1D and 3D radiative transfer – a MYSTIC experience with libRadtran

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libRadtran

http://www.libradtran.org
1991 – 2005

• Flexible and comprehensive radiative transfer package
• Spectrally resolved in the UV/visible, line-by-line, quasi-spectral (LOWTRAN), and correlated-k in the solar and thermal infrared
• Irradiance, actinic flux, radiance, heating rates
• User-friendly interface to various solvers:
  * disort 1.3 / 2.0, sdisort, twostr, sos, polRadtran, (MYSTIC)
• Compiled and tested under several UNIXes, Mac OSX, and Windows 95/98/NT/XP
• Validated in several intercomparisons
The libRadtran input file

atmosphere_file ../data/atmmod/afglus.dat
solar_file ../data/solar_flux/kurudz_1.0nm.dat

rte_solver disort2 # choose one of about 10 solvers
sza 45 # solar zenith angle
wc_file ./wc.dat # water cloud
wc_layer

ic_file ./ic.dat # ice cloud
ic_layer
ic_properties yang

correlated_k kato2 # treatment of molecular absorption
output sum # sum over wavelength
Current libRadtran applications at DLR

- Remote sensing of water and ice clouds (Luca Bugliaro)
- Simulation of satellite observations (Luca Bugliaro/Tobias Zinner)
- Radiative forcing of aircraft-induced contrail-cirrus (Waldemar Krebs)
- Remote sensing of inhomogeneous clouds (Tobias Zinner)
- Effect of 3D RT on cloud formation (Kathrin Wapler)
- Radiation balance at the tropical tropopause (Ulrich Hamann)
- Direct and global irradiance for solar energy applications (Sina Lohmann)
- Photochemistry in broken clouds (Ronald Scheirer/Bernhard Mayer)
Example: Direct normal irradiance

Radiative Transfer Calculations for the Atmosphere of Mars in the 200-900nm Range

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Oberpfaffenhofen, Germany.
Example: Remote sensing of Titan using CASSINI-VIMS

Adriani et al.,
*Earth, Moon, and Planets*, submitted 2005
Example: Artificial satellite images
MYSTIC: Monte carlo code for the physically correct Tracing of photons In Cloudy atmospheres. Mayer [1999, 2000]

- Forward photon tracing in plane-parallel geometry, without simplifying assumptions
- Solar and thermal sources
- 3D clouds, topography, inhomogeneous albedo, BRDF
- Rayleigh scattering, aerosol, molecular absorption (ozone, CO₂, ...)
- Runs as part of libRadtran
- Solves all I3RC phase 1 and 2 cases
- Online visualization
MYSTIC: Test remote sensing methods

→ Test of cloud detection and classification
→ Validation of the retrieved microphysical properties
Cubic clouds - in the 21st century?

SZA $90^\circ - 0^\circ - 90^\circ$

Viewing angle $30^\circ$

![Graph showing radiance vs. solar zenith angle with independent pixel approximation and 3D calculation.]
Spherical clouds - the better alternative?

Optical thickness

Nadir radiance, SZA = 50°

240 \times 240 \times 120 = 6,912,000 \text{ grid cells}
Spherical clouds - the better alternative?

![Graph showing actinic flux at different altitudes](image)

- Direct
- Diffuse down
- Diffuse up

Altitude $z$ [km]

Actinic flux [arbitrary units]

$4\pi(\text{direct} + \text{diffuse down} + \text{diffuse up})$

Clearsky reference

I3RC 2005, Bernhard Mayer, DLR
Spherical clouds - the better alternative?

Actinic flux

Nadir radiance, $\text{SZA} = 50^\circ$

horizontal cross section
“Real” clouds

0.6 µm radiance  2.1 µm radiance

Solar zenith angle 30°

→ Presentation by Tobias Zinner, Wednesday
The aircraft perspective

ACE-2 CLOUDYCOLUMN experiment

CASI = compact airborne spectrographic imager
- wavelength 754nm
- angular resolution 0.07°
- pixel size at cloud top: 2 x 75 m²
The aircraft perspective

Satellite

Aircraft
Observation of the backscatter glory

Mayer, Schröder, Preusker, Schüller: Remote sensing of water cloud droplet size distributions using the backscatter glory: a case study 
Retrieval test by sensor simulation

Left: Observation

Right: Simulation

- libRadtran
- RTE solver
  MYSTIC (3D Monte Carlo)
- Cloud data:
  Same day, different flight leg; smaller optical thickness
Retrieval test by sensor simulation

- Optical thickness
- Effective radius [μm]

* retrieved
true, upper boundary
true, lower boundary
Surface representation in MYSTIC

Elevation grid

DEM

\[ z = a + bx + cy + dxy \]
Surface: Nadir reflectivity at 600 nm
Surface: Nadir reflectivity at 600 nm

Polar angle $60^\circ$, azimuth $0^\circ$  Polar angle $60^\circ$, azimuth $180^\circ$
Surface: The BRDF of the Alps

Surface albedo 0.2, no atmosphere, flat surface

Nadir reflectivity at TOA

Viewing polar angle

"Sun in the back" Looking towards sun

Solar zenith angle: 0° 30° 45° 60° 75°
Conclusions

• Have a look at http://www.libradtran.org

• 3D MYSTIC is not part of the free package but may be used in close collaboration

• Although clouds are inherently three-dimensional, 1D approximations are still required for 99% of all applications. This will change!