libRadtran user course, lecture # 4

Arve Kylling

NILU-Norwegian Institute for Air Research

RTE assumptions

- Plane parallel atmosphere (Flat Earth), pseudo-spherical approximation often used for low sun.
- Mono-chromatic radiation. Raman scattering important for some applications
- Tenuous host medium.
- Independent (incoherent) scattering.
- Far-field scattering assumed.
- No relativistic effects (photons move in straight lines).
- No time dependence (medium does not change during photon transport).

Quite generally, the distribution of photons in a dilute gas may be described by the Boltzmann equation. For a derivation of the Boltzmann equation see a textbook on statistical mechanics, for example Reif (1965). Note that the Boltzmann equation is not a fundamental equation. For a derivation of the radiative transfer equation from the Maxwell equations see Mishchenko (2002).

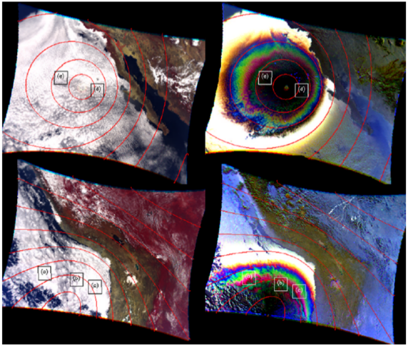
Polarization

Generally radiation is polarized. This is handled by replacing the scalar radiance I with the vector quantity $\mathbf{L}$

$$\mathbf{L} = (L, Q, U, V),$$

where L, Q, U and V are the so-called Stokes parameters (see e.g. Bohren and Huffmann (1998)). Furthermore, the phase function $p(r, \theta, \phi; \theta', \phi')$ is replaced by the 4×4 phase matrix $\mathbf{P}(r, \theta, \phi; \theta', \phi')$. If thermal radiation is under consideration the Stokes emission vector must also be accounted for.

POLDER



left: radiance L, right: polarized radiance P false color composite from 3 channels [0.87, 0.67, 0.49] m, from Bréon (2005).

Boundary conditions

Upper boundary (top of atmosphere)

$$L(z_{\text{toa}}, \mu) = L^0 \delta(\mu - \mu_0),$$

Lower boundary (bottom of atmosphere, surface)

$$\begin{aligned} L(\tau = \tau_g, \mu, \phi) \quad &= \quad \epsilon(\mu) B[T(\tau_g)] + \frac{1}{\pi} \mu_0 L_0 e^{-\tau_g/\mu_0} \rho(\mu, \phi; -\mu', \phi') \\ & \quad + \frac{1}{\pi} \int_0^{2\pi} d\phi' \int_0^1 \rho(\mu, \phi; -\mu', \phi') L(\tau, -\mu', \phi') \mu' d\mu', \end{aligned}$$

For Lambertian surface with albedo A

$$\rho(\mu, \phi; -\mu', \phi') = A$$

Fluorescence

$$L_g^F(\mu, \phi, \lambda) = F(\lambda), \tag{1}$$

Note on boundary conditions

What about radiation transport in underlying ocean/ice/snow?

Usually treated as a boundary condition

BUT

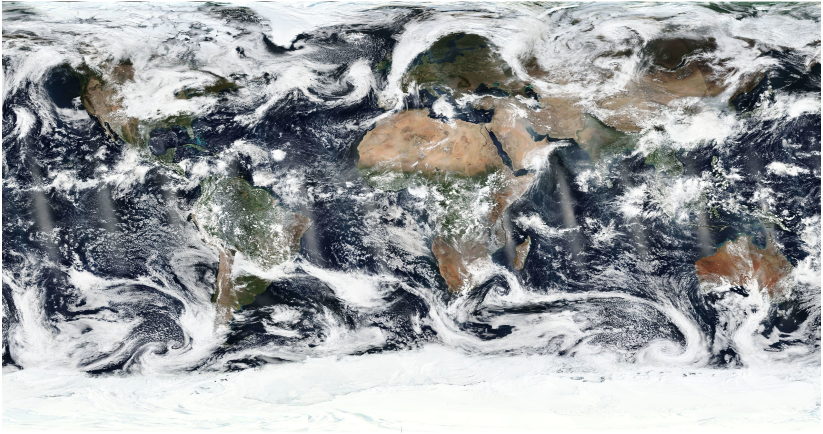
In reality a coupled problem. Ocean hard to solve because of change in refractive index across boundary. Solvers do exist. (Various parameterizations implemented in libRadtran).

The snow albedo model of Wiscombe and Warren (1980) is a two-stream solution of the radiative transfer equation. (Implemented in libRadtran).

Surface characteristics

- Surface albedo (wavelength dependent, see `data/albedo/`)
- Emissivity
- Bi-directional reflectance distribution functions

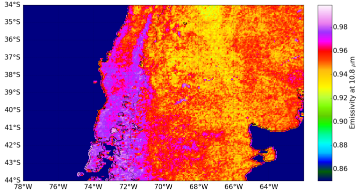
VIIRS rgb

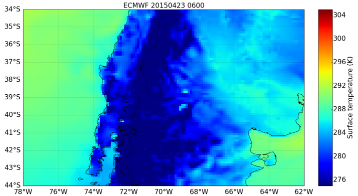


Office view

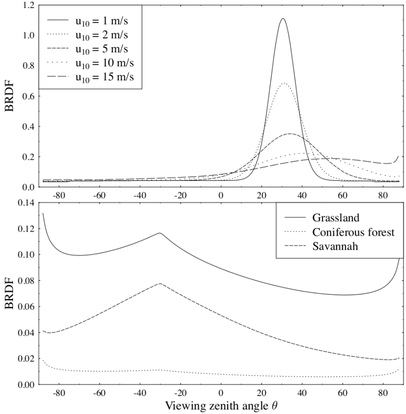
Surface inputs

IR, emissivity and temperature





Solar, bidirectional reflectance distribution function (BRDF)



BRDF parameterizations

- RPV (Rahman, Pinty, and Verstraete) parameterization, `brdf_rpv`
- RossLi BRDF, `brdf_ambrals`
- BRDF of water surfaces, `brdf_cam`

Today's exercises:

- Calculate solar spectra for cloudless sky at TOA for various surface albedo included with libRadtran
- Include small amounts of aerosol. What happens to TOA radiance?
- Include fluorescence. Can it be measured from space?
- Try the BRDF examples. Can you simulate sea glint?

Hints:

- example input files: `UVSPEC_FULIOU_IC.INP` and `UVSPEC_FLUORESCENCE.INP`
- options `albedo`, `albedo_file`, `fluorescence_file`, `UVSPEC_BRDF.INP`

References I

Bohren, C. F. and Huffmann, D. R.: Absorption and Scattering of Light by Small Particles, Wiley Science Paperback Series, iSBN 0-471-29340-7, 1998.

Mishchenko, M. I.: Vector radiative transfer equation for arbitrarily shaped and arbitrarily oriented particles: a microphysical derivation from statistical electromagnetics, Appl. Opt., 41, 7114–7134, 2002.

Reif, F.: Statistical and thermal physics, McGraw-Hill Inc., iSBN 0-07-Y85615-X, 1965.

Wiscombe, W. J. and Warren, S. G.: A model for the spectral albedo of snow, I, Pure snow, J. Atmos. Sci., 37, 2712–2733, 1980.