A new version of RTIASI (Matricardi 2003), the ECMWF fast radiative transfer model for the Infrared Atmospheric Sounding Interferometer (IASI), has been developed that features the introduction of multiple scattering by aerosols and clouds. In RTIASI, 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 (scaling approximation, Chou et al. (1999)). Since the scaling approximation does not require explicit calculations of multiple scattering, the computational efficiency can be increased in the radiative transfer equation for multiple scattering is identical to that in clear sky conditions: the absorption optical depth, $\tau_a$, replaced by the effective extinction optical depth, $\tau_e$, defined as

$$\tau_e = \tau_a + b \tau_s$$

where $\tau_s$ is the scattering optical depth and $b$ is the integrated fraction of energy scattered backward for incident radiation from above or below, $\tau_s = \int d\mu \phi(\mu)\mu d\mu$. It should be noted that the scaling approximation rests on the hypothesis that the diffuse radiance field is isotropic and can be approximated by the Planck function.

The RTIASI radiative transfer can include by default eleven basic aerosol components, five types of water clouds and eight types of cirrus clouds. The database of optical properties for aerosols and water droplets has been generated using the Lorenz-Mie theory for spherical particles taking the microphysical properties ascribed in the Optical Properties of Aerosols and Clouds (OPAC) software package (Hess et al. 1998). The aerosols optical properties can be computed for any mixtures of the default aerosol components that are assembled in ten aerosol types composed of pre-defined mixtures of basic components representative of average and extreme conditions for a range of climatologically important aerosols. For cirrus clouds, a composite database has been generated using the effect of non-spherical particles that is taken into account by scaling the optical depth by a factor derived by small crystals. The publicly available codes developed by Macek et al. (1996) and Kahnert (2004) have been used respectively. In either case, ice crystals have been assumed to have the shape of a hexagonal prism randomly oriented in space. For cirrus clouds we have used the Heymsfield and Platt (1984) size distribution. To account for the radiative effects due to the presence of small crystals, the Heymsfield and Platt distribution has been extrapolated to 4 µm using the method described in Mitchell et al. (1996). For all the aerosol components and cloud types included in default RTIASI, the optical properties have been obtained based on microphysical properties that, given their intrinsic variable nature, do not necessarily reflect an actual situation. For this reason, RTIASI allows the user to externally specify the values of the optical properties used in the radiative transfer. In figure 1 we plotted the absorption, scattering and extinction coefficient for the five most significant (in radiative terms) aerosol types. The same optical properties for the five water clouds included in RTIASI are illustrated in figure 2 whereas for cirrus clouds are plotted in figure 3 where a selection of different temperature ranges has been chosen.

The accuracy of the scaling approximation has been assessed by comparing approximate radiances to exact radiances computed using a 42-stream doubling-adding algorithm (Bauer 2002). Spectra have been computed for a tropical and arctic air mass. For each of the aerosol and cloud types included in RTIASI, we have considered vertical profiles representative of average and extreme conditions. The desert dust aerosol type has by far the largest impact on the radiance. Figure 5 shows that for the extreme condition case (tropical profile) the presence of desert aerosol in the tropical air mass can result in a reduction of the top of the atmosphere clear-sky radiance by 4 K in the thermal infrared and by 1.8 K in the short wave. The same figure shows that errors introduced by the scaling approximation are less than 1 K in the thermal infrared and less than 0.25 K in the short wave. For the other aerosol types, errors introduced by the scaling approximation never exceed 0.1 K. For all the water cloud types considered in RTIASI, errors are typically less than 1 K in the thermal infrared and below 4 K in the short wave. It should be noted that for the cases considered here the presence of a water cloud in a tropical or arctic air mass can result in a reduction of the top of the atmosphere radiance by 30 K in the thermal infrared and by up to 40 K in the short wave. Results for a low level cloud (Stratus Continental) and for a middle level cloud (Cumulus Continental Clean) are shown in figures 6 and 7 respectively. Finally, for the cirrus cloud type we found a remarkable agreement between approximate and references radiances. Some of the results are illustrated in figures 8 and 9 where it can be seen that for a tropical profile errors introduced by the scaling approximation never exceed 0.5 K whereas for an arctic profile errors are typically less than 0.1 K. This can be explained in the light of the fact that the phase function for ice crystals is characterized by a narrow and sharp forward peak that results in a very small value of the $b$ parameter and in the limit of $b \rightarrow 0$ we expect the reference and approximate radiances to converge since in this case the attenuation of the radiance is only due to absorption.

References