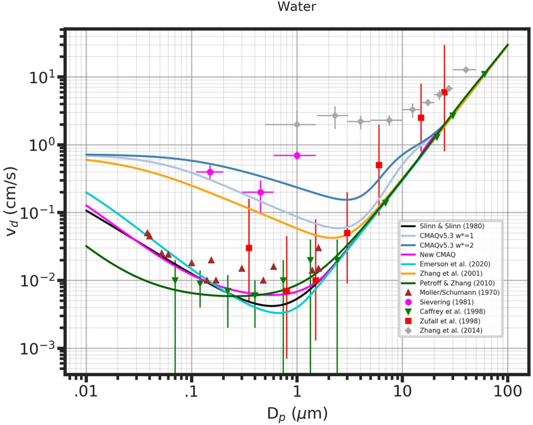


Fig. 6 from Pleim et al (2022)

Deposition on grass

V_d for 1 µm particles

- Direct measurements: $V_d \sim 0.1\,\mathrm{mm/s}$
- Mechanistic models: Same
- Indirect measurements: $V_d \sim 10\,\mathrm{mm/s}$
- Again orders of magnitude difference
- V_d is one of many uncertainties in transport models

Experiments and parametrisations

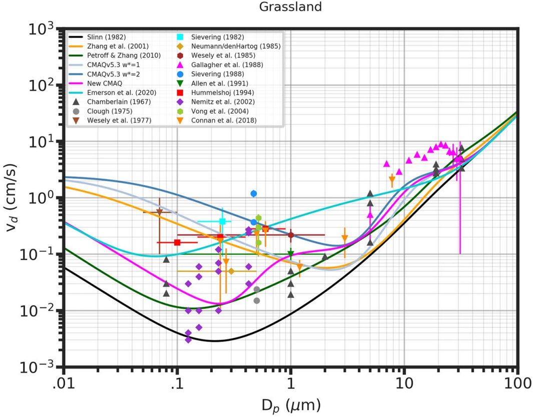


Fig. 4 from Pleim et al (2022)

Deposition on needle-leaf forest

V_d for 1 µm particles

- Measurements: $V_d \sim 10\,\mathrm{mm/s}$
- Impressive consensus
- Mechanistic models: $V_d \sim 0.1\,\mathrm{mm/s}$
- ”Ground truth” often preferred
- Is it a clear case?
- All observations are indirect

Can we simulate high 'V_d' with KS2012?

Experiments and parametrisations

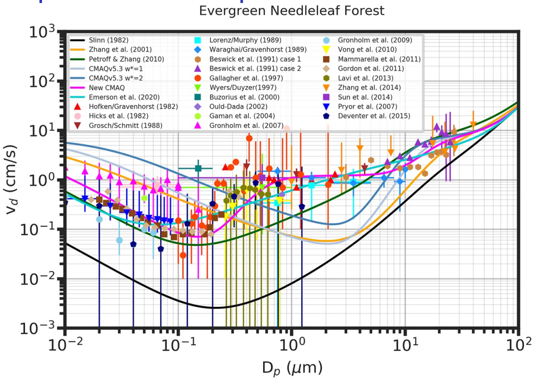


Fig. 2 from Pleim et al (2022)

Fluxes with mechanistic model?

Measurements (Gallagher, 1997)

- Fluxes (0.1 – 0.4 µm) over forest canopy
- Eddy Covariance with OPC

SILAM simulation

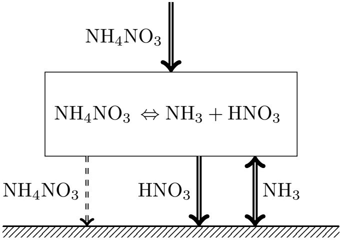
- European air-quality setup
- Primary and secondary inorganic aerosols

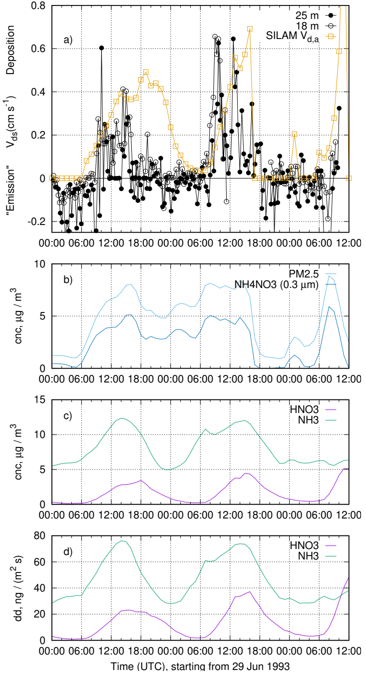
NH_4NO_3 flux

Apparent V_d @ obs. height

vs

Particle and gas deposition @ sfc

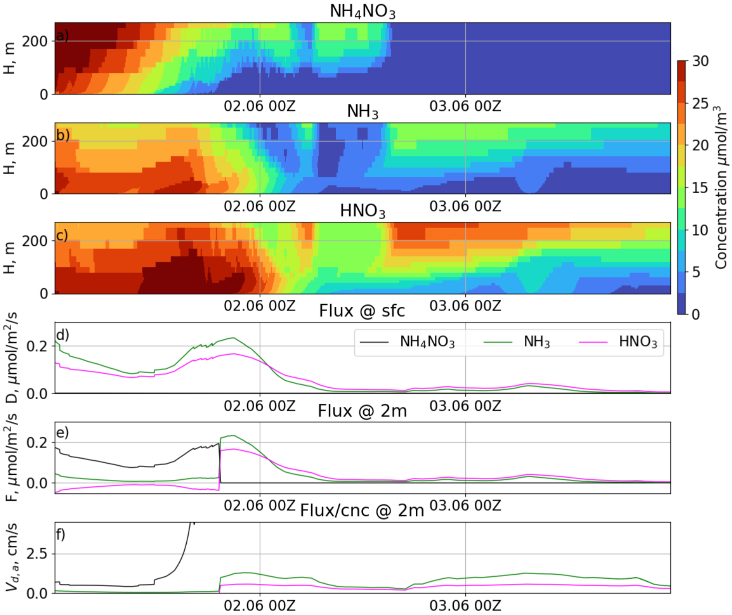




Single-column experiment

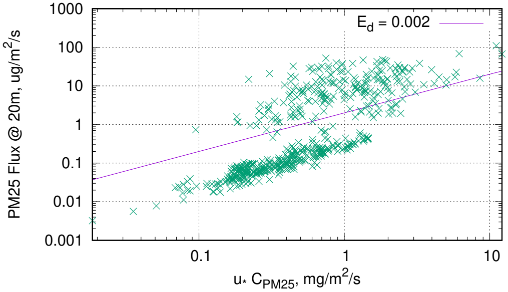
Indirect V_d "measurements"

- Uniform $5\,\mu g/m^3$ NH_4NO_3 at start
- No wind, no rains
- V_d for aerosol $\sim 0.1\,mm/s$
- Observe
  - Concentrations
  - Fluxes at 2 m height
  - Depositions (surface)



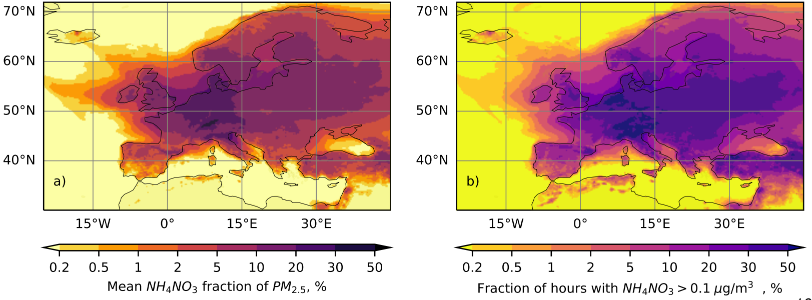
Flux proportional to concentration?

- Scatter of flux vs concentration
- For the simulated case above
- Clusters – present/absent NH_4NO_3
- Never plotted for field studies
- Line – Sulphate 'V_d' from Weseley (1985)



Abundance of NH_4NO_3

- SILAM CAMS-REG, 2024
- Mean fraction of PM
- Fraction of hours when NH_4NO_3 present



Concluding remarks

- V_d implies that flux is proportional to concentration:

$$\text{Flux} = V_d(\text{particle, flow, surface}) \cdot \text{Concentration}$$

- V_d does not apply to NH_4NO_3 particles
- Same true for many other aerosols
- NH_4NO_3 alone sufficient to break V_d for ambient particles
- SILAM with KS2012 *can* reproduce observed fluxes and apparent V_d
- Accumulation mode deposits at $\sim$ 0.1 mm/s (below detection limit?)
- ”Ground-truth”-based models overstate accumulation-mode V_d over forests
- KS2102 scheme (Kouznetsov & Sofiev, 2012, JGR)
    - One deposition-specific parameter of surface for particles
    - Has been used in SILAM since 2011
    - LUC-agnostic