RECENT ADVANCES IN THE SCIENCE OF RTTOV

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RTTOV is the NWP SAF fast radiative transfer model and is developed jointly by ECMWF, the Met Office and Météo France.

In this presentation we describe the contribution given by ECMWF to the development of RTTOV-88, the most recent and significantly improved version of RTTOV.

This work was supported by EUMETSAT through IASI pre-launch definition studies.

RTTOV is a regression based (on fixed pressure levels) fast radiative transfer model.

- Layer optical depths τ_j are parameterized as a linear combination of profile dependent predictors $X_{k,j}$:

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

- The model uses the polychromatic form of the radiative transfer equation (i.e. the use of convolved transmittances in the radiative transfer equation is based on the assumption that this equivalent to the convolution of the monochromatic radiances).

The introduction of variable trace gases

The accurate optical depths needed to compute the regression coefficients for the fast transmittance model are generated using the GENLN-2 (Edwards 1992) line-by-line radiative transfer algorithm using the year 2000 version of the HITRAN molecular database (Rothman et al. 2003).

In RTTOV-88, fixed amounts are used for N_2, O_2, **OCS, CCl_4, CF_4, CCl_3F, CCl_2F_2 and HNO_3** whereas H_2O, **CO_2**, O_3, **N_2O, CO, CH_4** are allowed to vary and are profile variables in the fast model.

The introduction of variable trace gases

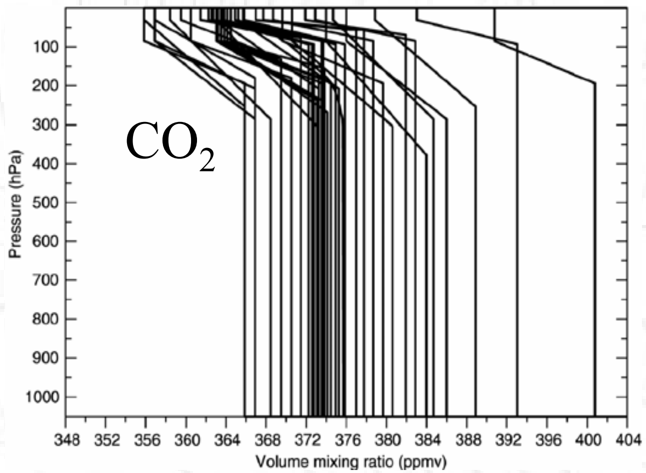
The training profiles for CO_2, N_2O, CO and CH_4 are selected using profiles from in-situ measurements and profiles generated using a chemistry model (Matricardi 2003).

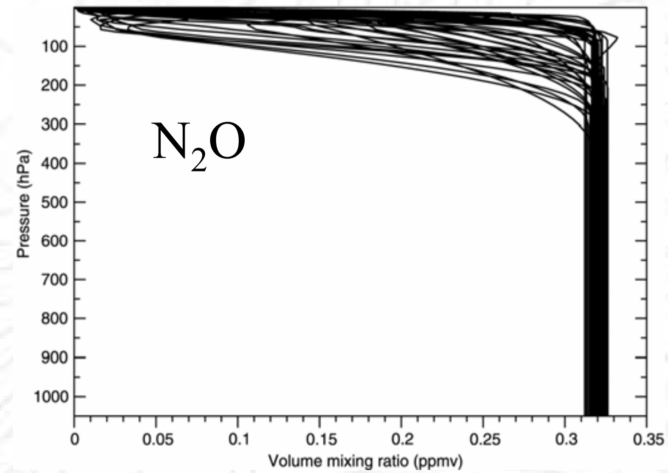
Stratospheric profiles for CH_4 and N_2O are from the Cryogenic Limb Array Etalon Spectrometer (CLAES) dataset. N2O is assumed to be well mixed in the troposphere whereas tropospheric profiles for CH4 are based on the IMAGES model calculations (Muller and Brasseur 1995; Clerbaux et al. 1998).

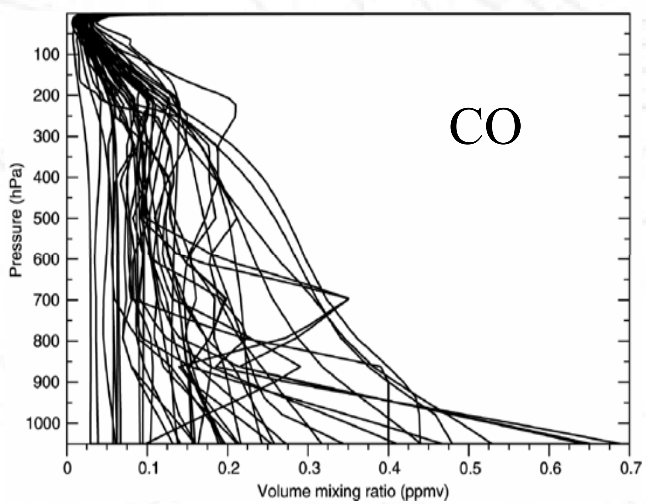
CO2 profiles are based on the assumption that this gas is well mixed in the troposphere and decreases by 5 to 10 ppmv between the tropopause and about 22 km altitude (Bischof et al. 1985).

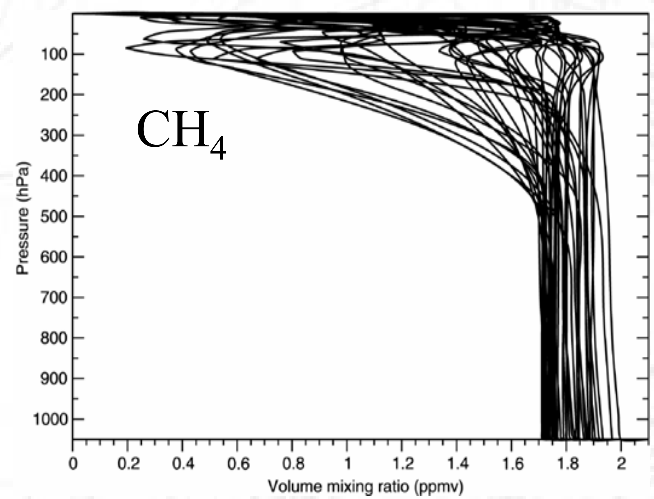
Tropospheric profiles for CO are based on MOZART 3D model calculations (Brasseur et al. 1998; Cunnold, 2001) and measurements taken during the STRATOZ III and TROPOZ campaign (Marenco et al. 1995).

The introduction of variable trace gases









The improvement of the fast transmittance model

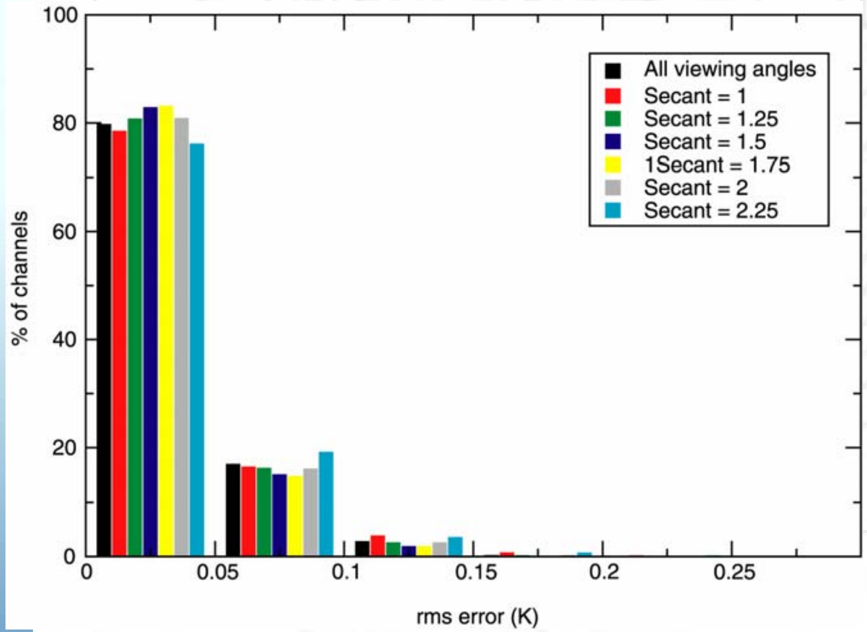
In RTTOV-88, water vapour continuum type absorption is handled separately from line absorption so that any change in the continuum can be addressed without the need of generating a new line-by-line database.

Revised predictors are used for water vapour, ozone and well mixed gases. (Matricardi 2003).

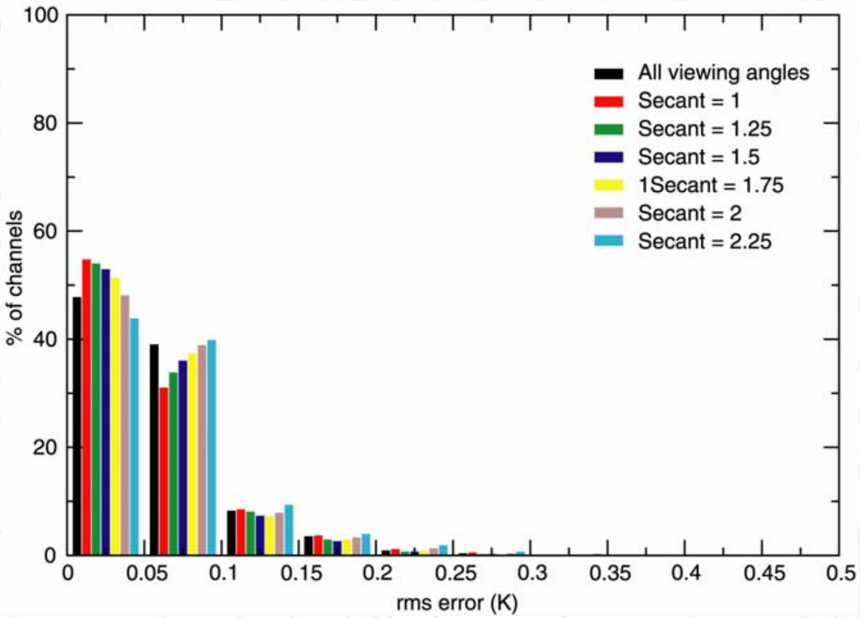
A fast transmittance model is introduced for CO_2, N_2O, CO and CH_4 (Matricardi 2003).

The improvement of the fast transmittance model

IASI: dependent set



IASI: independent set



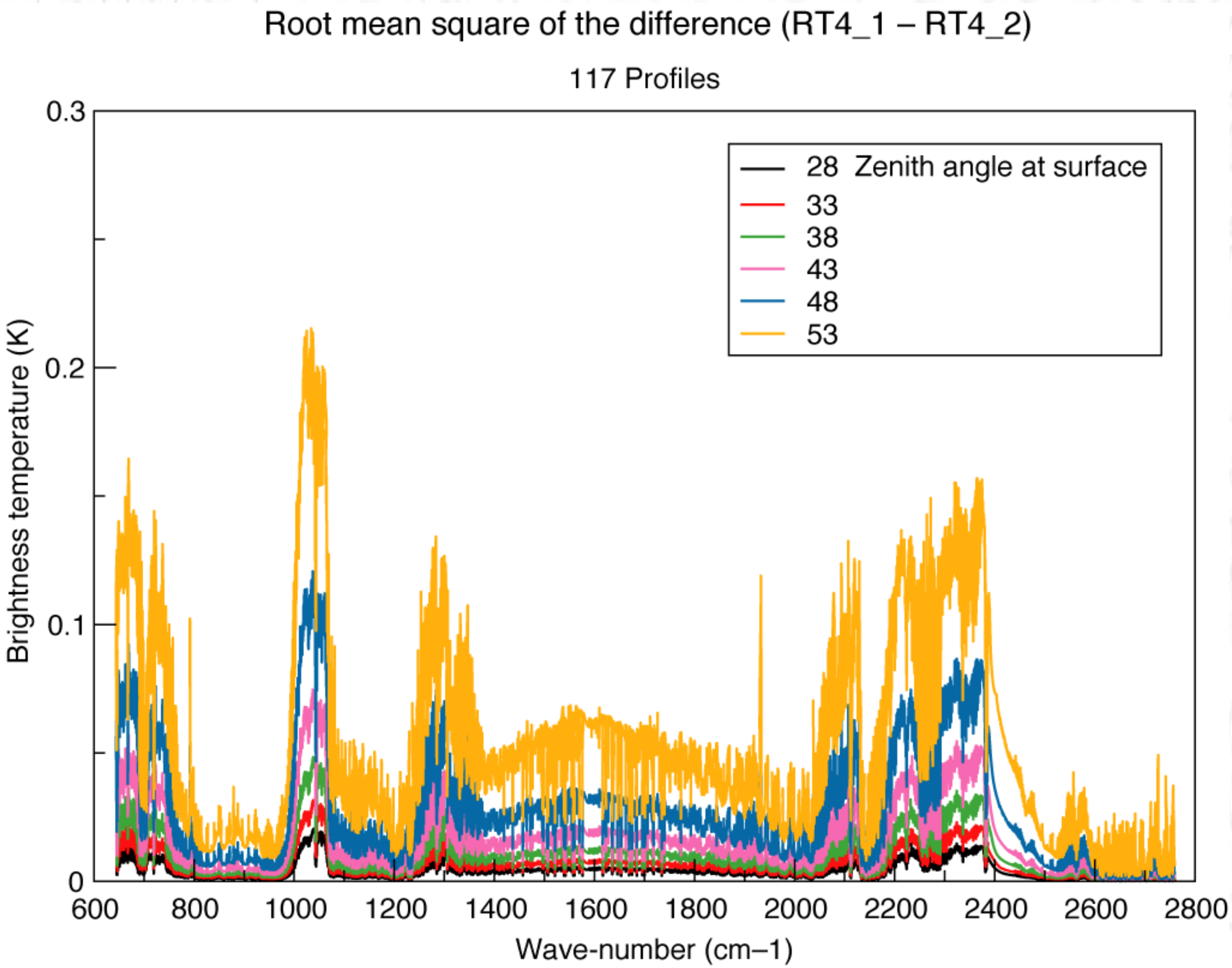
The improvement of the accuracy of the radiance computation: introduction of an altitude dependent local path angle

In RTTOV-88 the satellite viewing angle (and the solar zenith angle) are converted into a local path angle that decreases with altitude because of the curvature of the Earth and its surrounding atmosphere.

The evaluation of the local path angle involves the numerical integration of the hydrostatic equation. We take fully into account the displacement of dry air molecules by water vapour (i.e. we use virtual temperatures) and the variation of gravity with latitude (Woollard 1979).

Atmospheric refraction can be optionally included. If this is the case, the refractive index of air is computed using an updated version of Edlen’s equation (Birch and Downs 1993).

The improvement of the accuracy of the radiance computation: introduction of an altitude dependent local path angle



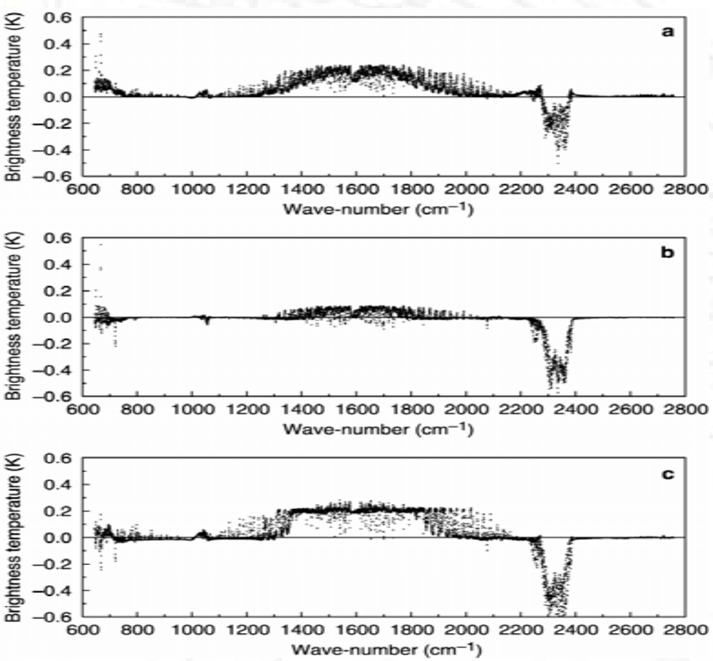
The improvement of the accuracy of the radiance computation: refinement of the vertical pressure grid and introduction of linear in tau approximation

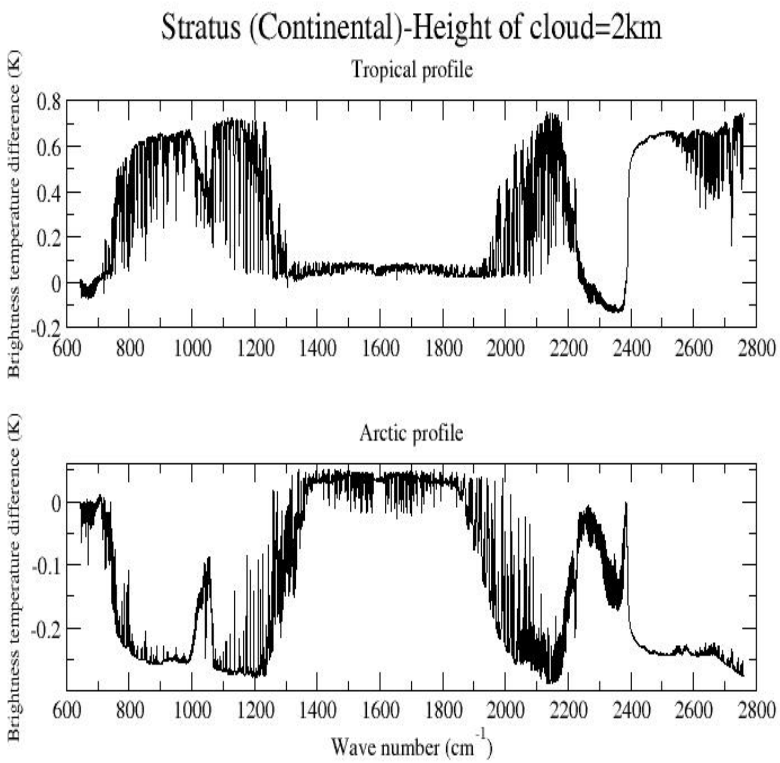
In RTTOV-88 radiance computations for the high resolution sounders (AIRS and IASI) are performed by dividing the atmosphere into 100 layers of fixed pressure levels extending from 1050 hPa to 0.005 hPa.

Radiance computations are performed assuming that the source function throughout each atmospheric layer varies linearly with the optical depth of the layer (linear in τ approximation). This is in contrast with the standard RTTOV assumption that the source function is the average of the Planck function.

Difference between IASI level 1C spectra computed using 43 and 101 vertical levels. Results are shown for:
(a) Mid-latitude spectrum
(b) Arctic spectrum
(c) Tropical spectrum

Difference between IASI level 1C spectra computed using the average Planck function and the linear in τ approximation

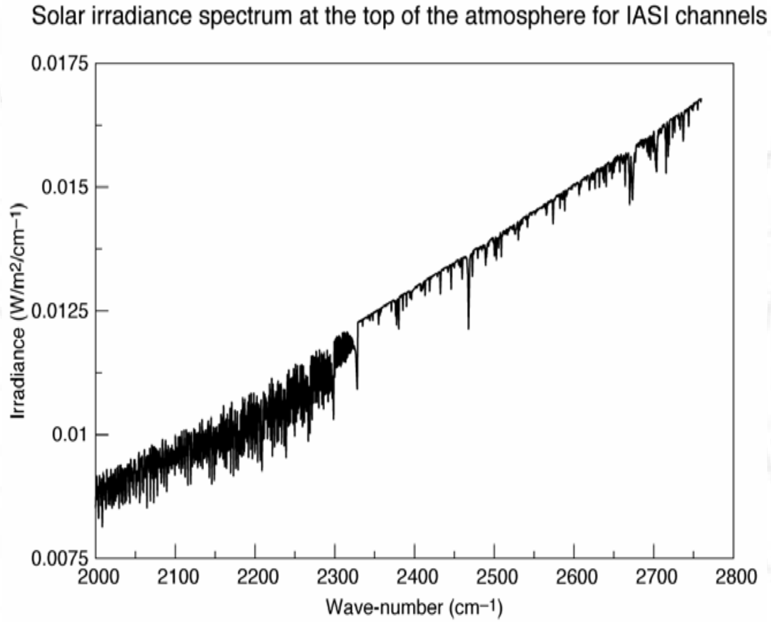




The introduction of the solar term

The RTTOV-88 radiative transfer can optionally include solar radiation in the region of the spectrum between 3.6 μm and 5 μm.

We use a top of the atmosphere solar irradiance spectrum obtained from theoretical radiative transfer calculations made by Kurucz (1992) based on measurements made by the ATMOS instrument on the space shuttle.



The introduction of the solar term

For solar radiance reflected by a land surface, the reflecting surface is treated as a perfect diffuser following the Lambert law.

For solar radiance reflected by a wind roughened water surface, the bistatic reflectivity is computed explicitly using the scheme by Yoshimori et al. (1995).

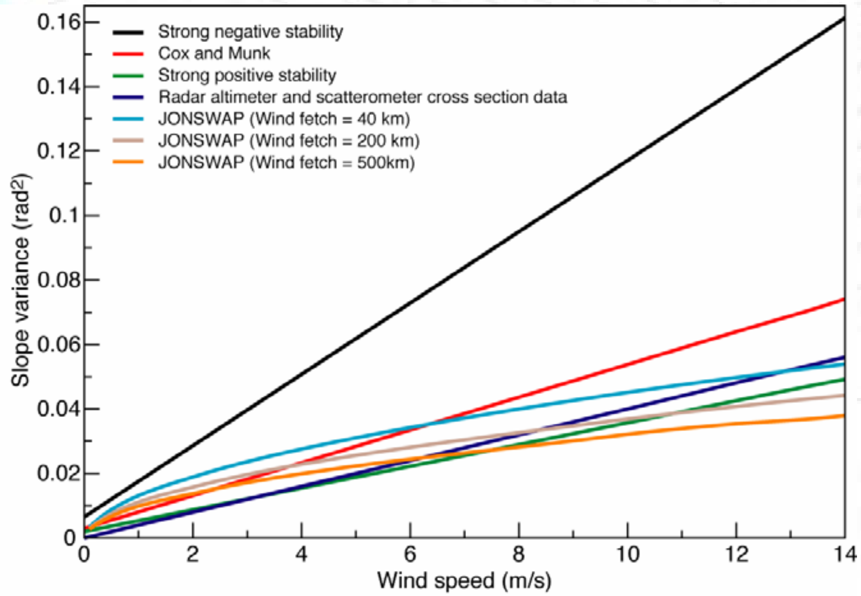
The wave slope probability density obeys a Gaussian distribution and the total variance of the slope is determined from the spectrum of the wave slope as specified in the Joint North Sea Wave Project (JONSWAP) wave-spectral model.

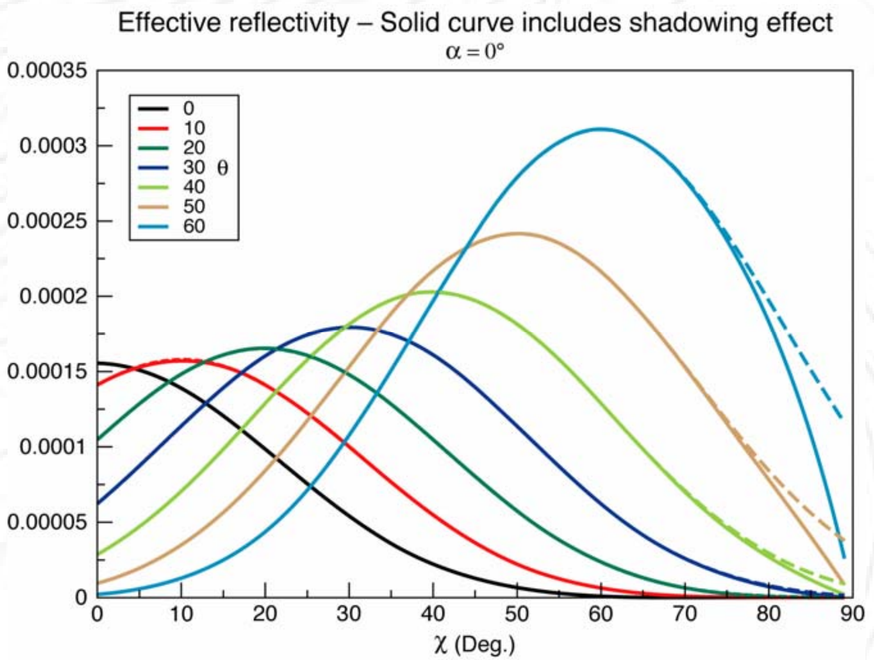
Shadowing (the fact that slopes on the back sides of the waves and deep in the troughs between waves are hidden from view) is fully accounted for.

The introduction of the solar term

The dependence on the wind speed of the total variance of the slope.

The bistatic reflectivity of a wind roughened water surface for a wind speed of 7 m/s and a wind fetch of 40 km.





The introduction of the solar term

The computation of the solar term requires the evaluation of transmittances at very large zenith angles. This increases the difficulty of fitting the line-by-line optical depths and consequently a dedicated fast transmittance model for the shortwave has been developed that uses a set of revised predictors.

The fast transmittance model in the shortwave can accurately reproduce line-by-line transmittances for solar zenith angles as large as 85^{o}.

The introduction of multiple scattering

RTTOV-88 features the introduction in the radiative transfer of multiple scattering by aerosols and clouds.

Since RTTOV-88 uses the polychromatic form of the radiative transfer equation, lower order approximations (e.g. two stream) for multiple scattering were found not amenable for implementation in RTTOV.

In RTTOV-88, we parameterize multiple scattering 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.

The introduction of multiple scattering

The parameterization used in RTTOV-88 (referred to hereafter as scaling approximation) does not require explicit calculations of multiple scattering (the radiative transfer equation for multiple scattering is identical to that in clear sky conditions) and consequently the computational efficiency of the code is retained.

In the scaling approximation the absorption optical depth, τ_a, is replaced by an effective extinction optical depth, $\tilde{\tau}_e$,

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

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 introduction of multiple scattering

The RTTOV-88 radiative transfer can include by default eleven basic aerosol components.

The database of optical properties required by the scaling approximation was generated for each IASI and AIRS channel using the Lorentz-Mie theory for spherical particles.

The microphysical parameters (i.e. size distribution, refractive indices) used in the database were obtained from the Optical Properties of Aerosols and Clouds (OPAC) software package (Hess et al. 1998).

All the aerosol components are characterized by a lognormal size distribution with the exception of the volcanic ash component for which a modified Gamma distribution was used.

The introduction of multiple scattering

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

The introduction of multiple scattering

The optical properties for water clouds are parameterized as functions of the effective radius and liquid water content.

To compute the regression coefficients, the Lorentz-Mie theory was used to generate a database of optical properties for five different cloud types using the microphysical properties obtained from the OPAC database assuming a modified Gamma size distribution.

Cloud type	Effective radius(μm)	LWC(gm^{-3})
Stratus (continental)	7.33	0.28
Stratus (maritime)	11.30	0.30
Cumulus (continental clean)	5.77	0.26
Cumulus (continental polluted)	4	0.30
Cumulus (maritime)	12.68	0.44

The introduction of multiple scattering

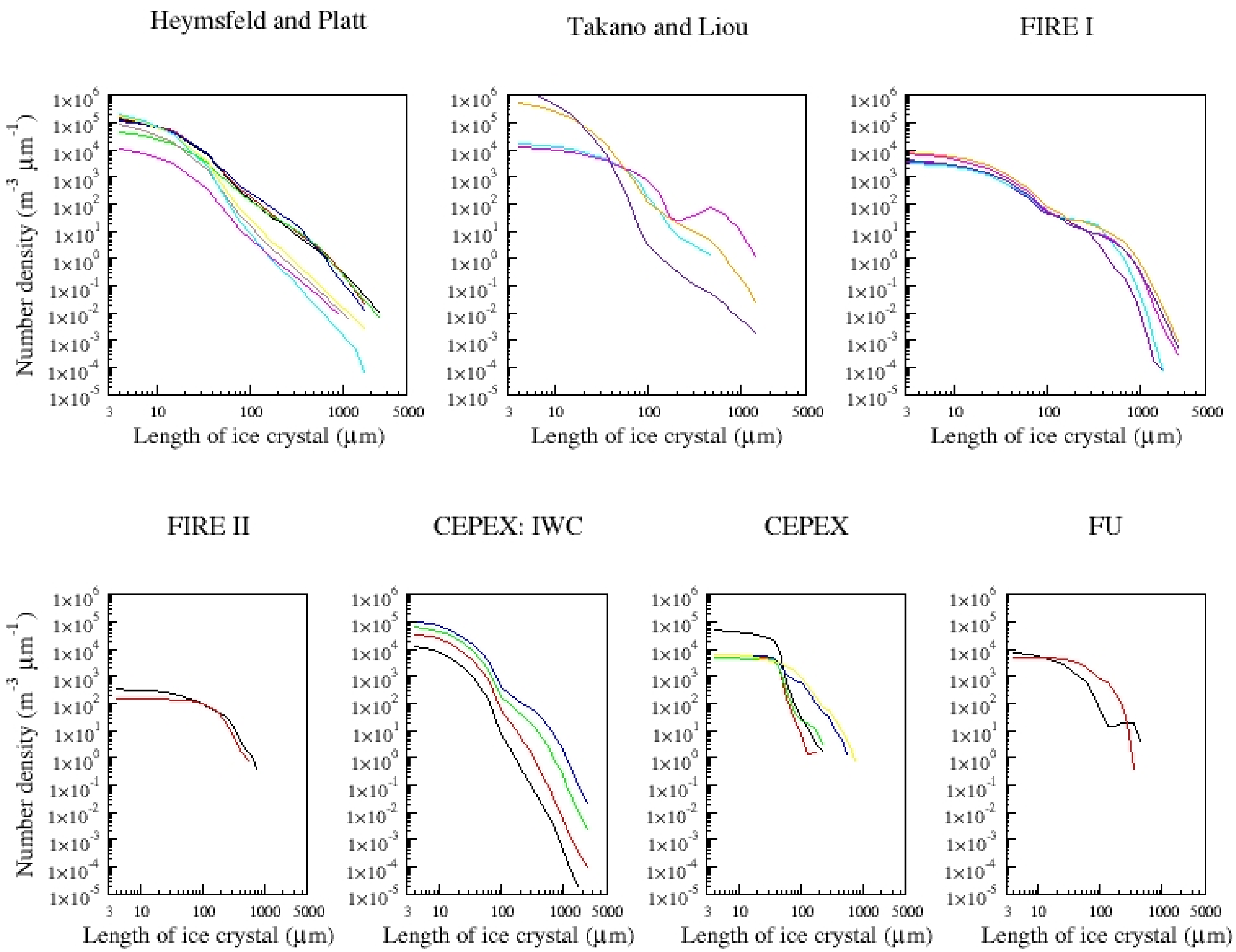
The optical properties for ice clouds are parameterized as functions of the generalized effective diameter of the ice crystal and ice water content.

In RTTOV-88, ice clouds can be considered either to be made of randomly oriented hexagonal ice crystals or randomly oriented ice aggregates.

The optical properties for hexagonal ice crystals were computed (Matricardi 2005) using the Geometric Optics (GO) method (Macke et al., 1996) and the T-matrix method (Kahnert 2004) whereas the optical properties for ice aggregates were computed using the finite-difference-time-domain and improved geometric optics method (Baran 2003).

To compute the regression coefficients, a database of optical properties for ice crystals was generated using the 30 size distributions prepared by FU (1996).

The introduction of multiple scattering



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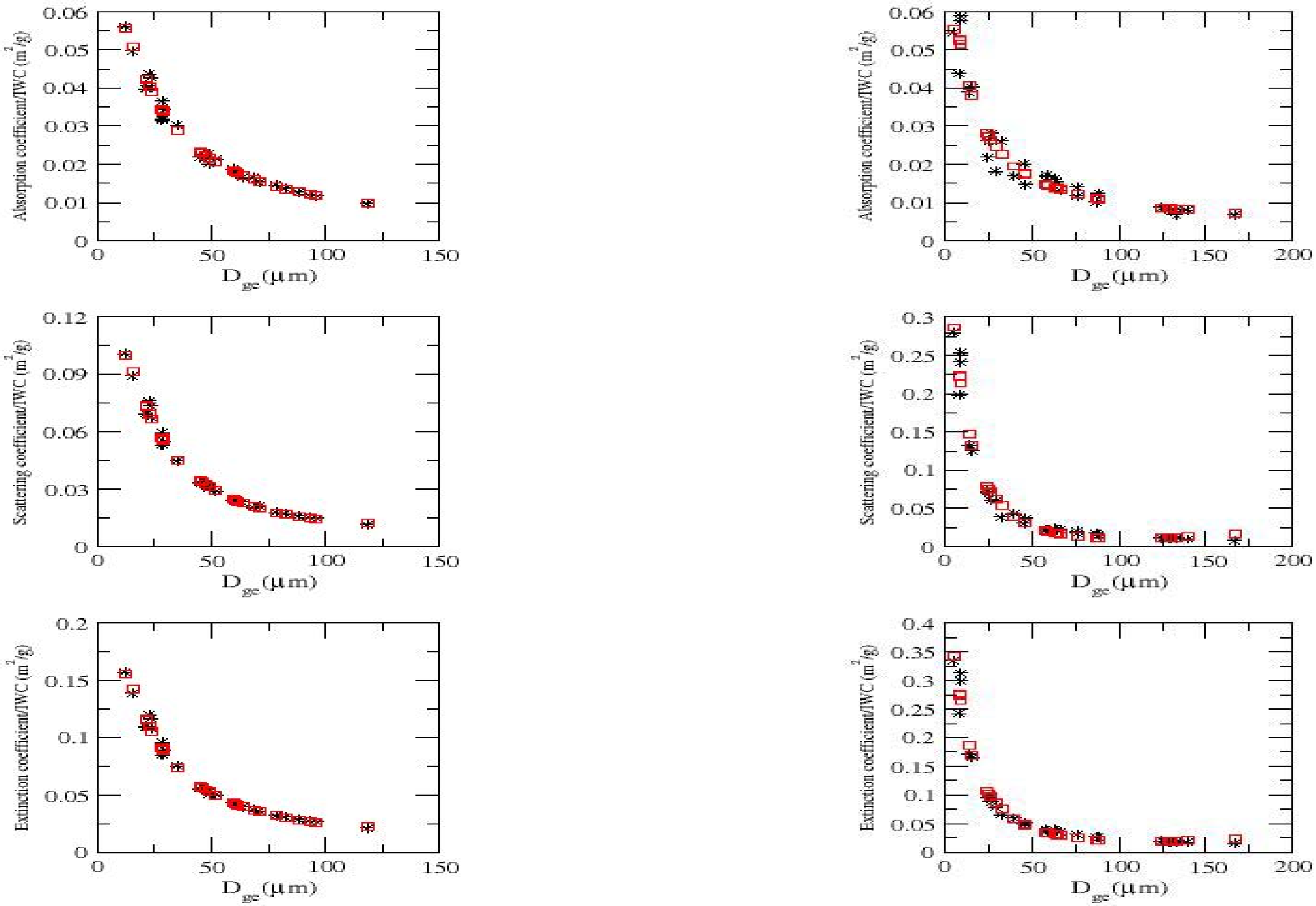

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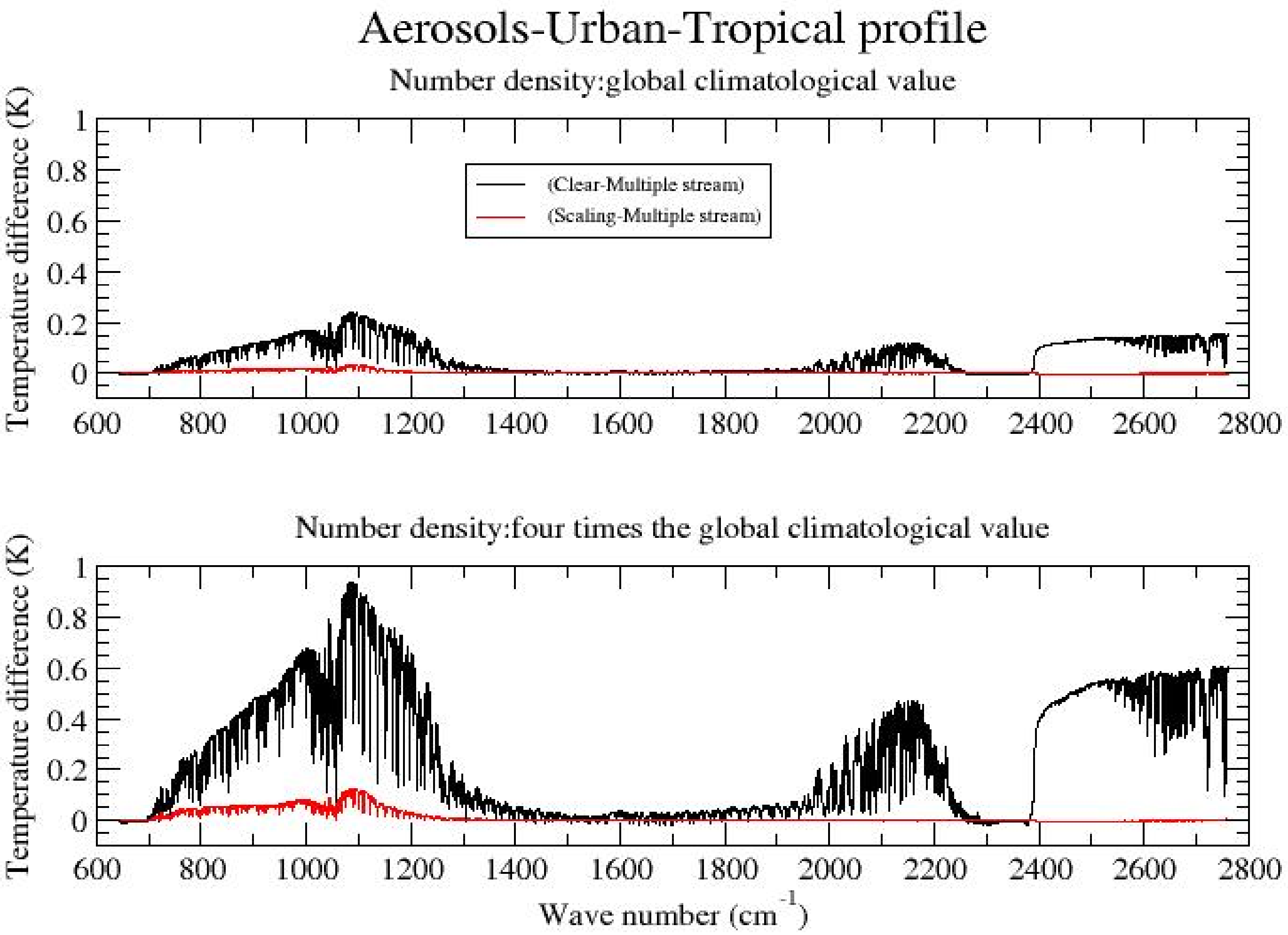

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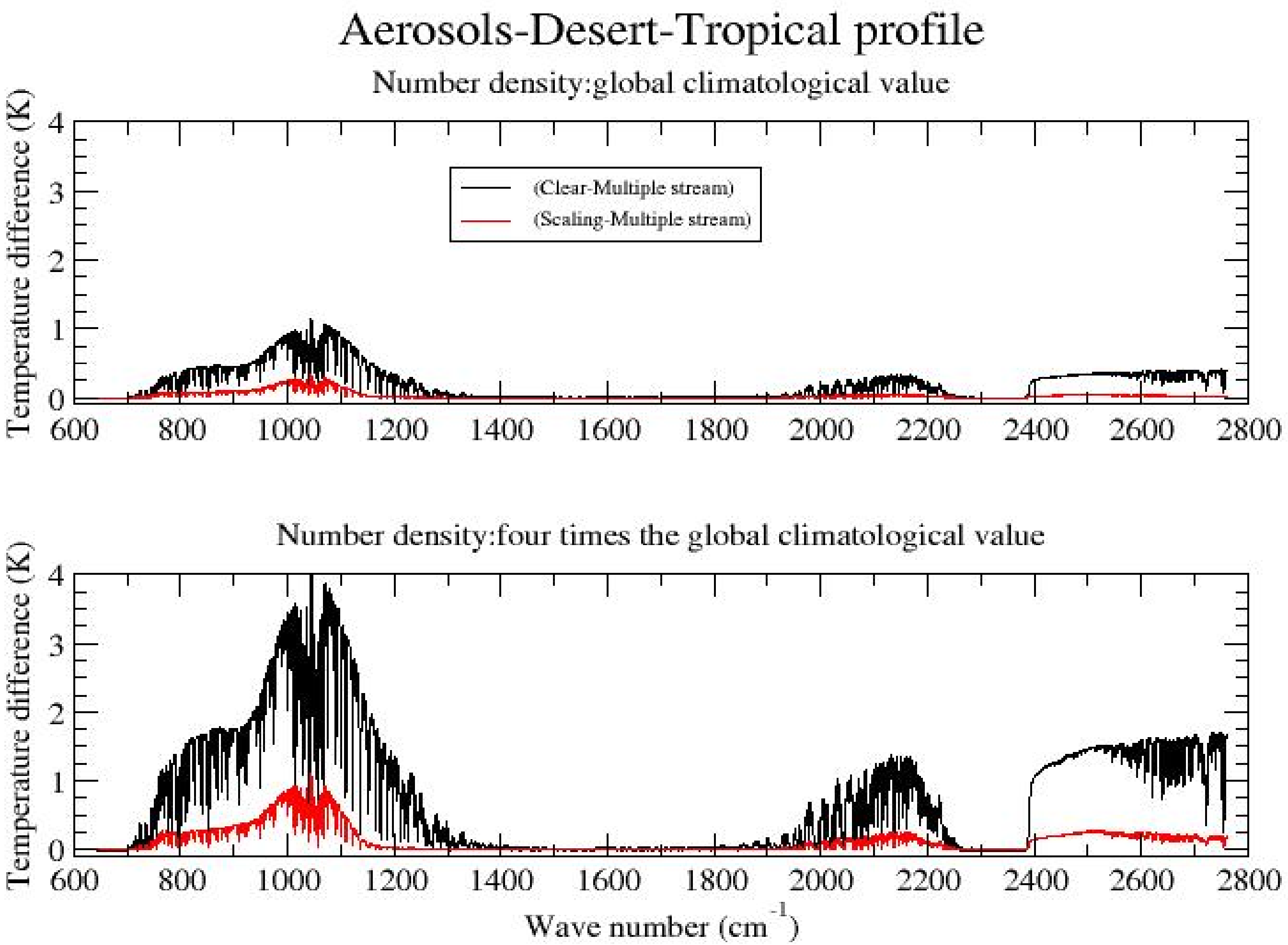

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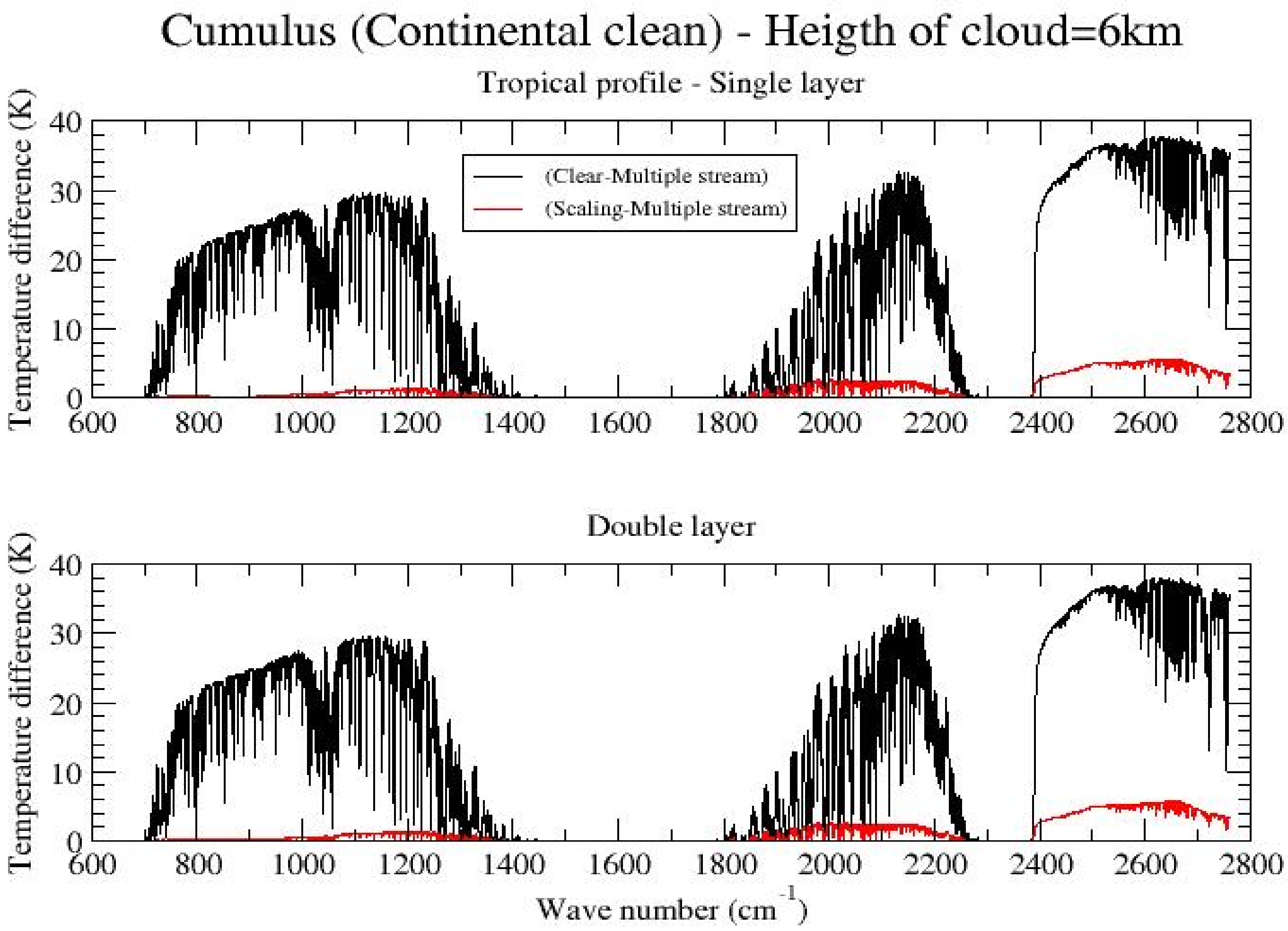

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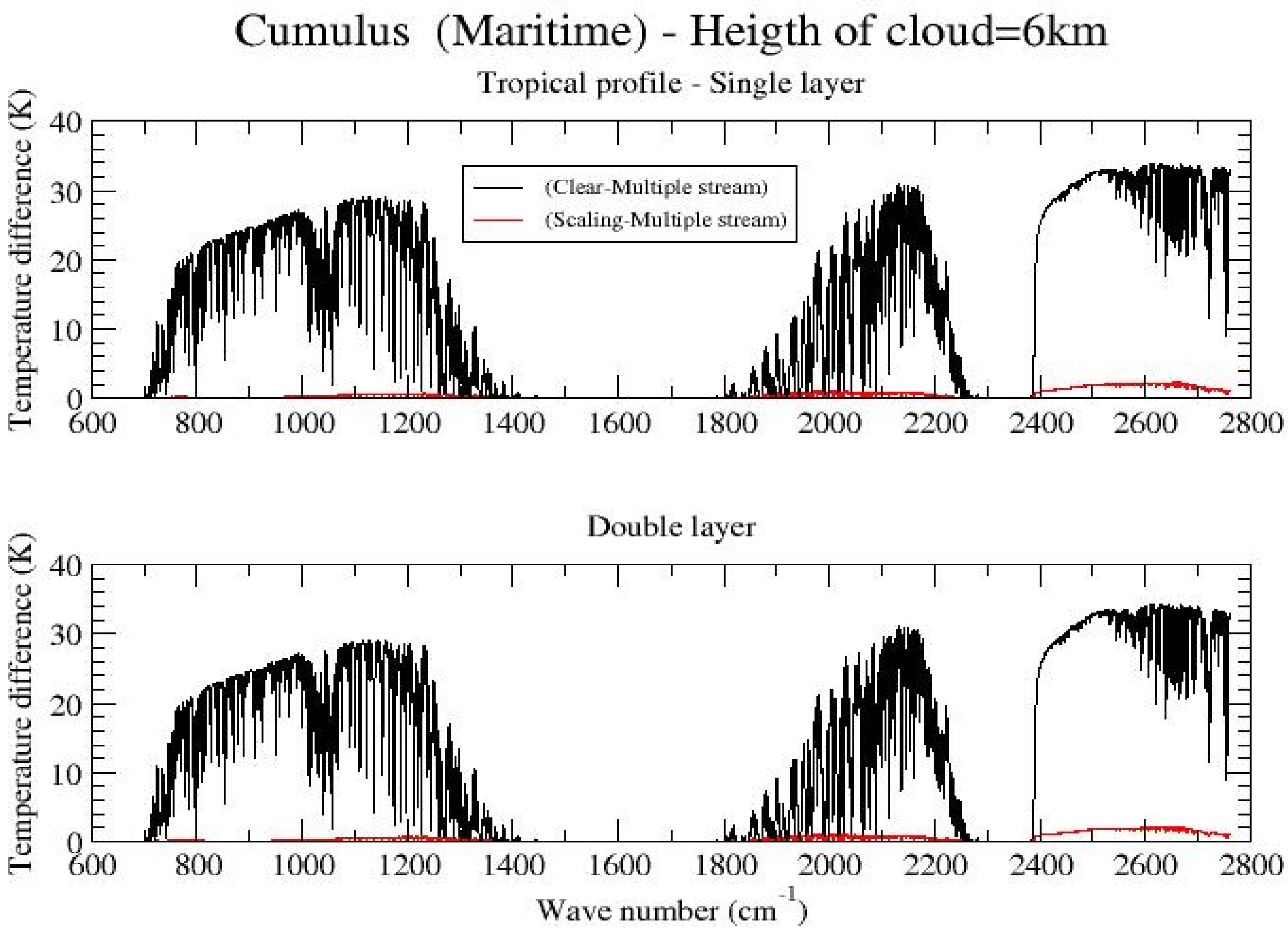

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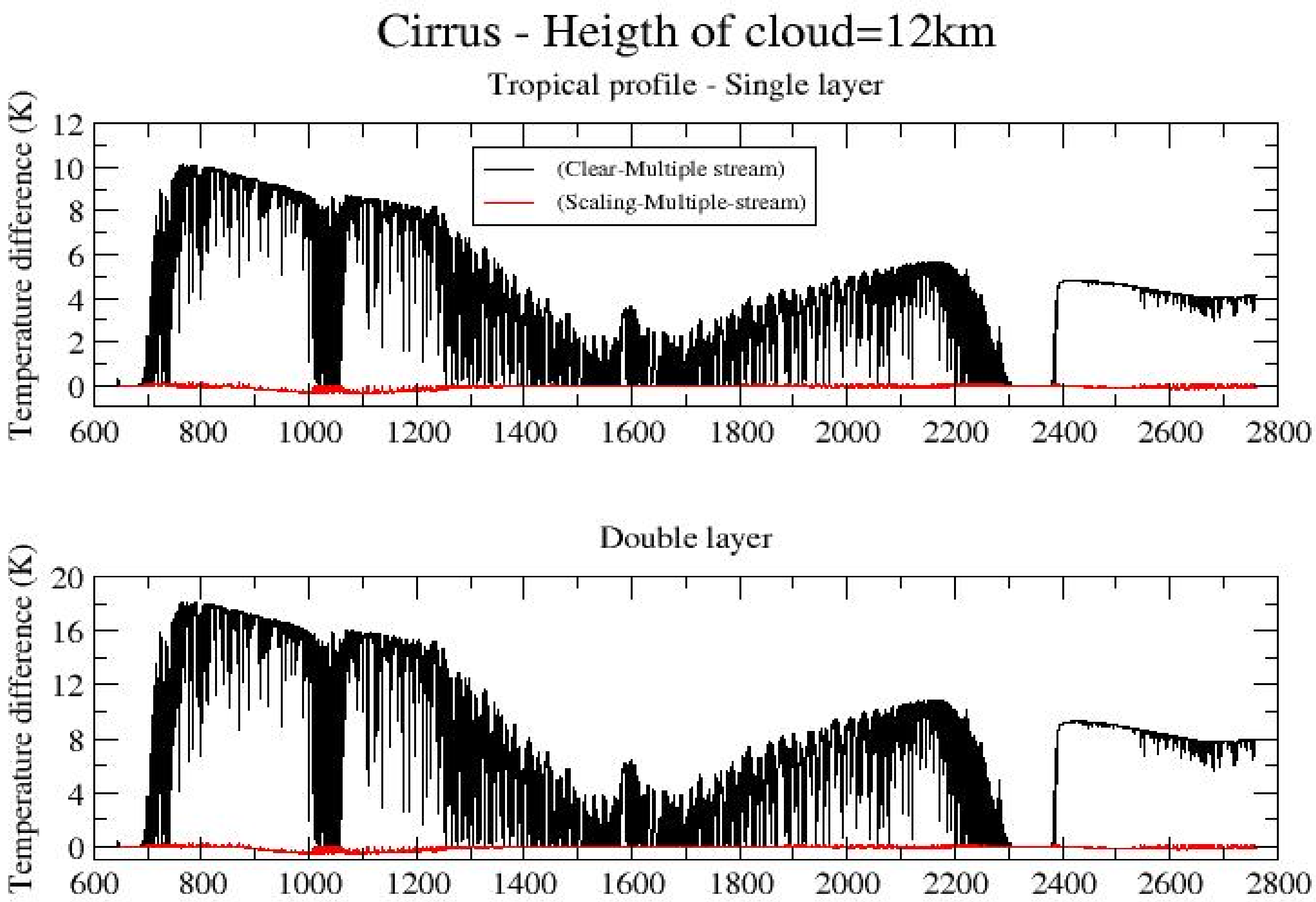

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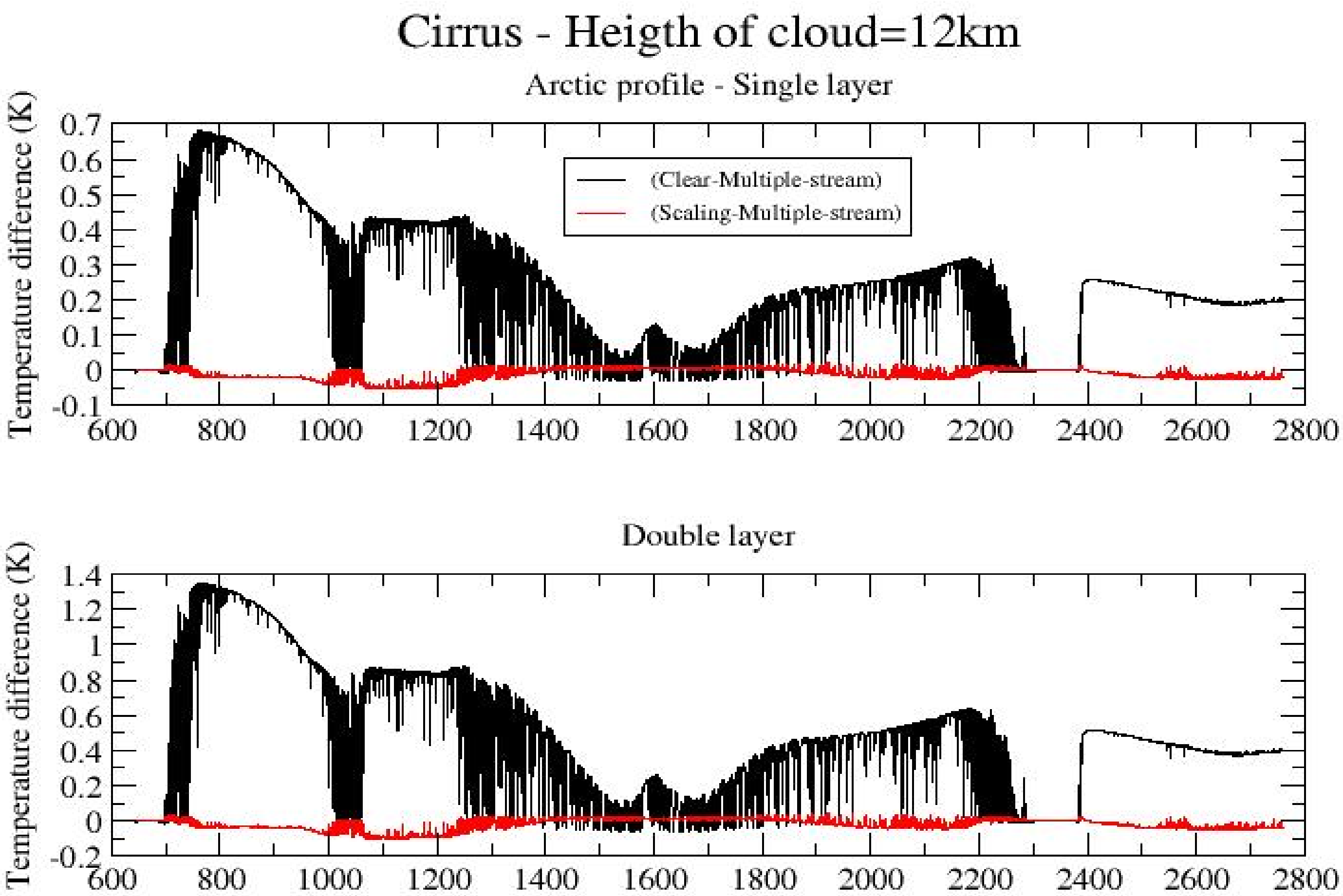

The stream method

To solve the radiative transfer for a partly cloudy atmosphere (i.e. horizontally non-homogeneous) RTTOV-88 uses a scheme (stream method) that divides the field of view (FOV) into a number of homogeneous columns.

Each column is characterized by a different number of totally overcast layers, hence different radiative properties, and contributes to a fraction of the total overcast radiance that depends on the cloud overlapping assumption.

In RTTOV-88 we use the maximum-random overlap and the total overcast radiance is obtained as the sum of the radiances from the single columns weighted by the column fractional coverage:

$$L^{total} = \left\{ \sum_{s=1}^{n_c} L^{overcast} (X_{s+1} - X_s) \right\} + L^{clear} (1 - X_{n_c+1})$$

The stream method