Deposition Model Uncertainties

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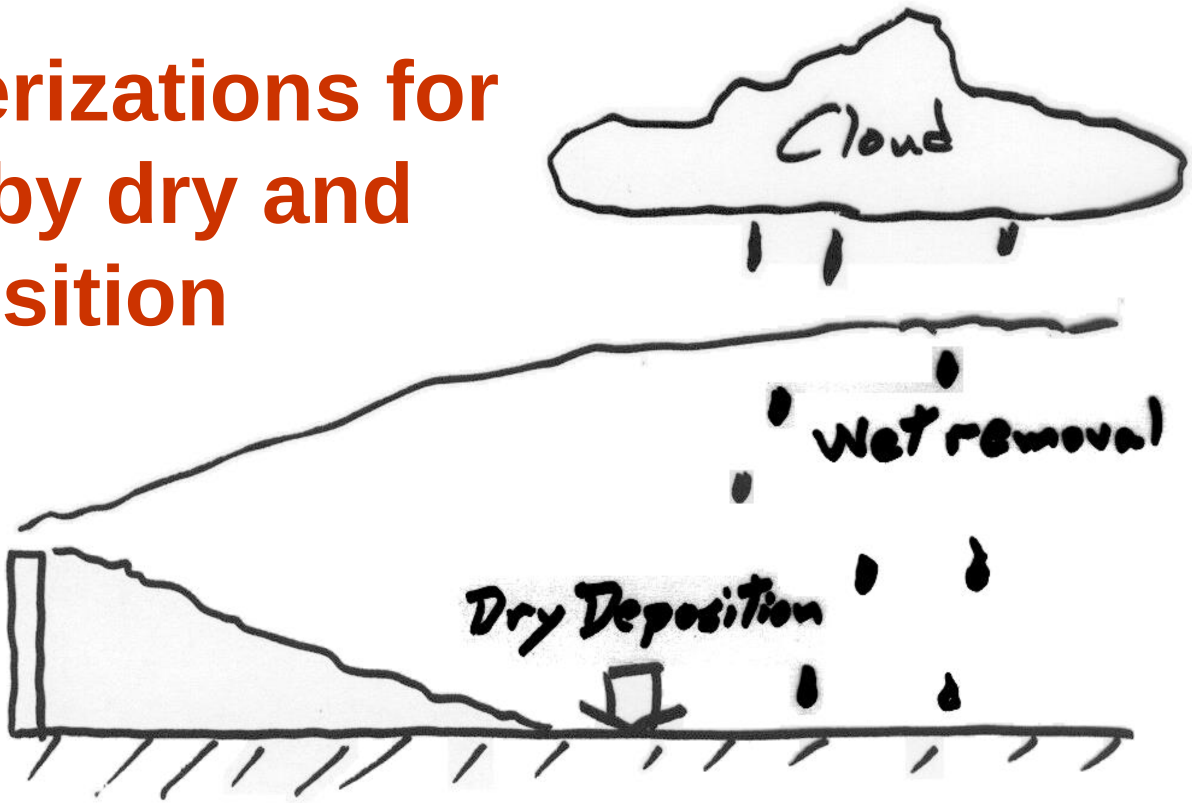
Mass flux to surface due to dry deposition = $v_d C_o$ (kg/s m^2)

Rate of loss of pollutant due to wet removal $\partial C/\partial t = -\Lambda C$

Simple parameterizations for removal by dry and wet deposition



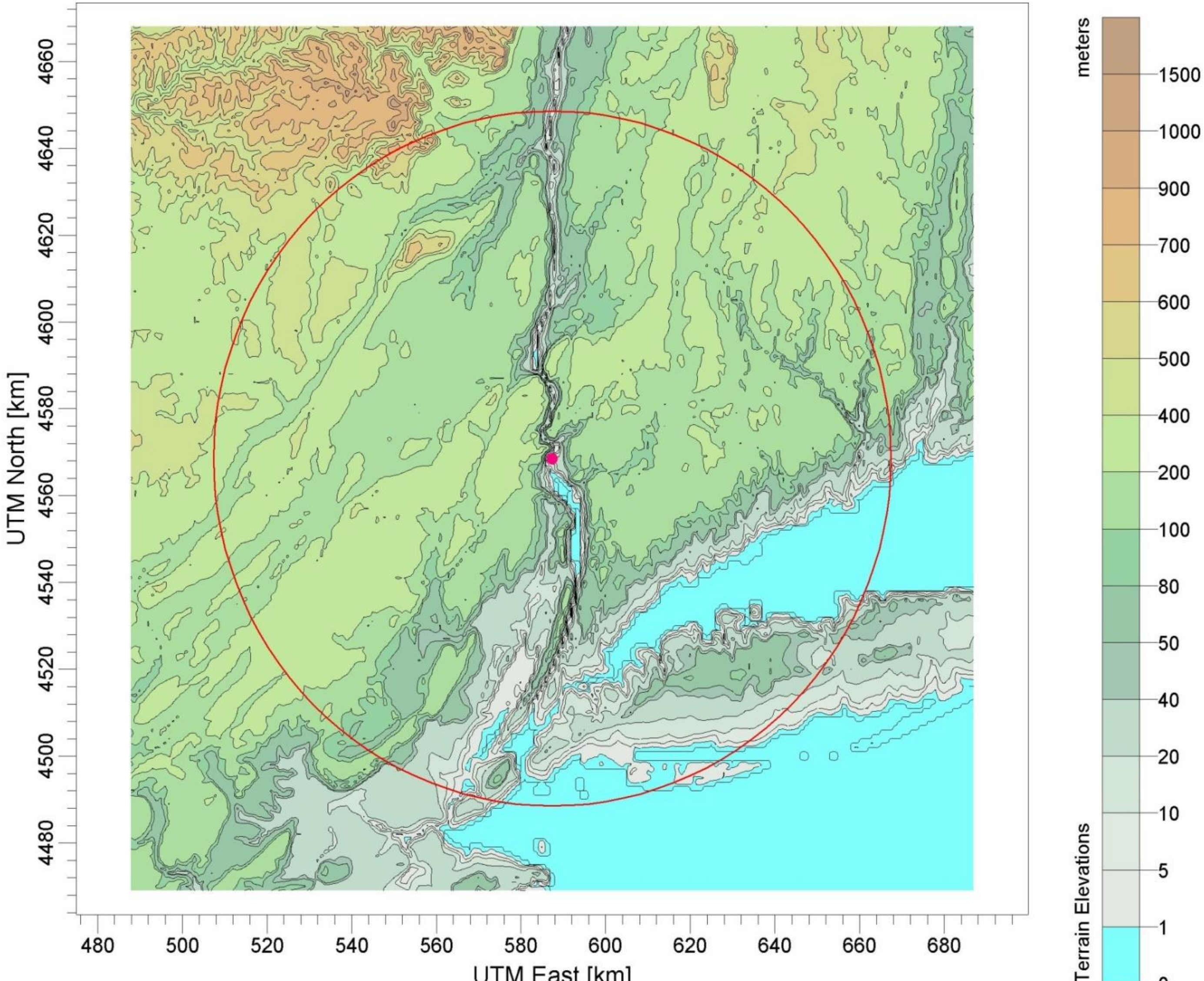
Deposition is important an most radionuclide release scenarios

- A large fraction of health effects are due to deposition
- There is deposition of gases and aerosols due to both dry and wet deposition
- Most of models use parameterizations based on observations
- Many uncertainties

USNRC XOQDOQ (Reg Guide 1.111)

- For continuous or intermittent releases from routine operations
- Straight-line Gaussian plume model
- Doses are due to inhalation (i.e., air concentrations) and from groundshine and ingestion (estimated from calculated air concentrations and deposition)
- Dry deposition; no wet deposition. Deposition nomograms (for stability class and wind speed class) based on Markee 1967 paper.

USNRC MACCS2/ATMOS SAMA Domain Indian Point



Red circle has 50 mile radius

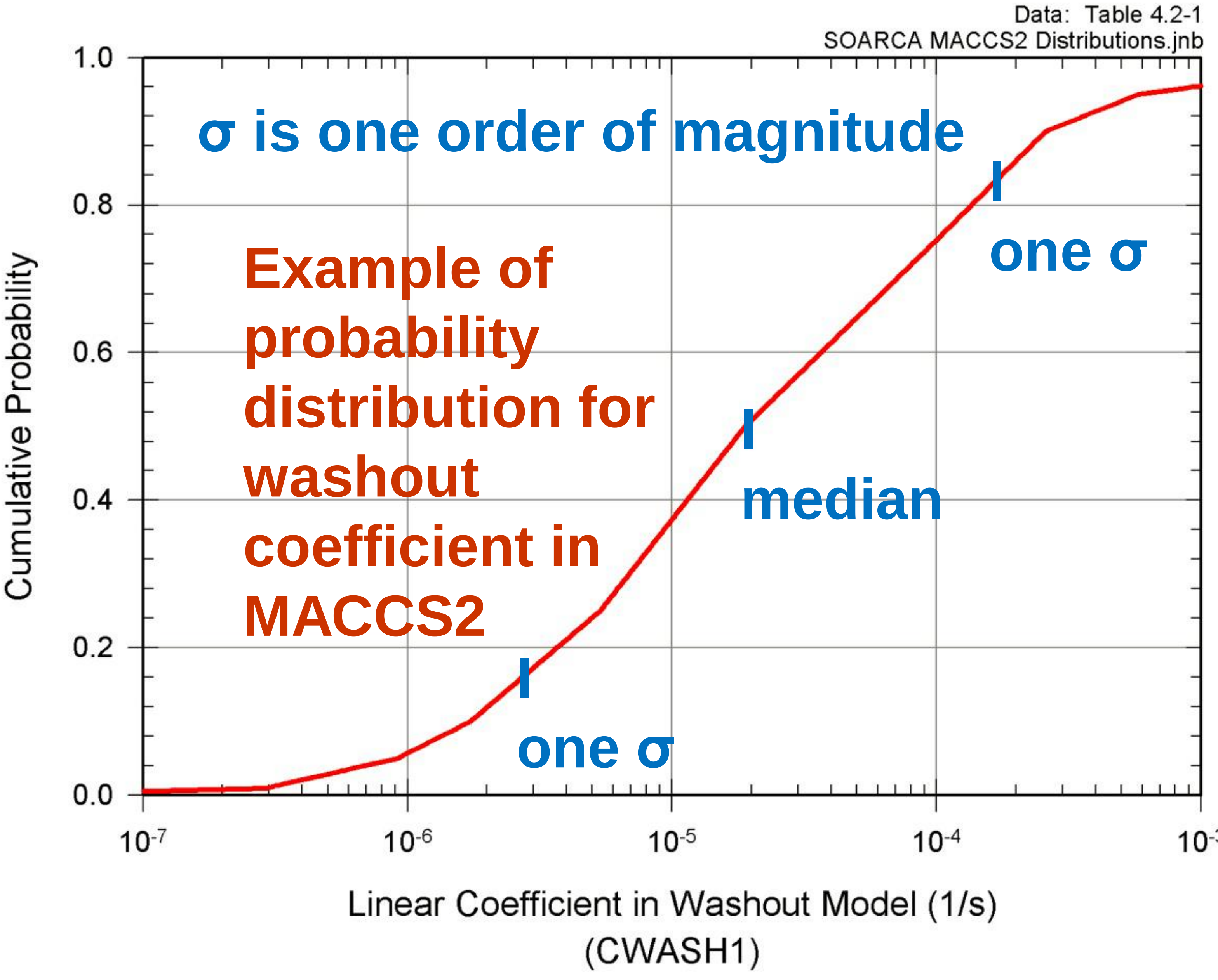
NY City is 30 mi to south

USNRC MACCS2/ATMOS Deposition

- Dry deposition uses source depletion model, can account for a range of particle sizes. Deposition rate (g/m^{2}s) = v_dC, where v_d is dry deposition velocity and C is concentration near surface.
- Wet deposition (washout) – uses exponential formula with "washout coefficient" Λ (1/s) dependent on precip intensity. Placement of deposition on domain depends on "plume segment length" and duration of precipitation.

Uncertainty in MACCS2 Outputs

- It is possible to estimate the uncertainty in MACCS2 outputs based on Monte Carlo software now available from NRC
- On NRC web site, ADAMS Accession number ML13186A190 NUREG/CR-7155, State-of-the-Art Reactor Consequence Analyses Project Uncertainty Analysis of the Unmitigated Long-Term Station **...** pbadupws.nrc.gov/docs/ML1318/ML13189A145.pdf - 2560k - 2013-08-02


Data: Table 4.2-1
SOARCA MACCS2 Distributions.jnb
σ is one order of magnitude
Example of probability distribution for washout coefficient in MACCS2
one σ
median
one σ
Cumulative Probability
1.0
0.8
0.6
0.4
0.2
0.0
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
Linear Coefficient in Washout Model (1/s)
(CWASH1)

NRC example of uncertainty analysis for Peach Bottom plant

- Inputs were varied for 21 MELCOR and 20 MACCS2 groups of parameters
- Examples of Monte Carlo outputs and determinations of variations in a key output variable are given in report
- Of the dispersion and deposition inputs that were varied, dry deposition velocity was the most influential

History of Deposition Research

- Progress through about 1980 was mostly a result of research related to radionuclides released to the atmosphere.
- Since about 1980, deposition research has been mostly driven by the needs of the non-nuclear pollutant researchers (e.g., acid rain, global mercury deposition, CO_2 etc.). This is when the resistance formula was suggested.
- Some NRC models use deposition results from the 1970s; others use more state-of-the-art methods.

Listing of removal processes

- Chemical reactions
  - Simple exponential (e.g., most radionuclides)
  - Complete chemical reaction set (e.g., ozone)
- Dry deposition and gravitational settling
  - ***Gravitational settling*** for particles of size > 10 μm (settling speed is function of density, size and shape)
  - ***Dry deposition*** of gases and small particles due to Brownian motion and chemical interactions with surface - parameterized by a deposition velocity, v_d, which is on the order of 0.1 to 1 cm/s for many chemicals.
- ***Wet removal***
  - Usually combines in-cloud (i.e., with no rain or snow) and below cloud (due to rain)
  - Depends or rate of precipitation

Major deposition inputs to many models

- v_d (m/s) – dry deposition velocity (about 0.001 to 0.01 m/s for small particles and gasses)
- Λ (1/sec) – precipitation removal scale

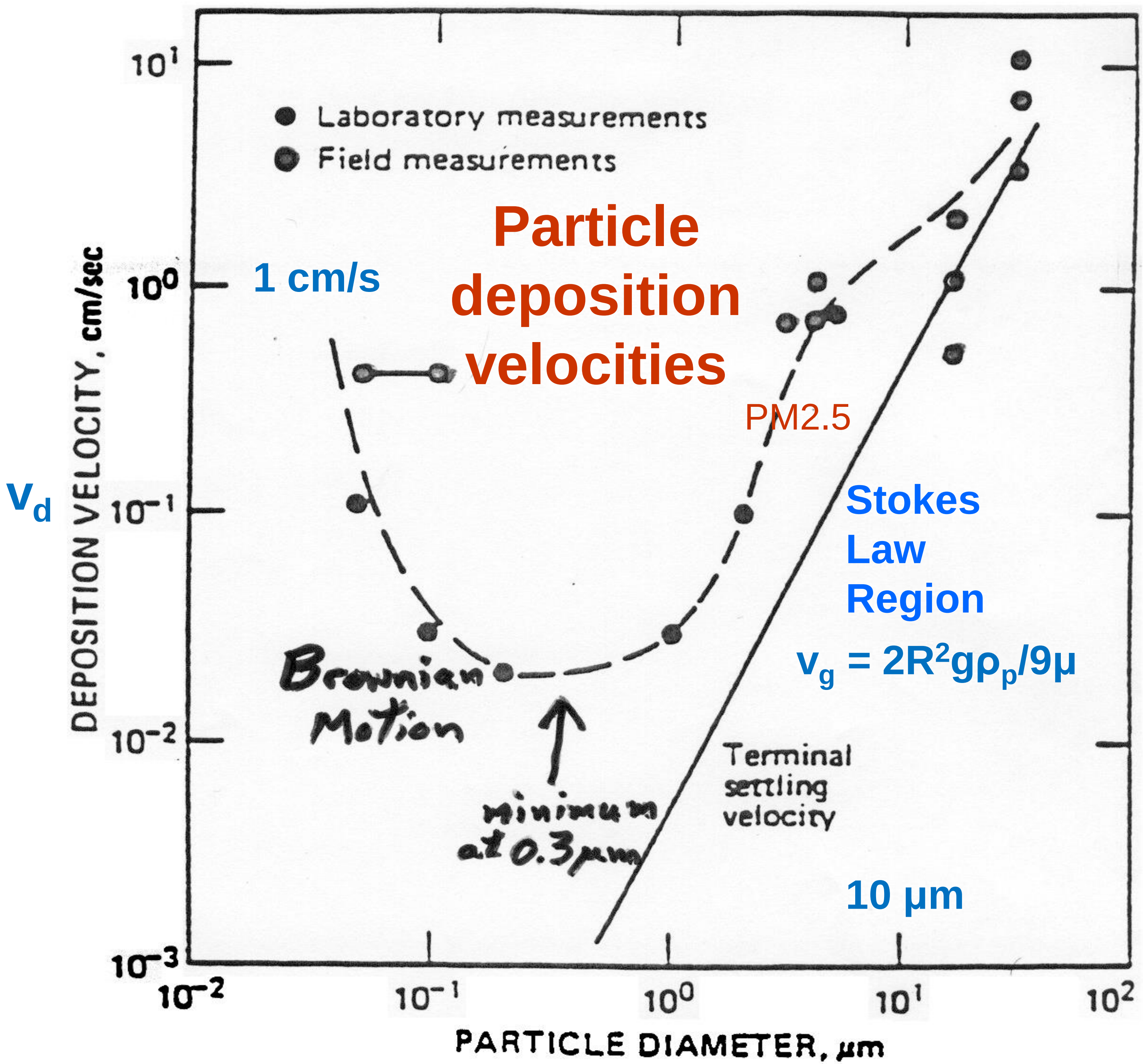
  1/Λ (sec) is time scale for 1/e removal (about 10^4 sec or 3 hrs)
- W_r - Washout ratio – equilibrium ratio of concentrations in precip and air

Dry Deposition Observations

- "Observed" v_d = Mass flux to surface per unit area divided by C_o
- Observed as say g/m^2 by pans, leaf analysis, and water or soil analysis
- Also observed by fast response observations of vertical velocity w' and concentration C'.   Flux = -<w'C'>
- If inert gas (argon, SF_6, PFTs), v_d = 0.0

Wesley and Hicks (1980s)

- Dry deposition can be considered for two different scales
  - 1) local deposition on specific plant leaf, small paved area, small area of desert dry lake bed, etc. (lower case symbols such as v_d or r_c)
  - 2) broad area deposition on land use area (area of corn fields, urban block, 100 km^2 area of forest) (upper case symbols such as V_d or R_c)



Particle deposition velocities
1 cm/s
v_d
PM2.5
Stokes Law Region
$v_g = 2R^2 g \rho_p / 9\mu$
10 µm
Laboratory measurements
Field measurements
Brownian Motion
minimum at 0.3µm
Terminal settling velocity
DEPOSITION VELOCITY, cm/sec
PARTICLE DIAMETER, µm
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2

State-of-the-Art Dry Deposition Velocity (as used in US NRC RASCAL 4)

- From EPA "acid rain" research in 1980s
- "Resistance Analogy" $\mathbf{v_d = 1/(r_a + r_s + r_t)}$
- Aerodynamic resistance $\mathbf{r_a = u(10m)/u^{*2}}$
- Surface resistance $\mathbf{r_s = 2.6/u^*}$ **(also called $\mathbf{r_c}$)**
- Transfer resistance $\mathbf{r_t}$ in RASCAL is assumed very small (1/10m/s) and is used to set a default limit
- $\mathbf{r_a}$ dominates over $\mathbf{r_s}$ when $\mathbf{u(10m)/u^* > 2.6}$ (which is nearly always the case)
- Ends up as $\mathbf{v_d}$ **= 0.1 to 1 cm/s**, just as in old models.
- However, according to Hicks these symbols should be upper case

Observation of dry deposition velocities of many types of gases

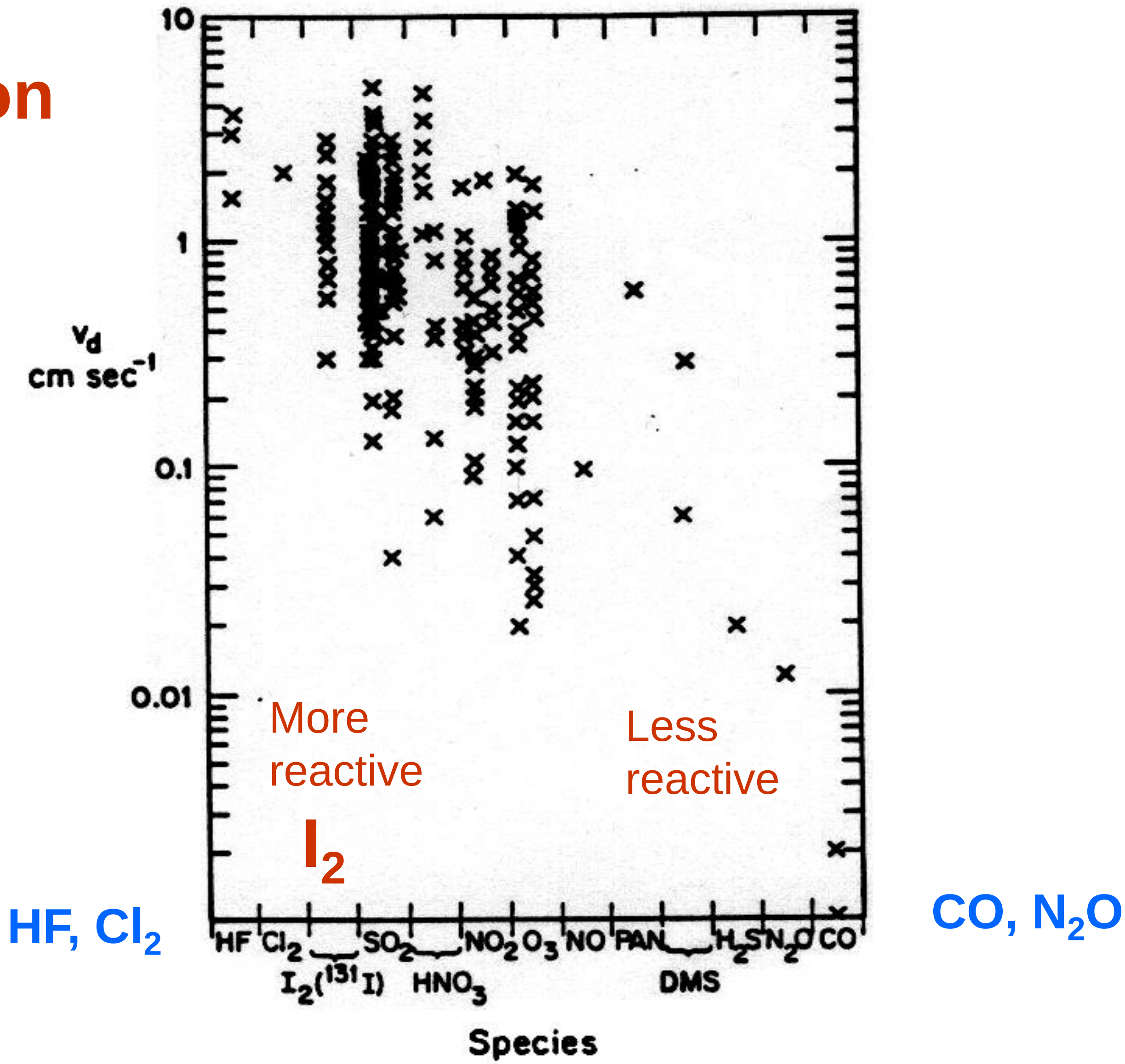


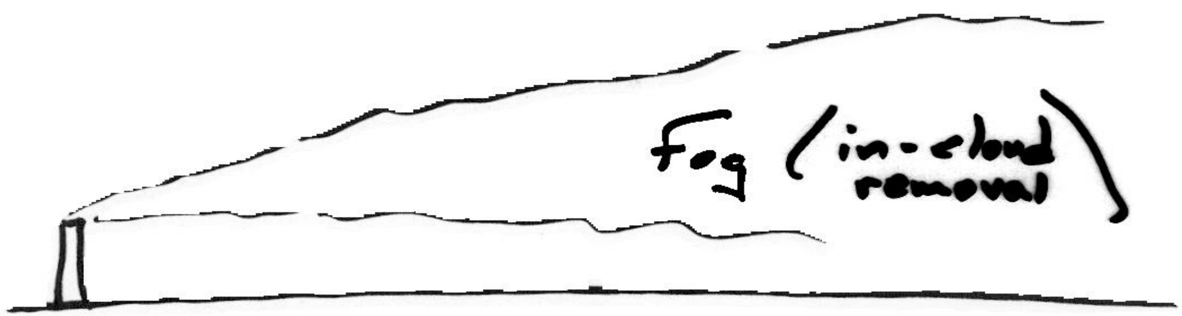
Figure 16.21. Experimental data on gas dry deposition velocities ranked approximately in order of reactivity (National Center for Atmospheric Research, 1982). DMS = dimethyl sulfide.

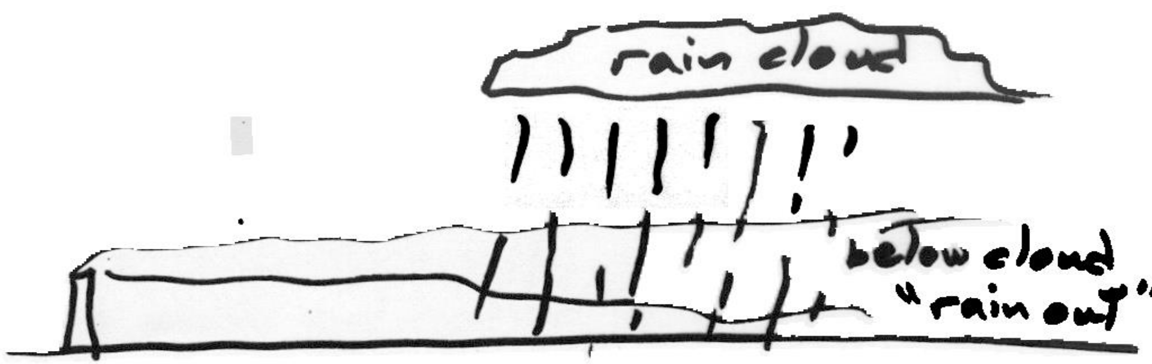
Wet deposition

$\partial C/\partial t = -\Lambda C$ **Local (at a specific height z)**

Solution $C(t) = C(t{=}0)e^{-\Lambda t}$

$1/\Lambda = 10^4$ s (about 3 hrs)
depends on precipitation rate





Wet deposition of particles

- **$C(t) = C(0) \exp(-\Lambda t)$** at a given height, **z**
  - **Λ** is scavenging coefficient with units 1/time
  - **t** is time since precipitation began
- The deposition rate (mass/unit area and time) at the ground surface is the integral over height from the surface to the top of the plume of $\int C\Lambda dz$
- **Λ** is a function of rain rate P_r and drop size and pollutant characteristics. It averages about 1/(3 hours)
- MACCS/ATMOS has $\Lambda = 9.5 \times 10^{-5} P_r^{0.8}$, where **$\Lambda$** has units of 1/s and P_r is in mm/hr, for all radionuclides. RASCAL 4 and RATCHET 2 have a slightly different power law formula

Wet Deposition (alternate method for gases)

- For gases, RASCAL and some other models assume a washout ratio $\mathbf{W_r}$. $\mathbf{W_r}$ is defined as the ratio of concentrations (mass per unit volume) of pollutant in the water drops and in the air (Henry's law at equilibrium).
- The wet deposition rate of pollutants to the surface is equal to the precipitation rate in mass per unit area and time, times the washout ratio, times the pollutant concentration in air.
- Note that a precip rate of 1 mm/hr is equal to a water mass deposition rate (to the surface) of 0.28 g/(m^2s). There have been many field observations of $\mathbf{W_r}$, since it only requires a near-surface observation of the concentration of the pollutant in air and in the rainwater.

Simple parameterizations of wet removal (e.g., RATCHET 2 and RASCAL 4)

- For particles, a washout coefficient **Λ** (1/hr) = 0.254, 3.26, and 4.78 is assumed for light, moderate and heavy rain and is calculated from $\mathbf{\Lambda = 1.43\ P_r^{3/4}}$

- For gases, an effective wet deposition velocity $\mathbf{v_d}$ (cm/s) = 0.014, 0.42, and 0.69 for light, moderate and heavy rain

- Light, moderate and heavy rain (at Hanford) are assumed 0.03, 1.5, and 3.3 mm/hr. These would be larger in non-desert environments

Uncertainties in dry and wet deposition

- All references caution that there can be much uncertainty in the assumed dry and wet deposition formulations (factor of 2 or 3 or more).
- The theory can be quite complicated, with dependences on drop and particle shapes and sizes, surface composition, boundary layer processes, etc.
- In real-world applications, the details of the scenario such as the rain rate and drop sizes are not known
- Therefore all operational models use parameterizations to simplify the estimates.

Recommendations

- Currently a broad range of methods are used to estimate dispersion and deposition.
- Many empirical parameterizations and simplifications are used; some are many decades old
- A thorough technical review of the field (operational models and published research) is needed, including studies focused on non-radiological pollutants
- New field experiments are needed, especially regarding wet removal/deposition
- Workshops are needed to allow information exchanges and expert elicitations
- Updated models can incorporate the state-of-the-art methodologies, including uncertainty estimation