A FAST FORWARD OPERATOR FOR THE ASSIMILATION OF VISIBLE SEVIRI OBSERVATIONS IN KENDA-COSMO
Leonhard Scheck1, Tobias Necker1, Bernhard Mayer2, Martin Weissmann1
1) Hans-Ertel-Centre for Weather Research, Data Assimilation Branch, LMU München, Germany
2) Meteorologisches Institut, Ludwig-Maximilians-Universität München, Germany

MOTIVATION
- km-scale models can explicitly represent convection
- need to incorporate frequent, high-resolution observations by remote sensing instruments
- Genostationary satellite observations have a high spatial and temporal resolution and provide information on atmospheric humidity, temperature and clouds
- Interpretation of VIS and near-infrared (NIR) channels of the SEVIRI instrument on Meteosat Second Generation (MSG)
- Complementary to IR information (mainly sensitive to clouds, low clouds clearly visible), snow convection earlier than radar, NIR sensitive to water phase
- VIS/NIR observations are used operationally mainly because no operator is available. Challenge: Scattering makes radiative transfer too slow.

RADIATIVE TRANSFER
MFASIS (Method for Fast Satellite Image Simulation)
Standard 3D RT solvers are too slow for operational DA
Operational 3D RT solvers take only SEVIRI second and fourth channel
- new, 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 table

Reflectance table generation
- DISORT calculations for idealized scenes. Two homogeneous clouds at fixed heights
- Only 4 parameters per column to describe clouds: optical depths and effective particle radii for the water and the ice cloud
- Vertical structure of clouds is ignored (Cloud top height has only weak influence on reflectance)
- 6 parameters for albedo and geometry
- 8-dimensional LUT with a size of about 12GB

Large LUT: problematic for online operators, cache misses limit performance → need to compress LUT
Problematic: Small scale features in R(θ, φ, a)

Reflectance table compression
- Reflectance as function of sun and satellite zenith angles and the difference of the azimuth angles: Expanded function, rainbow causes small scale changes in reflectance in large parts of the table → high resolution in θ, φ, a, R(θ, φ, a) required everywhere
- It is more useful to consider reflectance as a function of the zenith angles θ, φ and the scattering angle α (R(θ, φ, a) for a constant, smooth, symmetric function that is well-approximated by a few discrete Fourier series terms:

\[ R(θ, φ, a) = \sum_{m} \sum_{n} \frac{C_{m,n}(θ, φ)}{(2m+1)(2n+1)} \cos(mθ) \sin(nφ) \]

- Not all θ, φ, α combinations are valid (conditions: m = 0, n > 0, \(\theta < 90°\), \(\phi < 180°\), \(\alpha < 180°\))
- Fourier coefficients \(C_{m,n}(θ, φ)\): Obtained by least squares fit to 12GB DISORT LUT
- Coefficient table size: 100MB for \(\theta > 9\), \(\phi < 85°\), \(\alpha < 45°\)
- Rainbow affects only values around 140°
- Use adaptive grid
- Further reduction of table size by factor 3 ↔ 33MB
- Fits fairly well for \(\theta > 9°\), \(\phi < 85°\), \(\alpha < 45°\)
- Glory is a fundamental problem (a>170°)

Accuray & Speed
- For \(N_θ = N_φ = 4\) the fit error is in general negligible and the error with respect to DISORT is caused by ignoring the vertical cloud structure.
- Assuming that the error between 1D DISORT and 3D Monte Carlo is not correlated with the error between DISORT and MFASIS, the mean relative reflectance error with respect to 3D Monte Carlo should be similar for MFASIS (~6%) and DISORT (~5%)
- MFASIS is more than 3 orders of magnitude faster

FROM 1D TO 3D: SHADOWS AND CLOUD TOP INCLINATION
Work in progress. Include fast approximations for the most important effects not present in 1D RT results.

SYSTEMATIC DIFFERENCES BETWEEN OBSERVATIONS AND MODEL
The fast forward operator is used to quantify systematic differences between SEVIRI observations and model forecasts (master thesis Tobias Necker).

Goal: Identification of model and operator deficiencies

Latest development: Cloud overlap scheme for reflectance (compatible to random/maximum overlap scheme for transmissivity in COSMO RT code)

Results: Bias is strongly reduced, shape of reflectance histogram is very similar for model and observation. Work in progress. Consistent settings for all channels.

DATA ASSIMILATION EXPERIMENTS
KENDA setup for SEVIRI assimilation experiments:
- 1-hourly LETKF assimilation, analysis ensemble with 40 members
- 20 member ECMWF EPS boundary condition time-lagged = 40 BCS
- Spin-up phase: several cycles with conventional observations only
- Assimilation of 600nm SEVIRI observations (observation error assumed to be 0.2, no vertical localization) and/or conventional obs.
- Superoverlay with 3px radius
- Preprocessing:
  - Conventional observations are not able to reduce reflectance error
  - With SEVIRI: Ensemble is drawn towards observations, RMSE reduced
  - Larger ensemble and more spread improve results
  - Independent GNSS humidity observations show reduced error and bias
- Challenges: Strongly non-Gaussian first guess departures