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A two-day working meeting was held on 27-28 April, 2015 at the Met Office Hq in Exeter with the objective to exchange information about the radiative transfer (RT) methodsfor the visible spectral range available in RTTOV and the fast RT method MFASIS developed at LMU Munich, to plan a comparison of these methods and discuss the feasibility of including MFASIS into future RTTOV versions. The meeting involved discussions between Roger Saunders, James Hocking, Christina Köpken-Watts and Leonhard Scheck. Moreover, a talk on MFASIS was given by Leonhard Scheck in the framework of the SAF RT annual meeting.

As reported by James Hocking, with the current version of RTTOV it is possible to compute visible cloudy radiances with very limited accuracy, which is useful only for qualitative applications like visualizing the cloud distribution of the model state. To address this shortcoming, for RTTOV-12 the 1D discrete ordinate method (DISORT) has been implemented, which allows for higher precision, albeit at considerably higher computational costs. To limit reflectance errors to a few percent, as desirable for applications like data assimilation, at least 16 DISORT streams must be used. For the DISORT implementation used at LMU Munich several CPU hours are required to compute a synthetic SEVIRI image of Germany from COSMO-DE model output. For similar accuracy requirements, generating visible synthetic satellite images is thus orders of magnitude slower than generating infrared images, and often too slow for operational purposes.

The Method for FAst Satellite Image Synthesis (MFASIS) developed at LMU Munich is an approach that seems to be well-suited to address this problem. MFASIS was originally developed as part of the PhD work of Pascal Frerebeau (supervised by Bernhard Mayer) and has since been improved significantly in terms of speed and accuracy. It is based on a reflectance look-up table computed with DISORT. To limit the size of the look-up table one has to choose a minimal set of parameters to describe the state of the atmosphere and the geometry. For MFASIS, the vertically integrated optical depths and vertically averaged effective particle radii for ice clouds and water clouds, the albedo, the zenith angles of the sun and the satellite and the difference of their azimuth angles are used as parameters. Although information about the vertical structure of the clouds (including the cloud top height) are not contained in these 8 parameters, they are sufficient to define the reflectance with an accuracy of a few percent. However, an 8-dimensional reflectance table with a sufficiently fine spacing of parameters values to avoid large interpolation errors would be tens of gigabytes in size.

To avoid tables of this size, a reflectance function is fitted to the DISORT results and instead of the reflectance itself only the coefficients of the reflectance function are stored in a table. The reflectance function involves a cosine series in the azimuthal angle and a power series in the cosine of the zenith angle, thereby allowing for a good representation of the directional variation of the reflectance. The variation of the reflectance function with the other parameters is taken into account by a number of coefficients, which are determined by a least squares fit to results calculated with DISORT. These coefficients are stored in 6-dimensional look-up tables with a total size of less than 100MB. The computation of the top of atmosphere reflectance requires only to calculate the six parameters, to obtain the coefficients by linear interpolation in the look-up tables and to evaluate the reflectance function.

Therefore the current, not yet fully optimized implementation of MFASIS is three orders of magnitude faster than DISORT with 16 streams.

The accuracy of the method was tested by generating synthetic satellite images for the 0.6um and 0.8um channels of the SEVIRI instrument from German Weather Service (DWD) COSMO-DE model states and comparing them to DISORT results computed with 32 streams. For a test period in June the root mean squared absolute reflectance error of MFASIS with respect to DISORT is about 10^{-2} for both channels and the mean relative reflectance error is about 5% for 0.6um and 3.5% for 0.8um. Speed and accuracy of the new method are sufficient for operational data assimilation and high-resolution model verification applications.

Only for scattering angles larger than 170^{o} (which occur in February/March and October/November in the COSMO-DE model domain) the rapid variation of reflectance with the particle size related to the backscattering glory reduces the accuracy and the errors increase by a factor of 3--4. This behaviour reflects a more fundamental problem that is not specific for MFASIS: In backscattering glory the reflectance depends sensitively on the effective droplet radius and the width of the droplet radius distribution. Current NWP models cannot provide reliable information on these parameters. Reduced accuracy for large scattering angles thus cannot be avoided, independently of the RT method.

The core routines of MFASIS are implemented in Fortran and complemented by a Python layer handling input/output and the computation of the MFASIS input parameters from the model output. The simple code structure should make it relatively easy to develop tangent linear and adjoint models for this method.
At the moment, MFASIS tables exist for the 0.6 and 0.8 micron SEVIRI channels

and contain only angles required for the COSMO-DE regions. Including more instruments and extending the table to a larger region should be feasible.

The overall conclusions of the meeting and work plan for the next steps were established as follows. It was agreed that MFASIS could be a useful addition to complement the visible scattering code already developed for RTTOV-12. In the framework of a second, longer visiting scientist mission in 2016 it would be useful to

- compare the performance and accuracy of MFASIS and RTTOV
- investigate how the input parameters of MFASIS are related to the ones already in use in RTTOV
- check how the RTTOV-12 interface could be extended to allow for a easier integration of MFASIS before the release of RTTOV-13

End of report