Modelling polarized microwave radiation in a 3D spherical cloudy atmosphere

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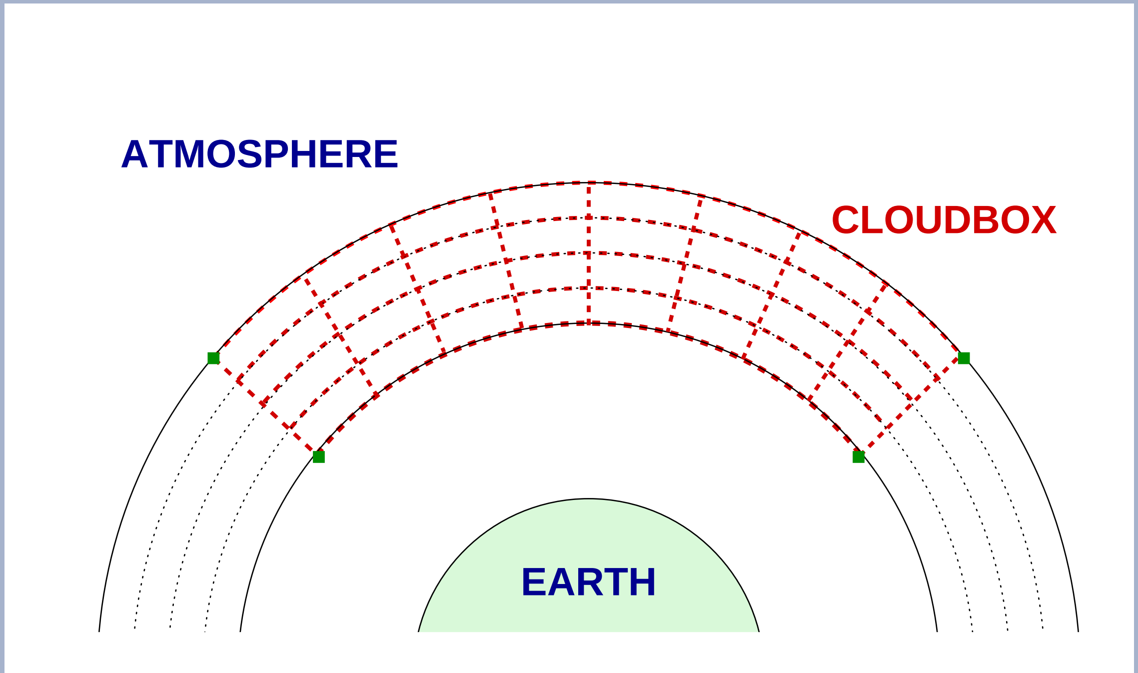
Model atmosphere

- **3D:**
  - Spherical coordinate system (pressure, latitude, longitude)
  - Realistic simulations (strongly inhomogeneous cloud coverage)

- **1D:**
  - Spherically symmetric atmosphere (only pressure coordinate).
  - Estimation of upper limit of scattering effects.
  - Much faster computation than 3D.

- **2D:**
  - Atmosphere extends inside plane (polar coordinate system).
  - Application: Satellite measurements (Observation inside orbit plane).
  - Scattering calculations impractical.

Cloudbox - scattering domain

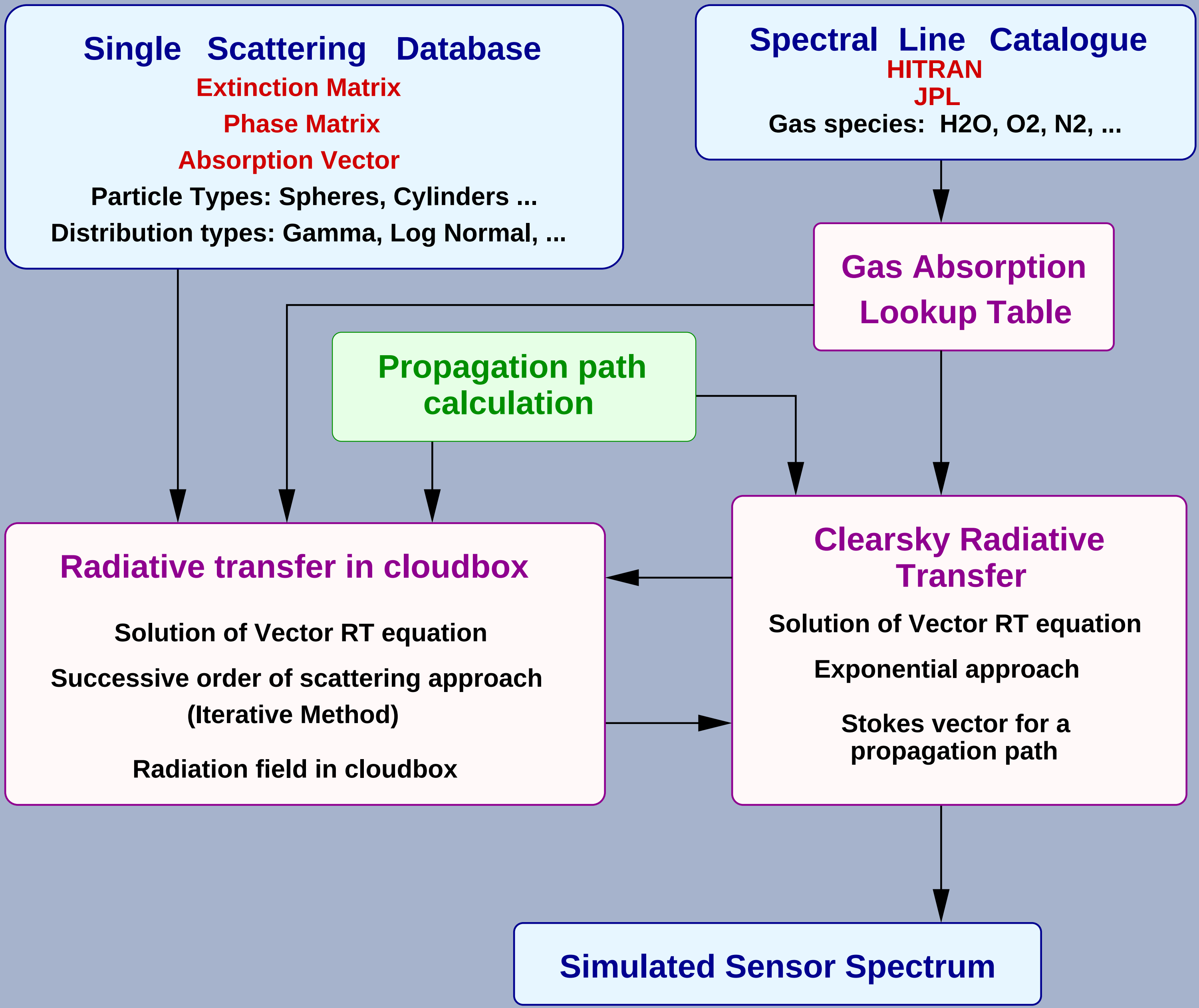


Scattered radiation field is calculated inside the cloudbox using **successive order of scattering approach**.

Definition of cloudbox:

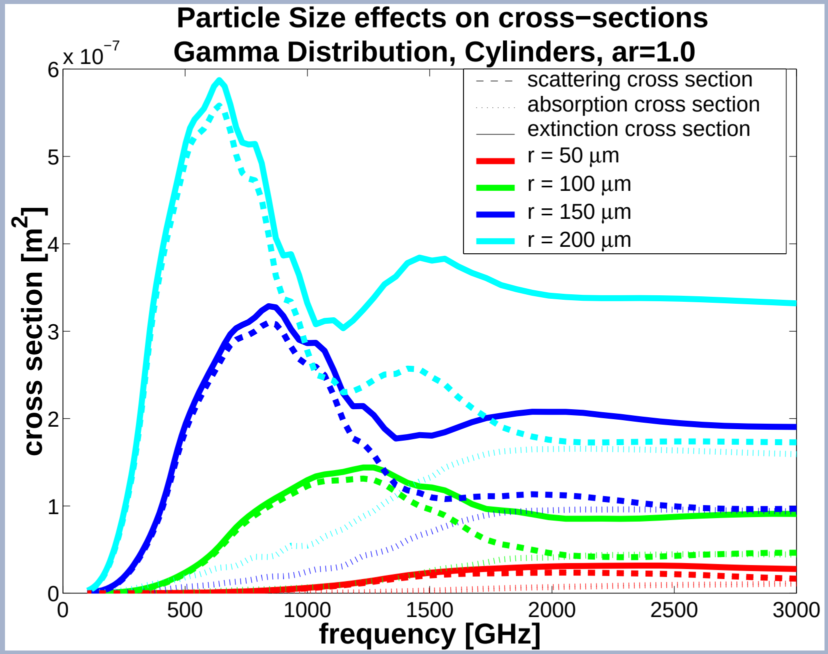
- corner points ⇔ atmospheric grid points
- 3D atmosphere:
  $[p_1, p_2, \alpha_1, \alpha_2, \beta_1, \beta_2]$

The concept of ARTS



Single Scattering Database

- Hydro-meteor species defined by
  - Phase matrix
  - Extinction matrix
  - Absorption vector
- One species can be ensemble or single particle.
- T-matrix method for computation (Mishchenko code).
- Data format: XML



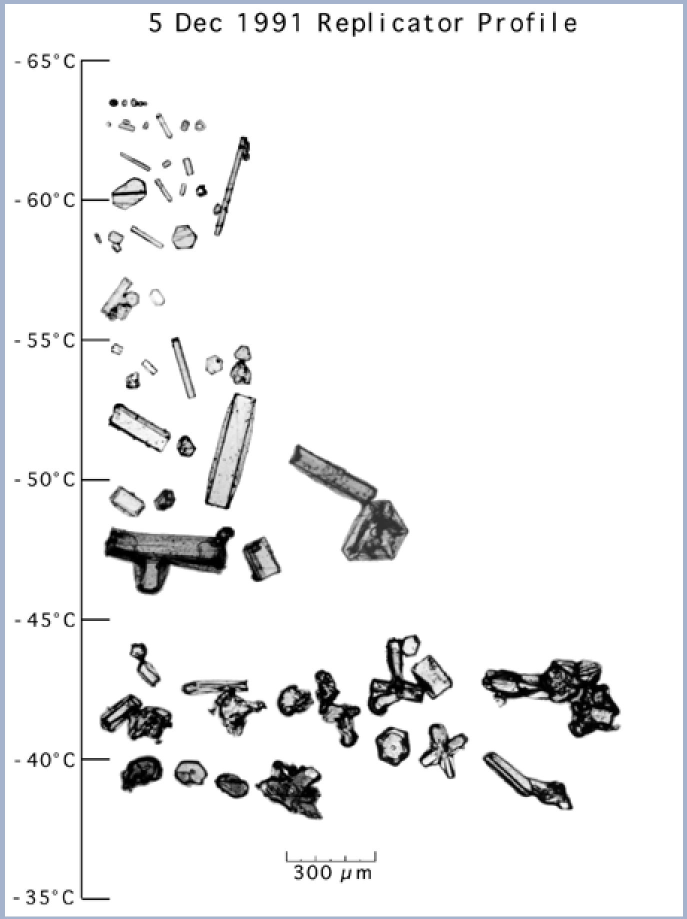
Hydro-meteor species

- **General case:**
  Scattering media exhibiting no symmetries.

- **Macroscopically isotropic and mirror-symmetric scattering media:**
  Randomly oriented particles.
  Optical properties are calculated in a special coordinate system to save storage memory.

- **Horizontally aligned plates and columns:**
  Azimuthally randomly oriented scattering media.

- **Spherical particles:**
  A special case of randomly oriented scattering media.



Cirrus particle shapes measured in FIRE campain.

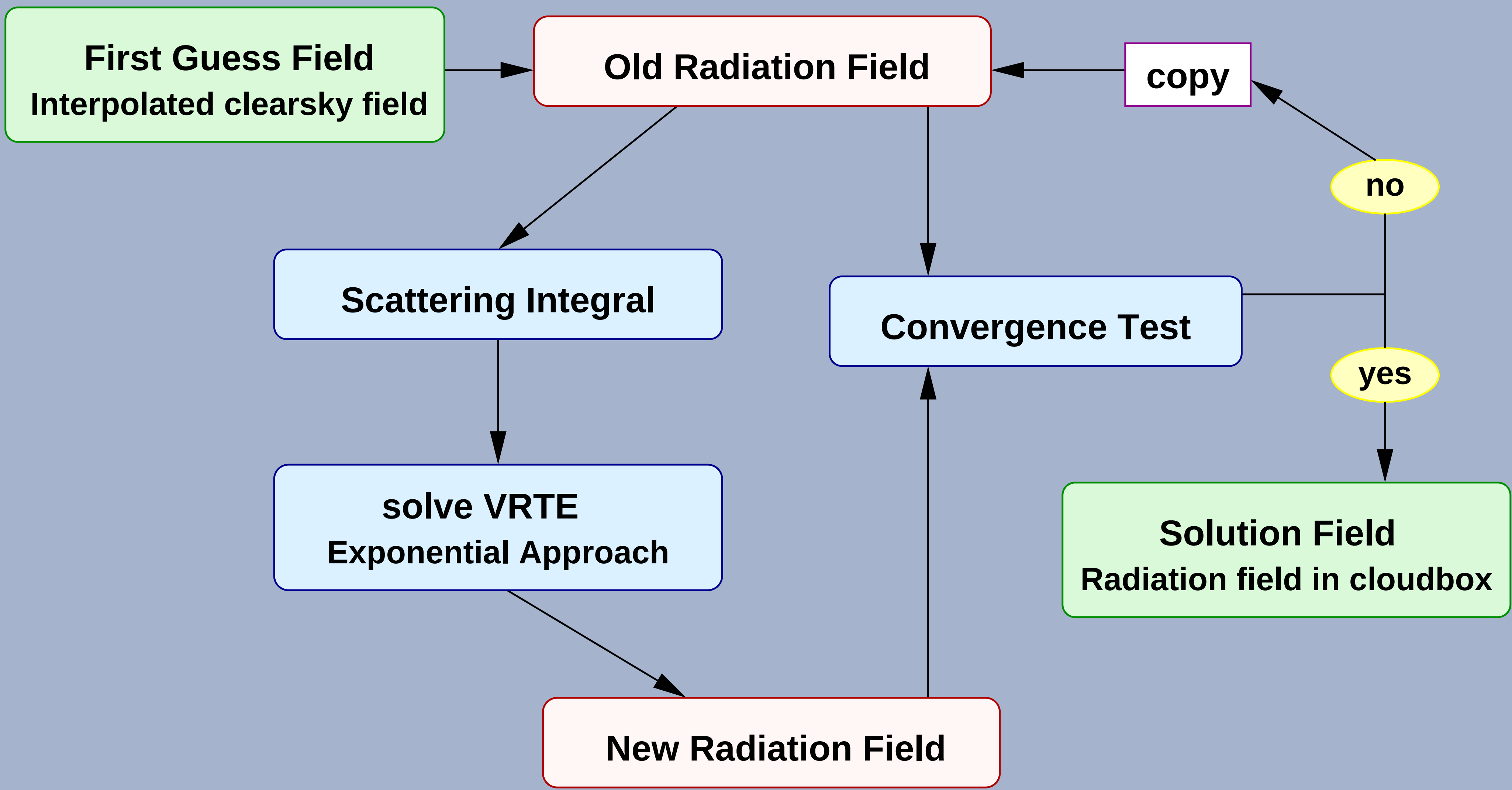
http://www.mmm.ucar.edu/science/cirrus/

Vector radiative transfer equation

$$\frac{d\mathbf{I}}{ds}(\mathbf{n},\nu) = -\mathbf{K}(\mathbf{n},\nu)\mathbf{I}(\mathbf{n},\nu) + \mathbf{a}(\mathbf{n},\nu)B(\nu) + \int_{4\pi} d\mathbf{n}'\mathbf{Y}(\mathbf{n},\mathbf{n}',\nu)\mathbf{I}(\mathbf{n}',\nu)$$

$\mathbf{I} = (I, Q, U, V)$	Stokes Vector
$\mathbf{n}$	propagation direction of the radiation
ν	frequency
$\mathbf{K}$	extinction coefficient matrix
$\mathbf{a}$	absorption coefficient vector
B	Planck function
$\mathbf{Y}$	phase matrix

Successive order of scattering method

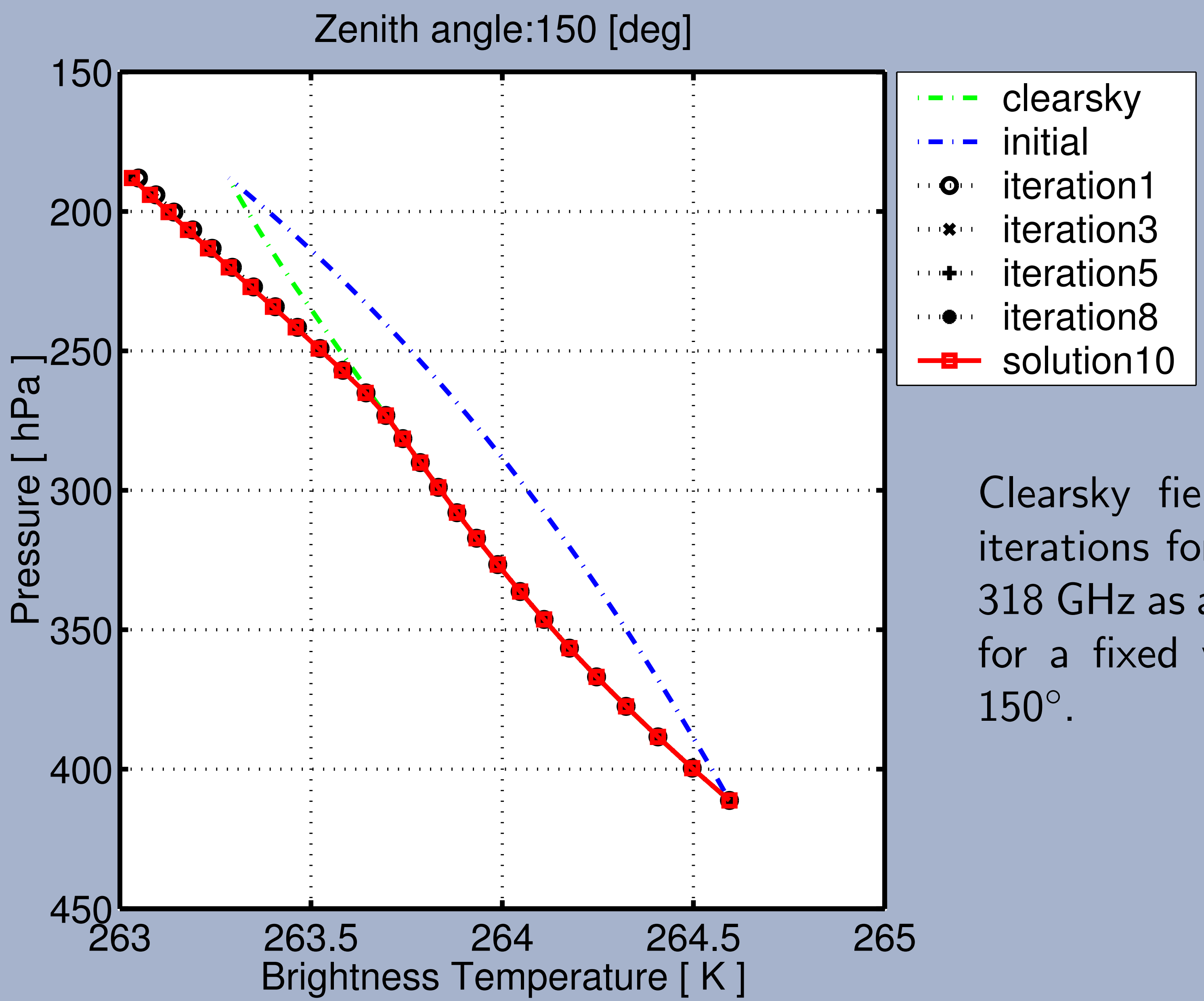


1D test calculations for a homogeneous cloud

Setup:

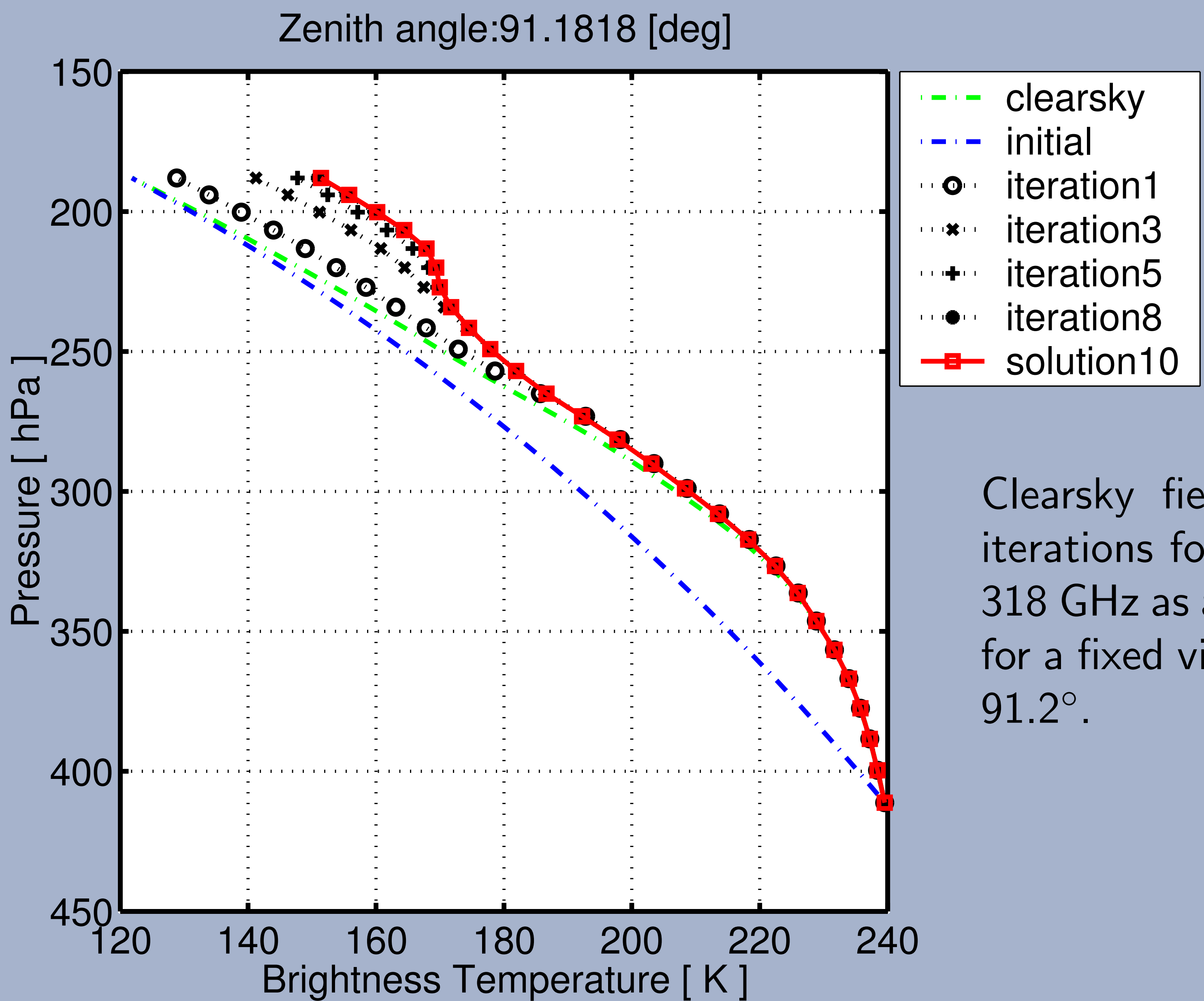
- 1D atmosphere.
- Cloudbox altitude: 7.0 - 12.2 km
- Cloud altitude: 9.8 - 12.1 km
- Spherical, and cylindrical ice particles
- Gamma size ditribution, effective radius 85.5 μm
- Ice mass content: 0.04 g/m^3
- Absorption from lookup table for the species: H_2O, O_3
- Frequency band: 318 - 325 GHz

Convergence behaviour



Clearsky field, initial field and iterations for the intensity (I) at 318 GHz as a function of altitude for a fixed viewing direction of 150°.

Convergence behaviour (2)

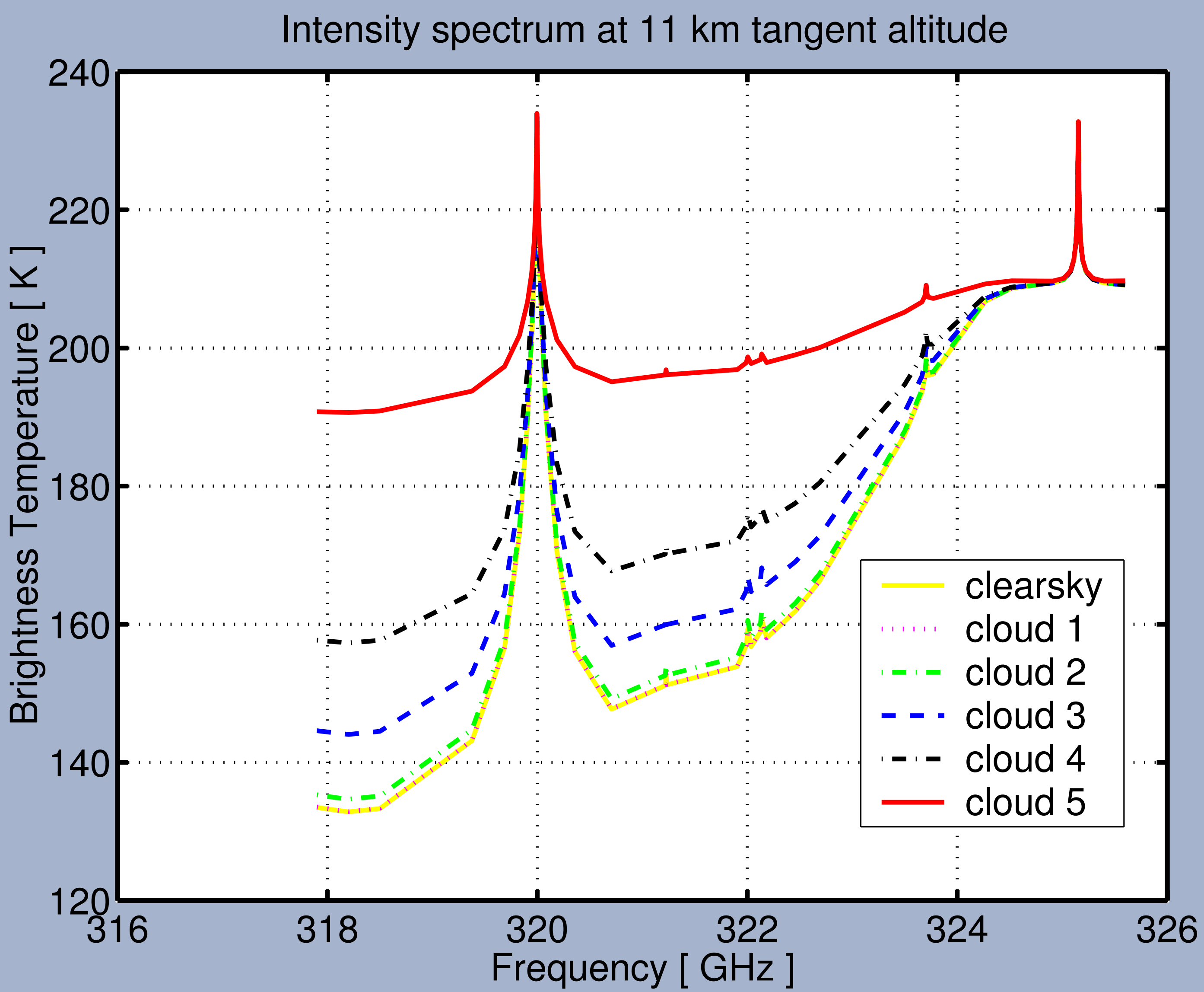


Clearsky field, initial field and iterations for the intensity (I) at 318 GHz as a function of altitude for a fixed viewing direction of $\approx$ 91.2°.

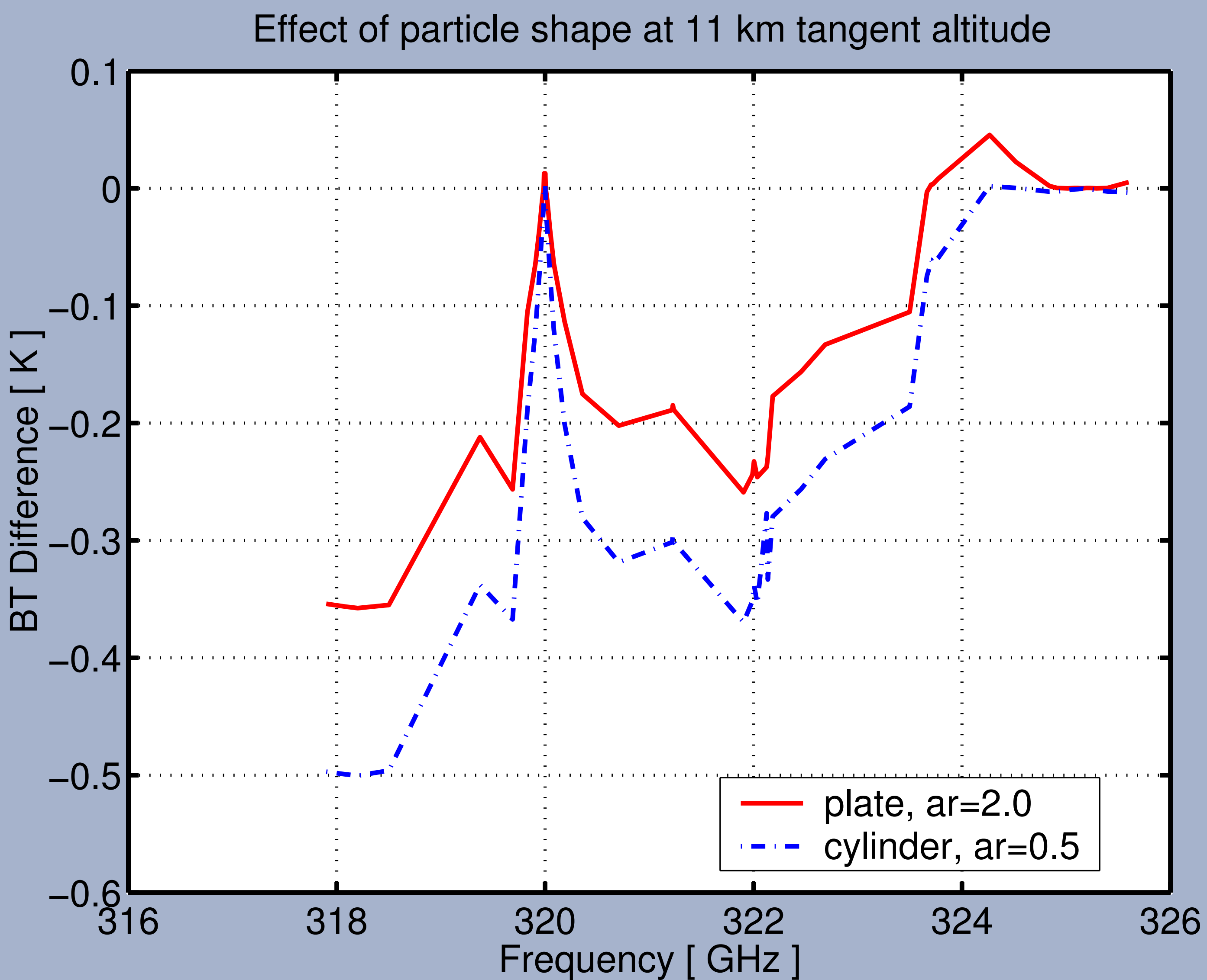
Different cloud scenarios

cloud	r_{eff} [μm]	IMC [g/m^3]	altitude [km]
1	21.5	0.0001	10 - 12
2	34.0	0.004	8 - 10, 10 - 12
3	68.5	0.02	6 - 8, 10 - 12
4	85.5	0.04	10 - 12
5	128.5	0.1	10 - 12

Spectra at 11 km tangent altitude



Effect of particle shape on intensity



Summary

- Scattering calculations performed for 1D and 3D test cases.
  $\Rightarrow$ Reasonable results.

- Successive order of scattering method implemented for solving VRTE.

- Polarized and unpolarized radiation fields can be simulated.

- T-matrix method selected for calculating single scattering properties.

- Geometrical propagation path calculations implemented for 1D, 2D and 3D; with and without refraction.

Outlook

- Main problem: Using all implemented features at the same time requires long computation time and large working memory.

- Optimizations planned to be implemented.

ARTS
The Atmospheric Radiative Transfer System

More information availabe on web-page:

http://www.sat.uni-bremen.de/arts/