Review on HTO washout

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Sommaire

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Context.

- To calculate HTO transfer from atmosphere to soil, dry and wet deposition should be calculated;
- Dry deposition
  - HT velocity to the soil surface is about 4.10^{-5}- 4.10^{-3} $m.s^{-1}$
  - HTO velocity to the soil surface is about 10^{-3}- 10^{-2} $m.s^{-1}$
  - depends of soil composition, soil humidity, landcover...
  - exchange velocity follow the Fick law;
  - [Foe88b, Foe88a, Gar80, OSB88, PCC+88, TWB88]
- Wet deposition during rain
  - HT solubility is very weak → deposition negligible
  - HTO solubility is important → HTO is exchanged with H_2O in the rain drop
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  - **a washout rate or a washout coefficient**

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1. HTO molecules migrate from the atmosphere to the surface of drop,
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Main knowledge.

- Total solubility is inadequat for HTO;
- HTO exchange between atmosphere and drop is reversible;
- Under the plume, desorbtion can be possible;
- but never in equilibrium because the raindrop velocity is high.
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$$\frac{\delta c(s;x,y,z)}{\delta z} = \frac{3v_d(s)}{v_t(s)s}\left[\chi(x,y,z) - H' c(s;x,y,z)\right]$$

- $c(s;x,y,z)$: concentration of HTO in raindrops ($Bq.m^{-3}$);
- z : height of a drop above ground level (m);
- $v_d(s)$: HTO deposition velocity at the drop surface;
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- is derived from relatively short measurement interval and single individual precipitation
- is functions of precipitation rate
- is apply preferably to individual scavenging conditions (drop-size distribution, different rain types, vertical variation)

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- is multiple integral over a variety of different scavenging parameters
- most of the washout ratios has been derived from long measurement periods
- assure the influence of a large variety of scavenging mechanisms = relatively small range

ω	: Washout ratio, dimensionless	R	: Raindrop radius, L
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- Used for a individual scavenging;
- Even if washout rate are determined as functions of drop size, drop size distribution, precipitation rate...;
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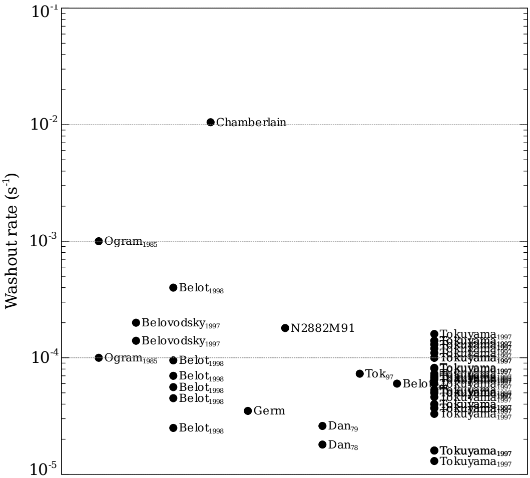
- from 10^{-5} to 10^{-2} s^{-1}
- depends of rainfall intensity (Ogram, Belot,...)
- depends of the stack height (Belot)
- depends of raindrops radius (Chamberlain)
- monthly mean (Tokuyama)



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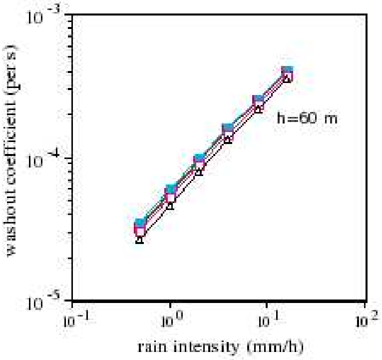

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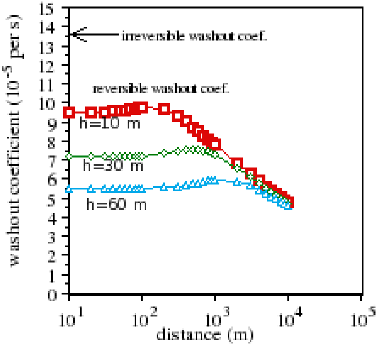

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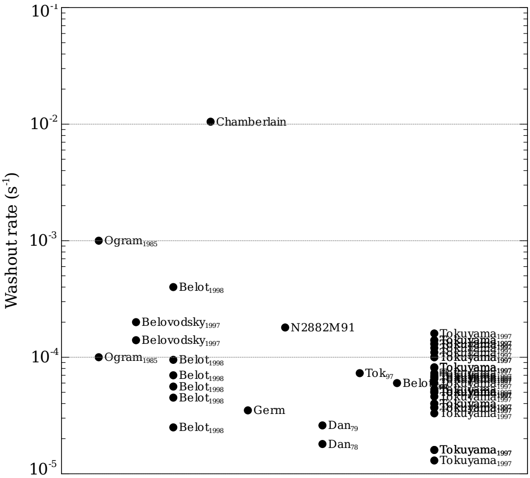

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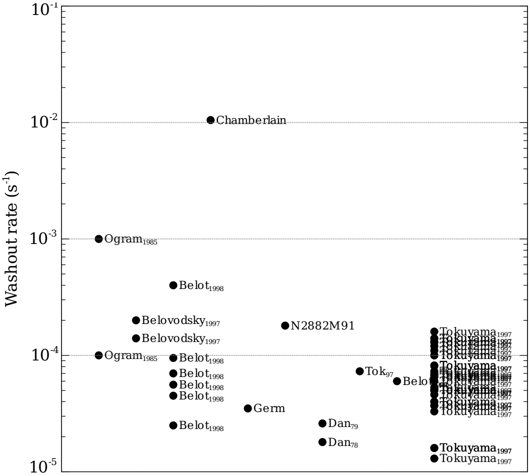


Samples of equation

$$\Lambda = a \cdot (J)^b$$

- a and b are two empirical coefficient which depends on local conditions;
- According to Melintescu the recommanded value are a=6.10^5 and $b = 0.77$;
- In litterature b ranges between 0.7 and 1.

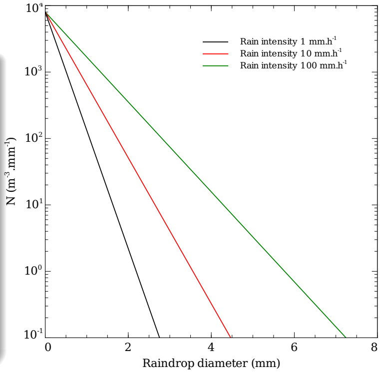
Sommaire

General meaning

- Washout rate strongly depends of drop characteristics;
- HTO rain activity depends of duration of raindrops throughout the plume;
- thus raindrop velocity depends
  - Rainfall intensity
  - Raindrop size
  - Raindrop size distribution

Raindrop distribution - Drop Size Distribution (DSD)

- can be described by several density functions;
- Marshall-Palmer;
- Gamma;
- Log-normal;
- Weibull
- ...



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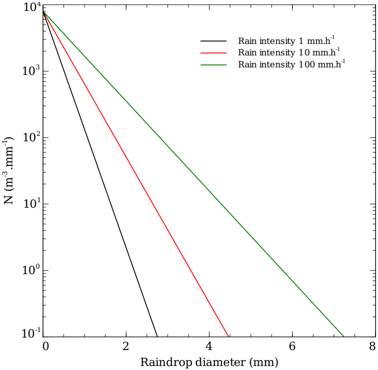

$$N_D = N_0 e^{-\Lambda D}$$
$$N_0 = 0.08 \text{ cm}^{-4}$$
$$\Lambda = 41 \cdot R^{-0.21} \text{cm}^{-1}$$

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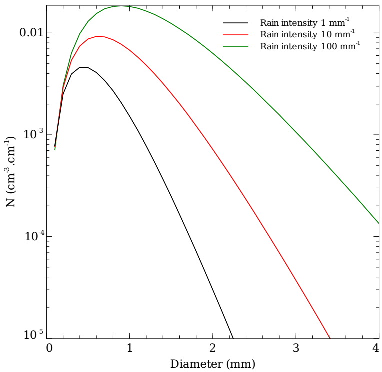

$$N_{(D_p)} = \frac{N_D}{\sqrt{2\pi} \cdot D_p \cdot log\ \sigma_D} e^{-\frac{(logD_p - log\overline{D}_p)^2}{2log^2\sigma_D}}$$

$$N = 172R^{0.22}\ \mathrm{m}^{-3}$$

$$D_r = 0.72R^{0.23}\ \mathrm{mm}$$

$$\sigma = 1.43 - 3.0 \times^{-4} R$$

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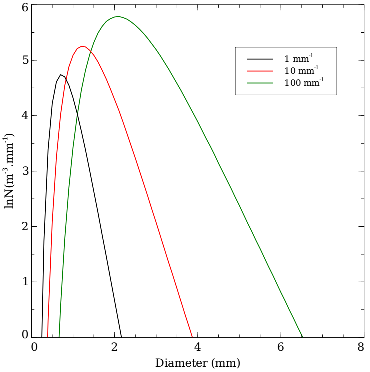

$$N_D = N_G D^{2.50} e^{-\Lambda D} \text{ cm}^{-4}$$

$$N_G = \frac{6.36\times10^{-4} M}{D_o^4} \left(\frac{1}{D_0}\right)^{2.50}$$

$$\Lambda = \frac{5.57}{D_0} \text{ cm}^{-1}$$

$$D_0 = 0.157 M^{0.168} \text{ cm}$$

$$M = 0.062 R^{0.913} \text{ g.m}^{-3}$$

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$$D_r = \alpha \cdot J^{\beta}$$

α	:	empirical coefficient	undimensionless
β	:	empirical coefficient	undimensionless
J	:	Rainfall intensity	$L.T^{-1}$

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Pruppacher and Klett	$0.96 \times J^{0.21}$	[PK98]
Marshall-Palmer	$0.243 \times J^{0.21}$	[MP48]
Andronache	$0.24364 \times J^{0.214}$	[And04]
Loosmore and Cederwall	$0.97 \times J^{0.158}$	[LC04]
Feingold and Levin	$0.72 \times J^{0.23}$	[FL86]
Cerro et al.	$0.630 \times J^{0.23}$	[CCBL97]
Underwood	$0.7 \times J^{0.25}$	[Und01]

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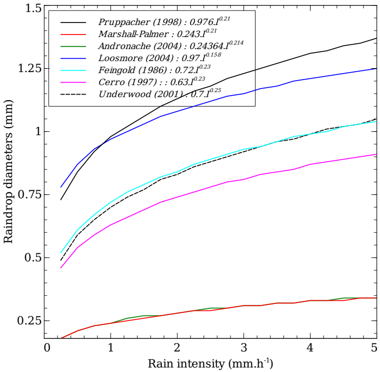

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Andronache	$130\ \sqrt{D_r}$	[And03]
Seinfeld	$9.58\left[1 - exp\left(-\left(\frac{D_r}{0.171\times10^{-2}}\right)^{1.147}\right)\right]$	[Sei85]
Andronache	$3.778 \cdot D_r^{0.67}$	[And04]
Loosmore and Cederwall	$4.854 \cdot D_r exp\left(-195 \times 10^{-3}\right)$	[LC04]
Best	$V_t(s) = a\left\{1 - exp\left[-\left(\frac{s}{b}\right)^n\right]\right\}$	
Chamberlain and Eggleton	$V_t(s) = 7000 \cdot s + 12000 \cdot s^{1.97}$ with $s = 0.037 Log(J) + 0.0661$	[Cha53]

Raindrop velocity

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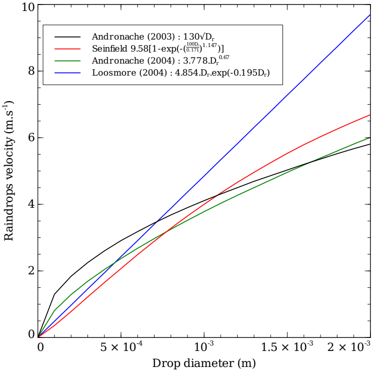
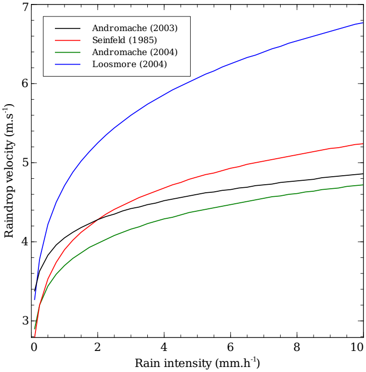
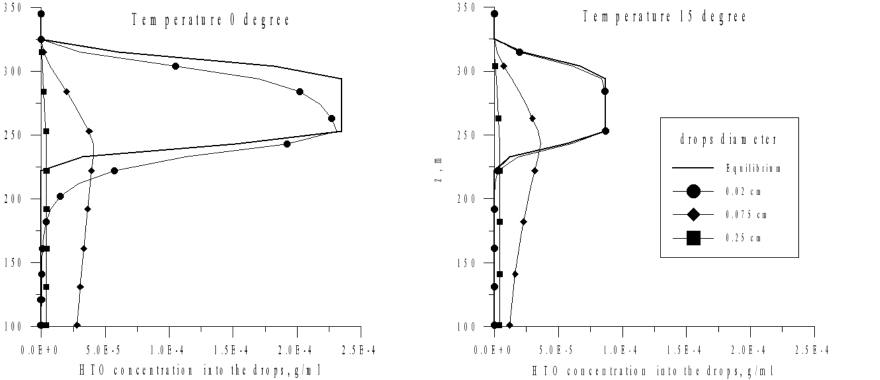




Influence of the temperature

- Washout process is influenced by air temperature
- Figure shows HTO drop concentration according to height
- Figure shows the temperature influence on the washout rate



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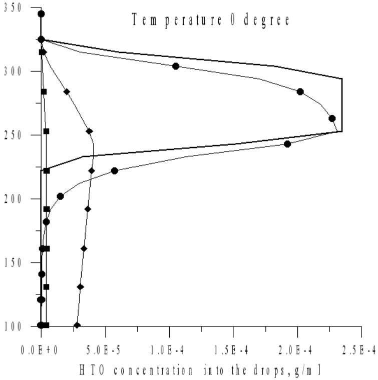

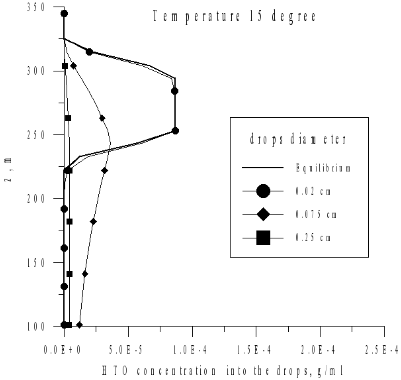

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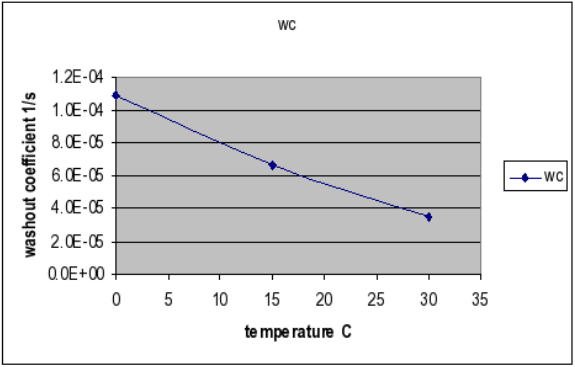

Sensitivity study from Atanassov

- Sensitive analysis of eulerian model (Atanossov) show the influence of rain parameters (70%) and the temperature (50%) on the washout process;
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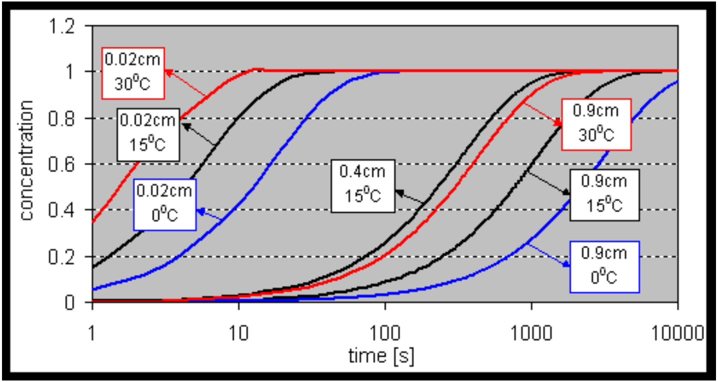

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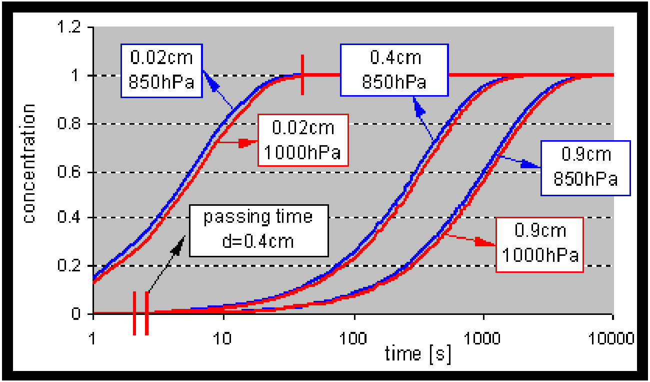

Other parameters

- The wind influence the raindrop trajectory (taking account by CEA model)
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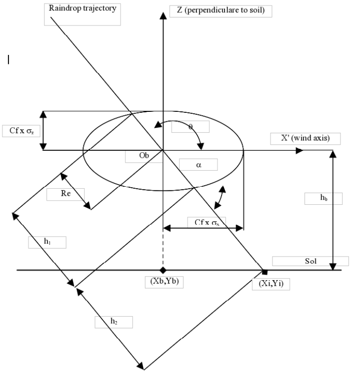

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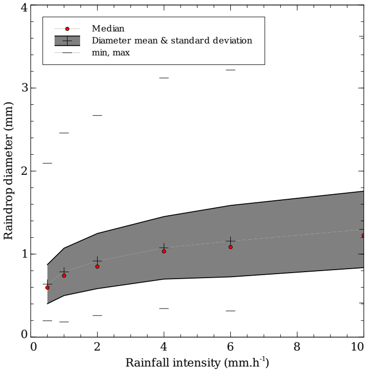
Models incertainty

- Average rainfall intensity, distribution, diameter of raindrop, velocity are often used but which uncertainty do we do ?;

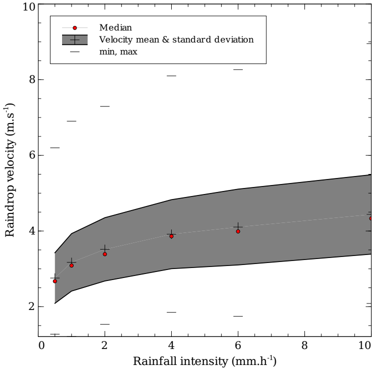
Models incertainty

- Figure shows mean and uncertainty of diameter for the lognormal distribution by using the parameters given by Feingold (1000 simulations that represents raindrops) and the Andronache formula to compute diameter;



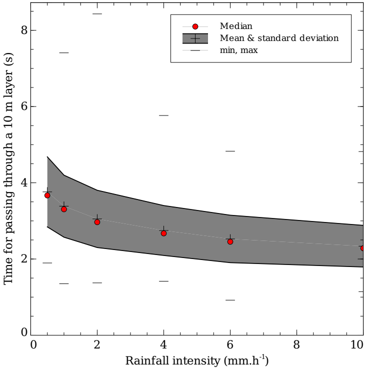
Models incertainty

- Figure shows the raindrop average velocity according to Andronache formula;



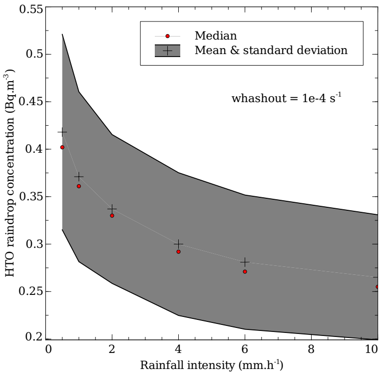
Models incertainty

- Figure shows the time needs by drops to cross a 10 m layer according to the rain drop velocity calculate before;



Models incertainty

- Figure shows the HTO average activity of raindrop computed by Chamberlain equation, for a specific activity of water vapor in air of 1000 Bq.m^{-3} and a washout rate of $10^{-4}s^{-1}$.



Sommaire

Models

- Simple model $C_{rain} = \alpha C_{atm}$
- $\alpha = 0.4 = const$ allows description of averaged experimental data;
- Complex model (Golubev, VNIIEF) can take into account kinetics of HTO exchange between vapor and liquid phase with parameters(rain drop spectra, rain intensity, condensation-evaporation on drop's interface);
- $\Rightarrow$ wind velocity and better choice of drop velocity explain the difference with the Belot model;
- Models often use gaussian approximation for the air concentration and selected empirical equation for DSD and drop velocity;
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- Improvements have to be done on inputs but which ?
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References

C. Andronache.
Estimated variability of below-cloud aerosol removal by rainfall for observed aerosol size distribution.
Atmospheric Chemistry and Physics, 3:131–143, 2003.

C. Andronache.
Diffusion and electric charge contributions to below-cloud wet removal of atmospheric ultra-fine aerosol particles.
Journal of Aerosol Science, 35:1467–1482, 2004.

C. Cerro, B. Codina, J Bech, and J Lorente.
Modeling raindrop size distribution and z(r) relations in the western mediterranean area.
Journal of Applied Meteorology, 36:1470–1479, 1997.

A.C. Chamberlain and E.J. Eggleton.
Washout of tritiated water vapour by rain.
Air Water Pollution, 8:135–149, 1964.

A.C. Chamberlain.
Aspects of travel and deposition of aerosol and vapor clouds.
UKEA Report HP/R1261, 1953.

M. T. Dana, N. A. Wogman, and M.A. Wolf.
Rain scavenging of tritiated water (hto): a field experiment and theoretical considerations.
Atmospheric Environment, 12:1523–1529, 1978.

G. Feingold and Z. Levin.
The lognormal fit to raindrop spectra from frontal convective clouds in israël.
Journal of climate and applied meteorology, 25:1346–1363, 1986.

H. Foerstel.
Ht to hto conversion in the soil and susequent tritium pathway: field release data and laboratory