The simulation of aerosol affected infrared radiances in RTTOV

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- A prerequisite for exploiting radiances from conventional and high-resolution sounders in NWP models is the availability of a fast radiative transfer (RT) model to predict a first guess radiance from the model fields.

- ECMWF (and many others NPW centres) utilises the RTTOV fast RT model (e.g. Matricardi et al 2004).

▶ RTTOV is a regression based fast radiative transfer model where the atmospheric optical depths, τ_j ,are modelled as functions of profile dependent predictors, $X_{k,j}$, that are functions of temperature, absorber amount, pressure and viewing angle :

$$\tau_j = \sum_{k=1}^{M} a_{k,j} X_{k,j}$$

▶ The expansion coefficients $a_{k,j}$ are obtained by multiple linear regression of accurate line-by-line computed optical depths against the corresponding values of $X_{k,j}$, for a diverse set of atmospheric profiles.

► The RTTOV radiative transfer can optionally include solar radiation in the region of the spectrum between 3.6 μm and 5 μm.

→ Over land, a Lambertian surface is assumed

→ Over a wind roughened water surface, the bidirectional reflectivity is computed explicitly considering the full geometry of the situation.

► RTTOV features the radiative transfer of multiple scattering in the infrared by aerosols and clouds.

► The azimuthally independent radiative transfer equation for the problem of multiple scattering in plane parallel atmospheres can be written as

$$\mu \frac{dI(\tau,\mu)}{d\tau} = I(\tau,\mu) - \frac{\omega}{2}\int_{-1}^{1} I(\tau,\mu')\bar{P}(\mu,\mu')d\mu' - \frac{\omega}{4\pi}F\,\bar{P}(\mu,-\mu_o)\,e^{\frac{-\tau}{\mu_o}} + (1-\omega)B[T(\tau)]$$

where ω is the single scattering albedo, $\bar{P}$ is the azimuthally averaged phase function, τ is the extinction optical depth and F is the solar irradiance.

→ Since the source function includes the local radiation field, the solution is an integral equation.

► Numerical solutions (e.g. discrete-ordinates, doubling-adding) are available that present few difficulties.

→ Within the NWP operational framework of RTTOV, we can only consider an analytical solution given by approximate methods since numerical solutions are too computationally expensive.

►A useful and accurate approximation is the two-stream approximation sometimes used in climate models (Liou 2002).

→ However, the implementation of a two-stream approximation is still too computationally expensive if hyperspectral data have to be processed in an operational environment in near-real-time.

► In RTTOV multiple scattering is parameterized by scaling the optical depth by a factor derived by including the effect of backward scattering in the emission of a layer and in the transmission between levels (Chou et al. (1999)).

→ This parameterization rests on the assumption that the diffuse radiance field is isotropic and can be approximated by the Planck function.

► Since the parameterization (referred to hereafter as scaling approximation) does not require explicit calculations of multiple scattering (the radiative transfer equation is identical to that in clear sky conditions) the computational efficiency of RTTOV can be retained.

► In the scaling approximation, multiple scattering is parameterized by replacing the absorption optical depth, τ_a, with an effective extinction optical depth, $\tilde{\tau}_e$, defined as

$$\tilde{\tau}_e = \tau_a + b\tau_s$$

where τ_s is the scattering optical depth and *b* is the integrated fraction of energy scattered backward for incident radiation from above or below.

$$b = \frac{1}{2}\int_0^1 d\mu \int_{-1}^0 \bar{P}(\mu, \mu')\, d\mu'$$

- The RTTOV radiative transfer can include by default eleven basic aerosol components.

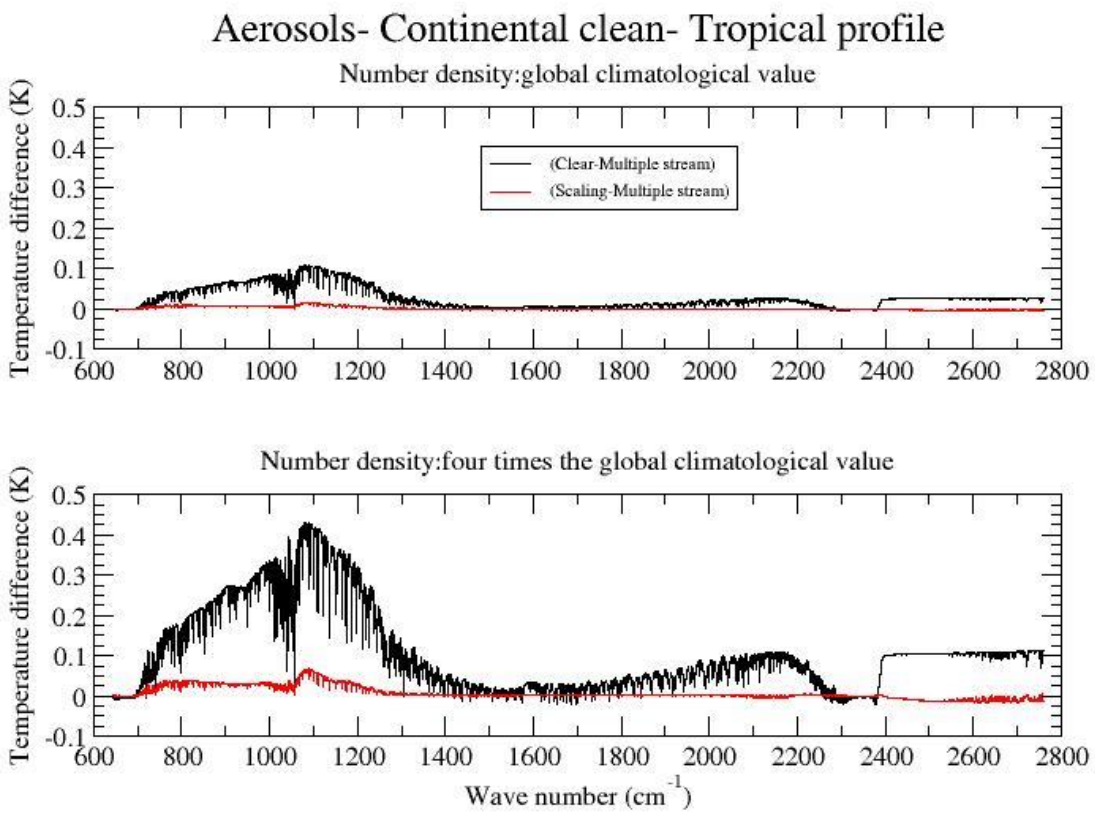
- A database of optical properties (i.e. absorption coefficient, scattering coefficient, backscatter parameter and phase function) for aerosols and water droplets has been generated using the Lorentz-Mie theory for spherical particles for every single channel of many infrared sounders including hyperspectral sounders like IASI.

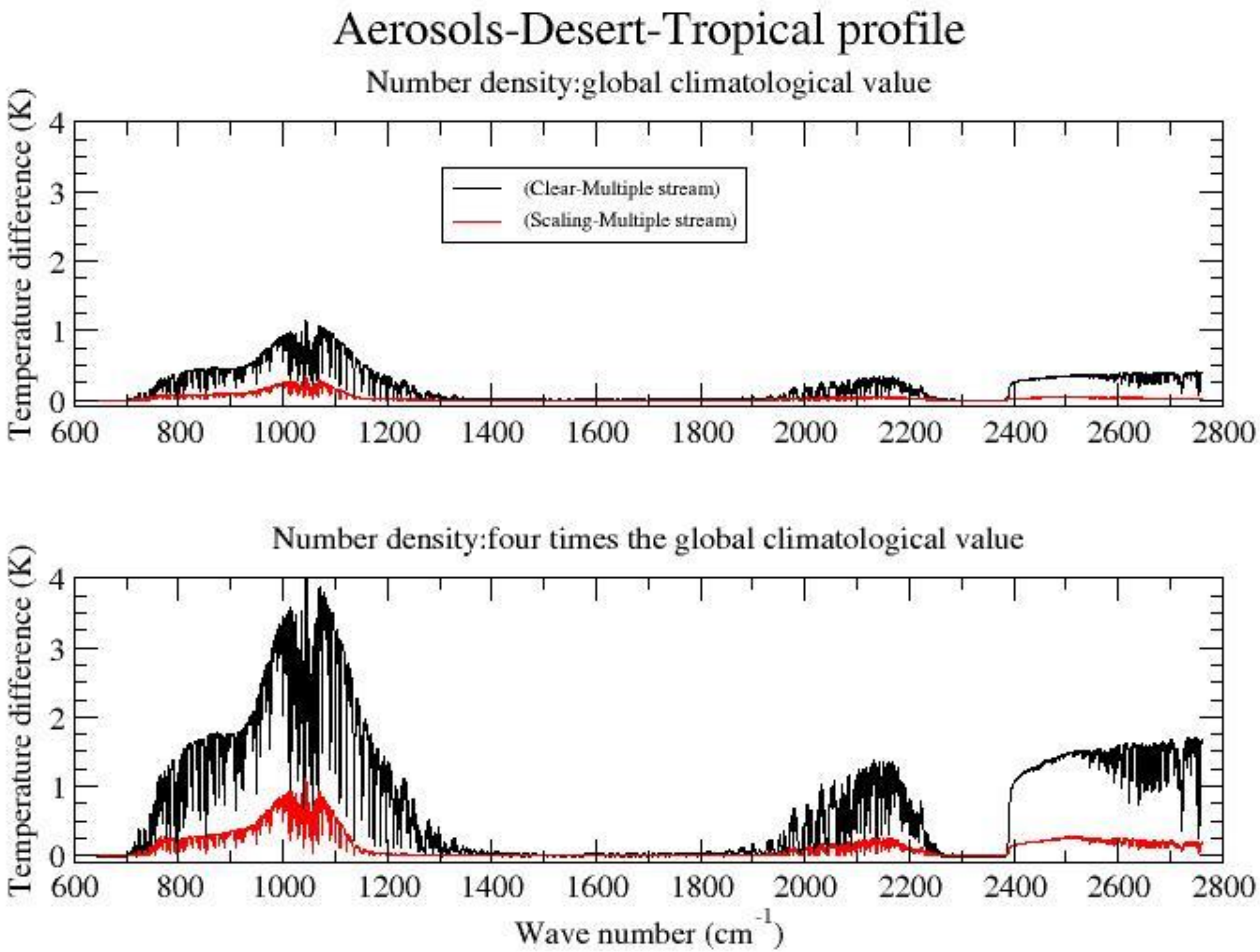
- Note that in RTTOV values of the phase function are available for a total of 208 scattering angles. Values are given for every 0.1º from 0º to 3º otherwise they are given for every 1º.

- The microphysical parameters (e.g. size distribution, refractive indices) used to generate the database of optical properties for aerosols are those included in the Optical Properties of Aerosols and Clouds (OPAC) software package (Hess et al. 1998).

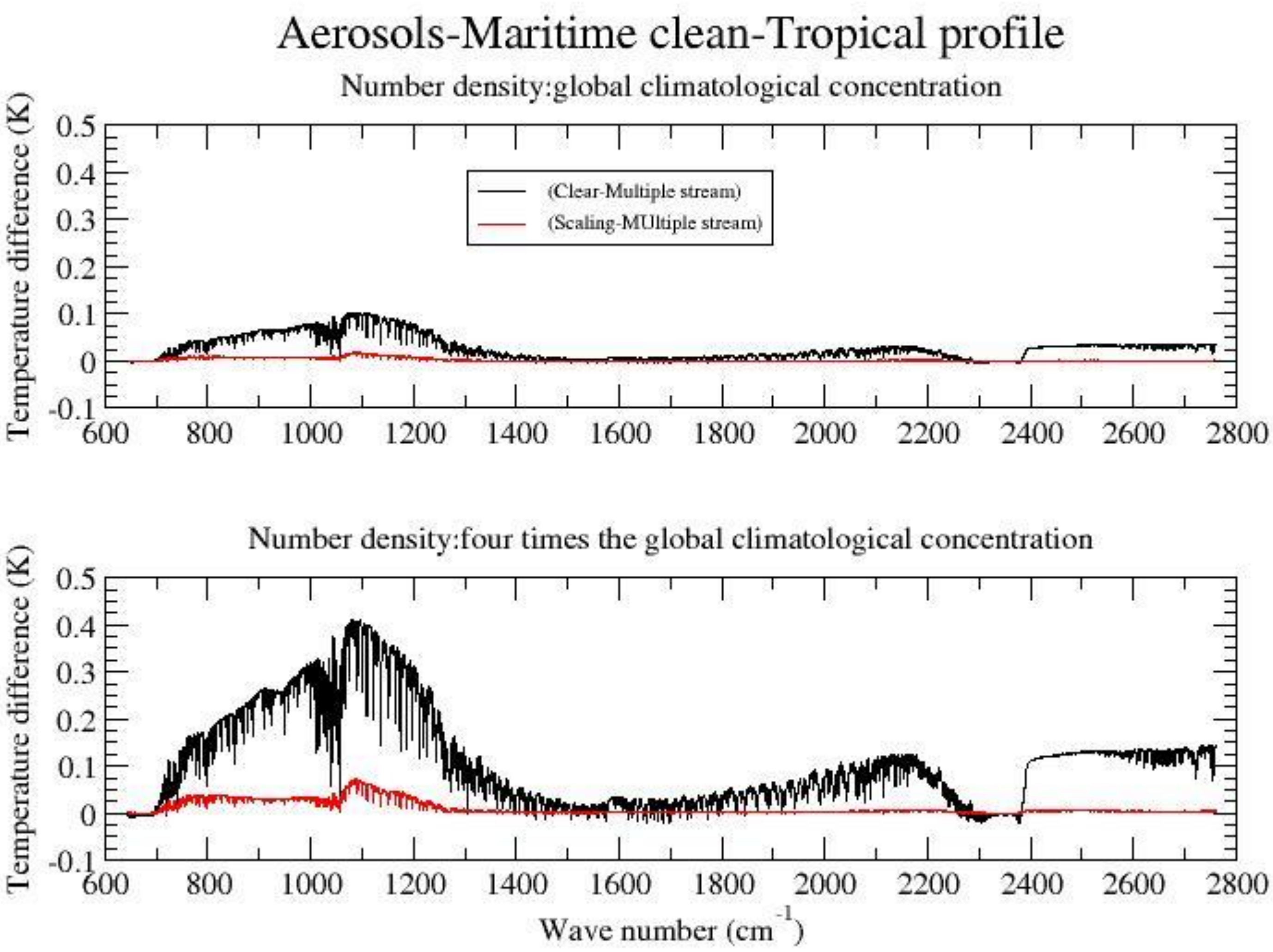
- The aerosol optical properties used by default in RTTOV have been obtained on the basis of microphysical properties that, given their highly variable nature, do not necessarily reflect an actual situation. For this reason, RTTOV allows the user to externally specify the values of the optical properties used in the radiative transfer.

► To asses the accuracy of the scaling approximation we have compared approximate radiances with reference radiances computed by using a doubling-adding algorithm.





Aerosols-Desert-Tropical profile
Number density:global climatological value
(Clear-Multiple stream)
(Scaling-Multiple stream)
Temperature difference (K)
0
1
2
3
4
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Number density:four times the global climatological value
Temperature difference (K)
Wave number (cm-1)



Aerosols-Maritime clean-Tropical profile
Number density:global climatological concentration
(Clear-Multiple stream)
(Scaling-MUltiple stream)
Temperature difference (K)
0.5
0.4
0.3
0.2
0.1
0
-0.1
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Number density:four times the global climatological concentration
Temperature difference (K)
Wave number (cm^{-1})

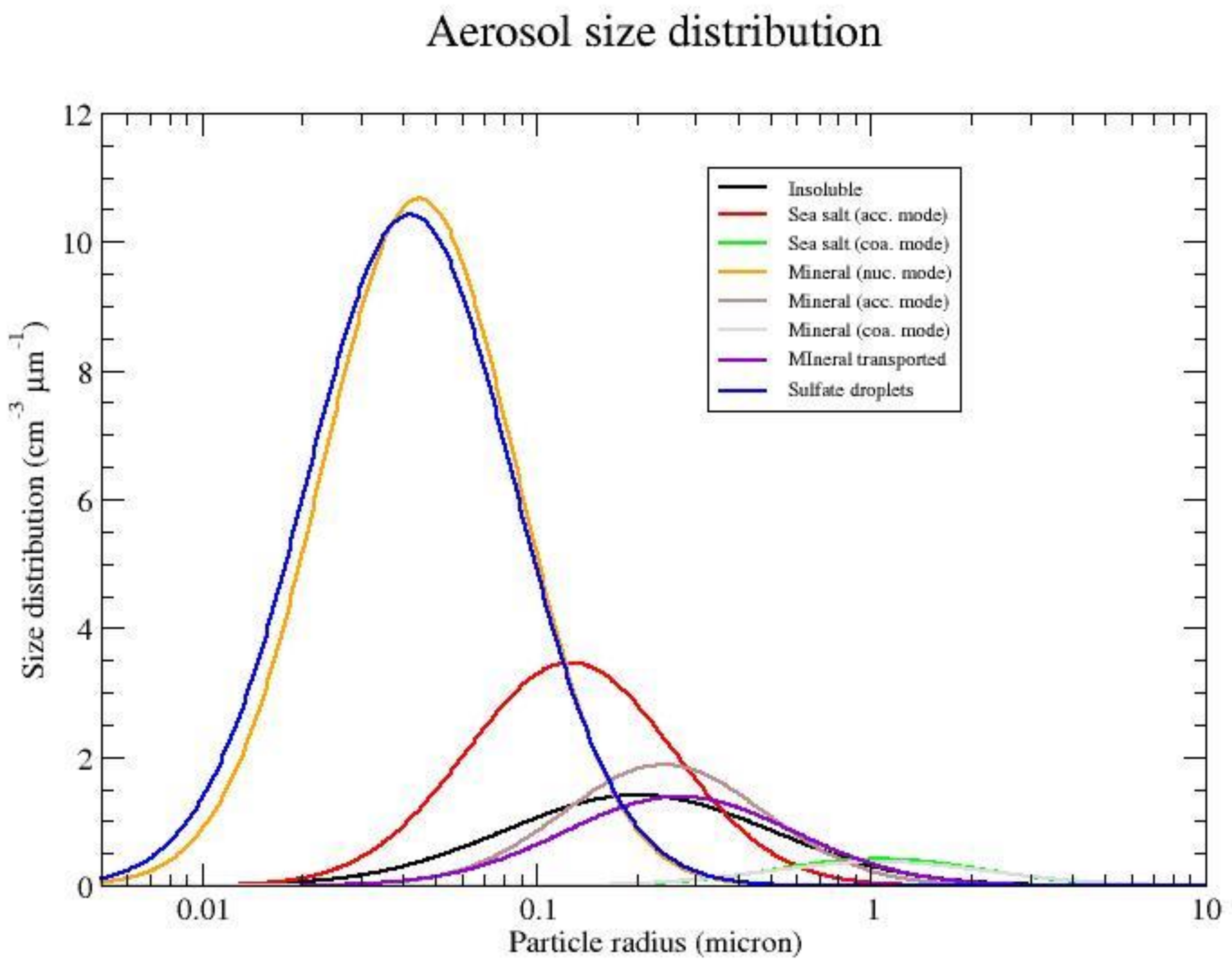
Summary and future work

- Operational applications require fast and accurate RT models which should include a full suite of Tangent Linear (TL) and Adjoint (AD) routines.

- RTTOV is used by more than 1000 users world wide and this include aerosol applications in the infrared.

- ECMWF is planning to use RTTOV to develop an aerosol detection scheme aimed at selecting hyperspectral channels not affected by aerosol signal.

- In the short term we are aiming at implementing in RTTOV a fast scheme for the simulation of aerosol affected radiances in the visible.


Aerosol size distribution
Insoluble
Sea salt (acc. mode)
Sea salt (coa. mode)
Mineral (nuc. mode)
Mineral (acc. mode)
Mineral (coa. mode)
MIneral transported
Sulfate droplets
Size distribution (cm^{-3} µm^{-1})
0
2
4
6
8
10
12
0.01
0.1
1
10
Particle radius (micron)

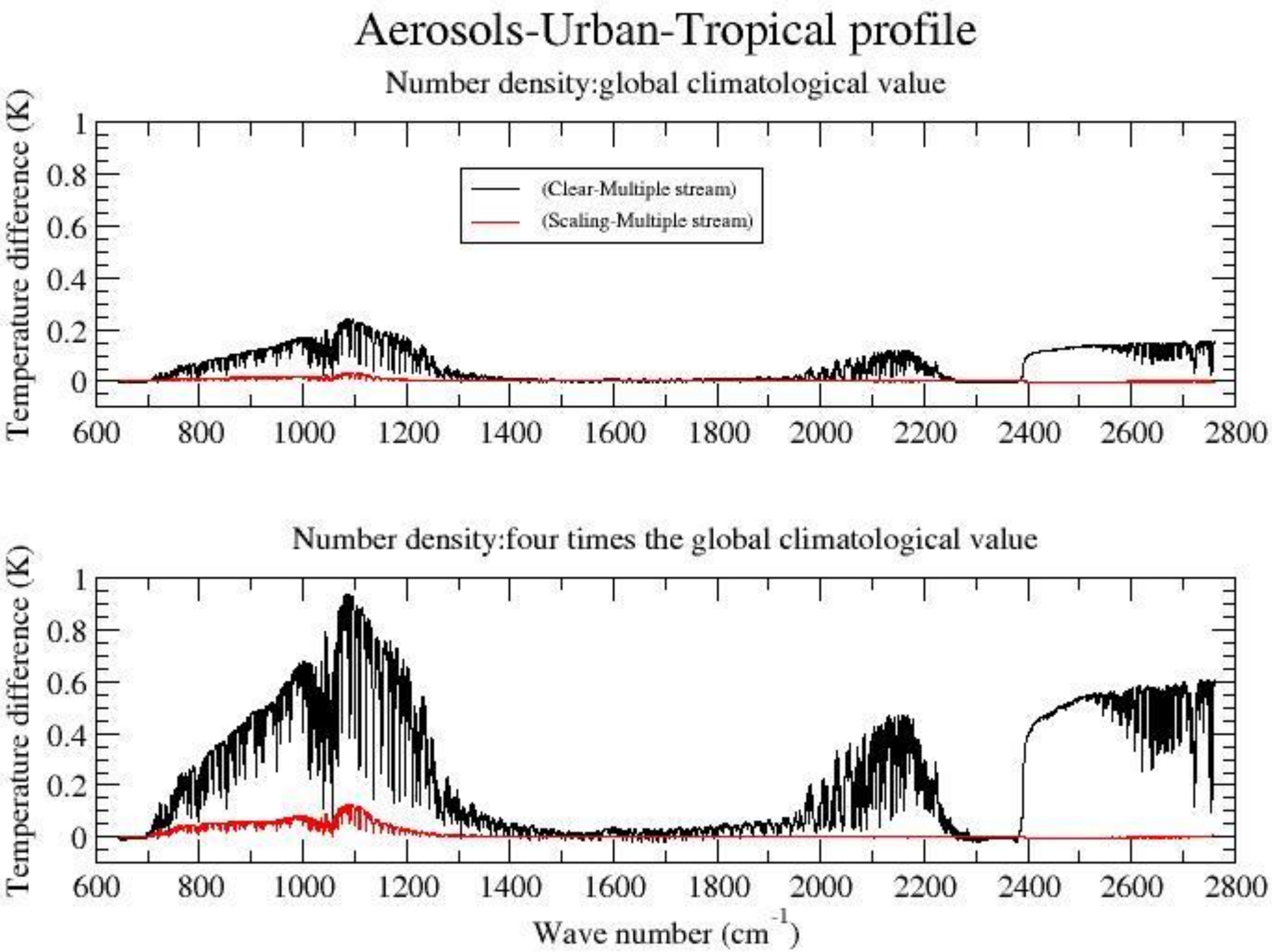
► The aerosols optical properties can be computed for any mixture of the default eleven components or, alternatively, for 10 aerosols types composed of pre-defined mixtures of basic components representative of average and extreme conditions for a range of climatological important aerosols.

The aerosol components

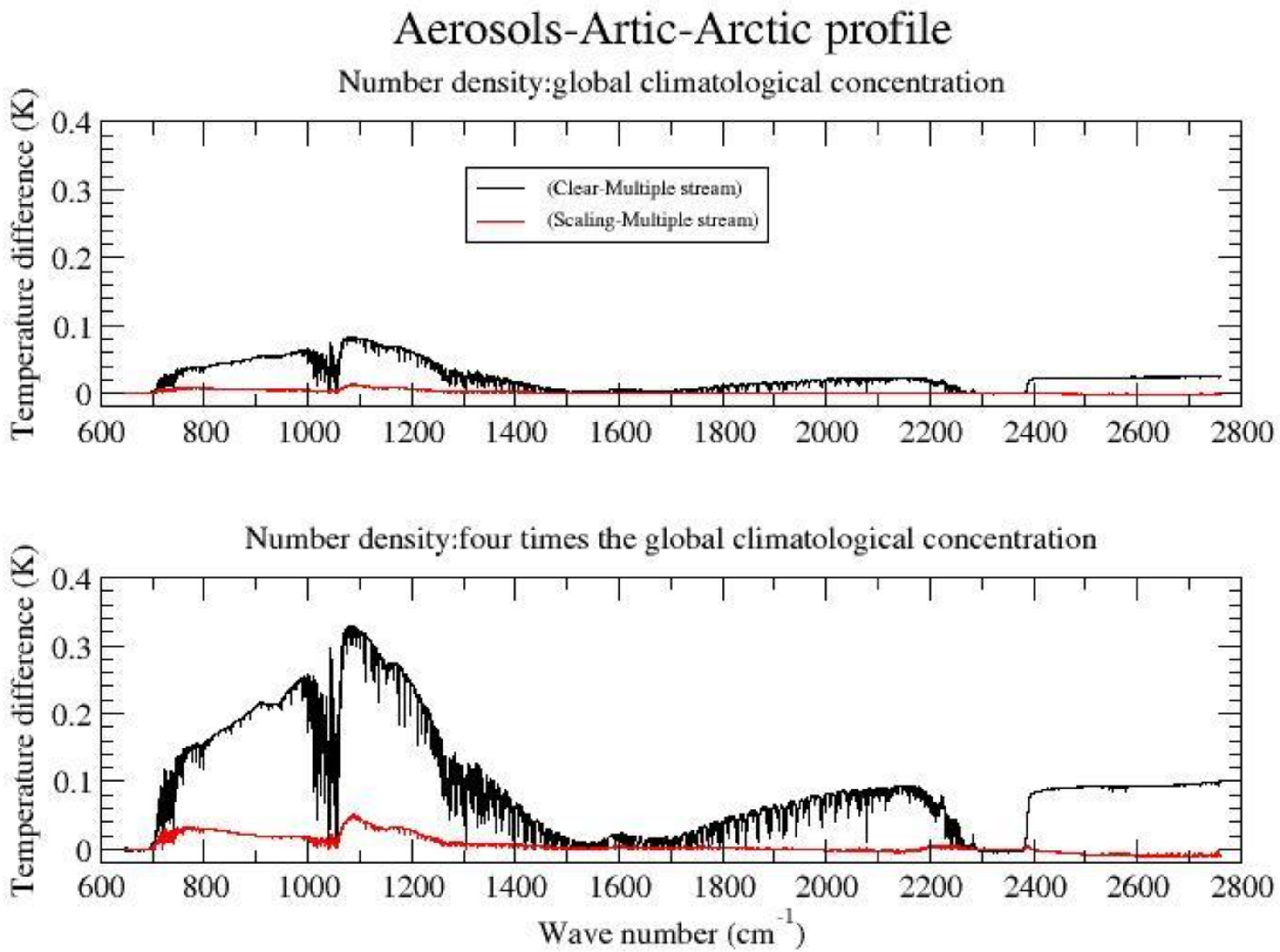
- Insoluble
- Water-soluble
- Soot
- Sea salt (two modes)
- Mineral (three modes)
- Mineral-transported
- Sulfate droplets
- Volcanic ash

The aerosol types

- Continental clean
- Continental average
- Continental polluted
- Urban
- Desert
- Maritime clean
- Maritime polluted
- Maritime tropical
- Arctic
- Antarctic


Aerosols-Urban-Tropical profile
Number density:global climatological value
(Clear-Multiple stream)
(Scaling-Multiple stream)
Temperature difference (K)
Number density:four times the global climatological value
Temperature difference (K)
Wave number (cm-1)

ECMWF



Aerosols-Artic-Arctic profile
Number density:global climatological concentration
Temperature difference (K)
0.4
0.3
0.2
0.1
0
(Clear-Multiple stream)
(Scaling-Multiple stream)
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
Number density:four times the global climatological concentration
Temperature difference (K)
Wave number (cm-1)