Generating synthetic visible satellite images with RTTOV

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Visible satellite images provide high-resolution information about the cloud distribution and cloud microphysical properties. This information is often complementary to the one that can be obtained from thermal infrared channels. Visible satellite images would thus be a promising type of observation for data assimilation (DA) and model evaluation. However, the importance of scattering and 3D effects in the visible spectral range hampered the development of a sufficiently fast and accurate forward operators. Only recently MFSAS, a fast radiative transfer (RT) method based on a look-up table (LUT) was implemented in RTTOV. The LUT is computed using the discrete ordinate method (DOM), an accurate 1D RT solver. Here we discuss MFSAS and a 3D extensions, report on experiments to replace the LUT by a neuronal network and show first DA results for the SEVIRI 0.6µm channel.

MFSAS: A FAST, LOOK-UP TABLE BASED METHOD FOR GENERATING VISIBLE SATELLITE IMAGES

Standard 1D RT solvers: too slow for operational DA and high-resolution model evaluation. MFSAS (Method for Fast Satellite Image Simulation): fast, look-up table based RT method

Basic strategy
- Describe relevant atmospheric properties and geometry by a minimal parameter set
- Compute look-up tables (LUTs) with DISORT for all parameter value combinations
- Compress LUT using Fourier series representation
- Compute reflectance = calculate parameters from model output, interpolate in tables

Reflectance table generation
- DOM 1D RT calculations for idealised scenes: Three homogeneous clouds at fixed heights, defined by only 4 parameters per column: optical depths and reflective particle radii for water and ice clouds
- Vertical structure of clouds (e.g. cloud top height) has only weak influence on V/E/NR reflectances
- 4 more parameters for albedo and geometry → 8-dimensional LUT with a size of about 8GB

Large LUT is problematic for online operator, causes cache misses
- Lossy compression of LUT
- Small-scale features in $R_b(k, 0, 0-\phi, 0)$ mix compression difficulty → use scattering angle as $R_b(g, 0, 0-\phi, 0)$ is smooth function for $
leq 90$°

18 Fourier terms describe $R_b(g, 0, 0-\phi, 0)$ well → LUT reduced to 21MB LUT (factor 390)

Mean error with respect to DOM for a 11-day period in June 2012.

Accuracy & Speed
- Error with respect to DOM < SEVIRI calibration error
- This error does not include 3D effects (see below) and assumed a fixed water vapor profile
- MFSAS is 4 orders of magnitude faster (only RT), total run time (including e.g. computation of optical properties) is reduced by 2 orders of magnitude

3D RADIATIVE TRANSFER EFFECTS: CLOUD TOP INCLINATION

Most important 3D RT effect: Cloud top inclination (=increased information content)


REPLACING THE LOOK-UP TABLE BY A NEURONAL NETWORK

Main motivation: Adding more dimensions to the LUT to take more RT effects or more particle species (aerosols) into account

LUT size will explode, generating the LUT (uncompressed 8GB) will become too expensive

Machine learning approaches: It could be sufficient to compute only a small fraction of the data required for the LUT approach

Popular choice: Multilayer Perceptron = (deep) feed forward neural network (NN)

Key issue: Is a sufficiently accurate NN as fast as the LUT-based MFSAS?

Preliminary result: A NN with 5 x 26 nodes (359K parameters) trained for 10h with 1% of the uncompressed 8GB LUT is sufficiently accurate and the computational effort for its evaluation is comparable to the one of MFSAS

The tangent linear code is about 30%, the adjoint code about 60% slower than the nonlinear code.

APPLICATION: ASSIMILATING SEVIRI 0.6µm IMAGES USING COSMO/KENDA

Assimilation experiments with the local ensemble transform Kalman filter (LETKF) implemented in DWD's Kilometre-scale ensemble data assimilation system (KENDA) and the COSMO model ($\Delta x= 2.8km$, domain covering Germany) for two strongly convective summer periods in 2016.

Settings: Non-operational (4 members), multiplet, additive inflation + RTPP, but no latent heat nudging, no MODIS, assimilation window 1h. Experiments with conventional obs., compared to conv. obs. = SEVIRI 0.6µm images.

Main results: Cloud cover is strongly improved, beneficial impact on precipitation and humidity. Impact tests for > 3h (we did not yet perform longer forecasts).

PUBLICATIONS:
- Scheck, Frenzel, Bures-Schieltz Meyer (2016): A fast radiative transfer method for the simulation of visible satellite imagery, JQSRT, 175, 54-67
- Scheck, Westermann, Mayer (2015): Efficient methods to account for cloud top inclination and cloud overlap in synthetic visible satellite images, JQSRT, 35, 683-688
- Scheck, Westermann, Bach: Assimilating visible visible images for convective scale weather prediction: A case study, in preparation

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