libRadtran user course, lecture # 3

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Direct/diffuse splitting

$$L(z,\mu,\phi) = L^{\text{dir}}(z,\mu_0,\phi_0) + L^{\text{sca}}(z,\mu,\phi),$$

One equation for the direct beam (solar beam)

$$-\mu \frac{dL^{\text{dir}}(z,\mu_0,\phi_0)}{\beta^{ext} dz} = -\mu \frac{dL^{\text{dir}}(z,\mu_0,\phi_0)}{d\tau} = L^{\text{dir}}(z,\mu_0,\phi_0)$$

With solution

$$L^{dir}(\tau,\mu_0) = L^0 \ e^{-\tau/\mu_0}.$$

Solution of the RTE in 1D: Direct/diffuse splitting

Equation for the diffuse radiation

$$
\begin{aligned}
-\mu\frac{dL(\tau,\mu,\phi)}{d\tau} &= L(\tau,\mu,\phi) \\
&\quad -\frac{\omega(\tau)}{4\pi}\int_0^{2\pi} d\phi' \int_{-1}^{1} d\mu' p(\tau,\mu,\phi;\mu',\phi')L(\tau,\mu',\phi) \\
&\quad -(1-\omega(\tau))B[T(\tau)] \\
&\quad -\frac{\omega(\tau)L^0}{4\pi}p(\tau,\mu,\phi;\mu_0,\phi_0)e^{-\tau/\mu_0}.
\end{aligned}
$$

This is the 1D equation solved by equation solvers like DISORT etc.

Solution of the RTE in 1D: Azimuth dependence

For scattering processes in the atmosphere the scattering phase function depends only on the angle Θ between the incident and scattered beams.

This allow us to expand the radiance as a cosine Fourier series:

$$L(\tau, \mu, \phi) = \sum_{l=0}^{2M-1} L^m(\tau, \mu) \cos m(\phi_0 - \phi)$$

to get m independent equations.

Solution of the RTE in 1D: Polar angle dependence.

For $m = 0$ the radiative transfer equation is:

$$\begin{aligned}
\mu \frac{dL(\tau,\mu)}{d\tau} &= -L(\tau,\mu) \\
&\quad + \frac{\omega(\tau)}{2} \int_{-1}^{1} d\mu' p(\mu,\mu') L^m(\tau,\mu') \\
&\quad (1-\omega(\tau))B[T(\tau)] \\
&\quad \frac{\omega(\tau)L^0}{4\pi} p(\mu,\mu') e^{-\tau/\mu_0}.
\end{aligned}$$

Replace integral over μ' with Gaussian quadrature rule:

$$\int_{-1}^{1} d\mu' \rightarrow \sum_{\substack{j=-N \\ j\neq 0}}^{j=N}$$

Here N is number of streams. $N = 1$ gives the much used two-stream approximation.

Solution of the RTE in 1D: Two-stream approximation.

- Easy to understand
- Solver are readily coded.
- Main reason for use is computational speed.
- Different two-stream solutions will differ because of the non-uniqueness of the solution.
- Should NOT be used for radiances.
- Is used for irradiances and actinic fluxes.

USE WITH CARE

Solution of the RTE in 1D: DISORT.

N-stream solution: DISORT- Discrete Ordinates Radiative Transfer (Stamnes et al., 1988).

- Computing time increases linearly with number of layers.
- Computing time increases as N^3.
- $N = 8$ normally sufficient for radiances. But careful with strongly peaked phase functions.
- Originally in FORTRAN 77. C-version exists as well. Use latter as it has better treatment of phase functions.
- Maybe the most used radiative transfer solver on this planet. (Well-coded, well-documented, numerically stable, and freely available (developed with public funding)).

Solution of the RTE in 1D: Solution methods.

- Doubling-adding
- Spherical harmonics
- Discrete ordinates
- Perturbation theory
- Monte Carlo
- and more

Method chosen largely depends on who is/was your supervisor.

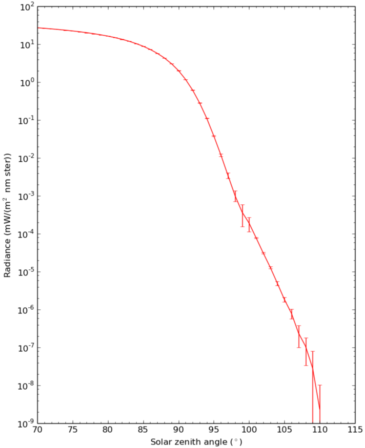
Note on pseudospherical approximation

In the pseudo-spherical approximation the extinction path τ/μ_0 is replaced by the Chapman function, $ch(r, \mu_0)$ (Rees, 1989; Dahlback and Stamnes, 1991)

$$ch(r_0, \mu_0) = \int_{r_0}^{\infty} \frac{\beta^{ext}(r, \nu)\; dr}{\sqrt{1 - \left(\frac{R+r_0}{R+r}\right)^2 (1 - \mu_0^2)}}.$$

Here R is the radius of the earth and r_0 the distance above the earth's surface. The Chapman function describes the extinction path in a spherical atmosphere. Works fine for some applications. For large solar zenith angle full spherical geometry is needed.

Zenith radiance in full spherical geometry



Aerosol

An aerosol is a suspension of fine solid particles or liquid droplets, in air or another gas. Aerosols can be natural or anthropogenic. Examples of natural aerosols are fog, dust, forest exudates and geyser steam. Examples of anthropogenic aerosols are haze, particulate air pollutants and smoke.

- Number of particles (size distribution)
- Composition (refractive index, wavelength dependent)
- Shape

uvspec: aerosol

Simple

```
aerosol_default
```

A little more complex

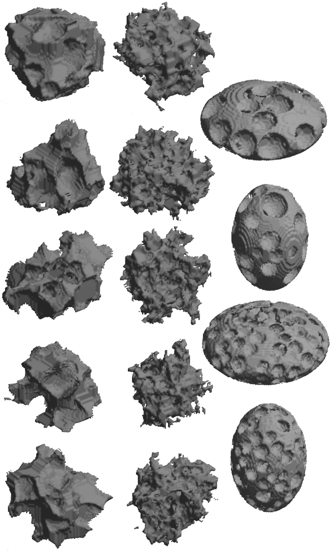
```
aerosol_vulcan 1               # Aerosol type above 2km
aerosol_haze 6                 # Aerosol type below 2km
aerosol_season 1               # Summer season
aerosol_visibility 20.0        # Visibility
aerosol_angstrom 1.1 0.2       # Scale aerosol optical depth
                               # using Angstrom alpha and beta
                               # coefficients
aerosol_modify ssa scale 0.85  # Scale the single scattering albedo
                               # for all wavelengths
aerosol_modify gg set 0.70     # Set the asymmetry factor
aerosol_file tau ./AERO_TAU.DAT
                               # File with aerosol optical depth profile
```

And more detail may be input...

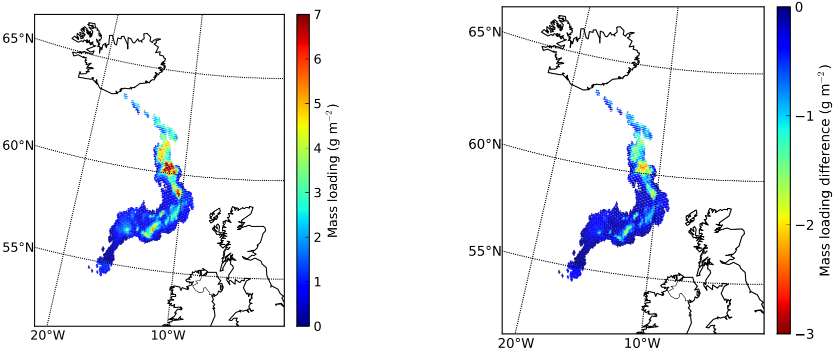
Non-spherical volcanic ash particles

Ash particles with large vesicles (left column), ash particles with small vesicles (middle column), prolate and oblate spheroids with large and small vesicles (right column).

From Kylling et al. (2014).



Non-spherical volcanic ash particles



From Kylling et al. (2014).

Today's exercises:

- Calculate top of the atmosphere (TOA) brightness temperature for 10.8 and 12.0 μm and take the difference (BTD=BT(10.8)-BT(12.0)).
- Include volcanic aerosol layer and calculate BTD for various aerosol layer altitudes. How does BTD change with aerosol layer altitude? And aerosol amount?
- Include ice cloud together with aerosol layer. What happens with BTD for various ice cloud amounts?

Hints:

- example input files: `UVSPEC_AEROSOL.INP`
- options `aerosol_species_file`, `output_quantity`, `output_user`

References I

Dahlback, A. and Stamnes, K.: A new spherical model for computing the radiation field available for photolysis and heating at twilight, Planet. Space Sci., 39, 671–683, 1991.

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Rees, M. H.: Physics and chemistry of the upper atmosphere. !. Upper atmosphere, Cambridge University Press, iSBN 0-521-32305-3, 1989.

Stamnes, K., Tsay, S.-C., Wiscombe, W., and Jayaweera, K.: Numerically stable algorithm for discrete–ordinate–method radiative transfer in multiple scattering and emitting layered media, Appl. Opt., 27, 2502–2509, 1988.