Hans-Ertel-Centre for Weather Research
DATA ASSIMILATION BRANCH

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Deutscher Wetterdienst

A FAST FORWARD OPERATOR FOR THE ASSIMILATION OF VISIBLE SEVIRI OBSERVATIONS IN KENDA-COSMO

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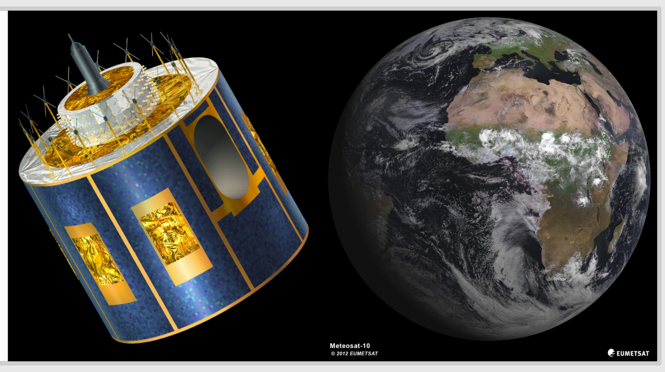
MOTIVATION

- Km-scale models can explicitly represent convection → Need to incorporate frequent high resolution observations by remote sensing instruments
- Geostationary satellite observations have a high spatial and temporal resolution and provide information on atmospheric humidity, temperature and clouds
- Here we focus on visible (VIS) and near-infrared (NIR) channels of the SEVIRI instrument on Meteosat Second Generation (MSG)
- Complimentary to IR information (mainly sensitive to clouds, low clouds clearly visible), show convection earlier than radar, NIR sensitive to water phase
- VIS/NIR observations are not used operationally mainly because no operator is available. Challenge: Scattering makes radiative transfer is too slow.



RADIATIVE TRANSFER

MFASIS (Method for FAst Satellite Image Simulation)
Standard 1D RT solvers are too slow for operational DA
Operator should take only a few seconds / satellite image
→ new, fast, look-up table based RT method

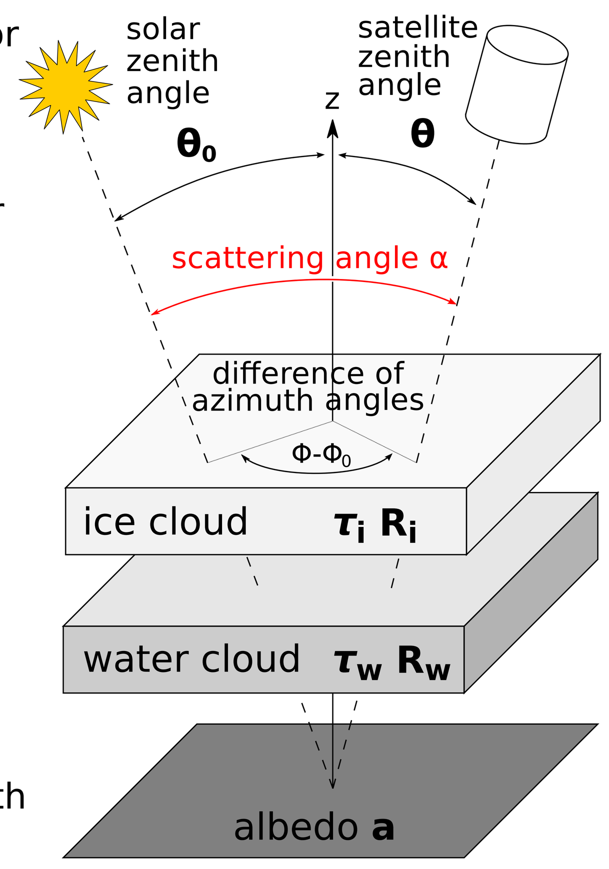
Basic strategy

- 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 tables

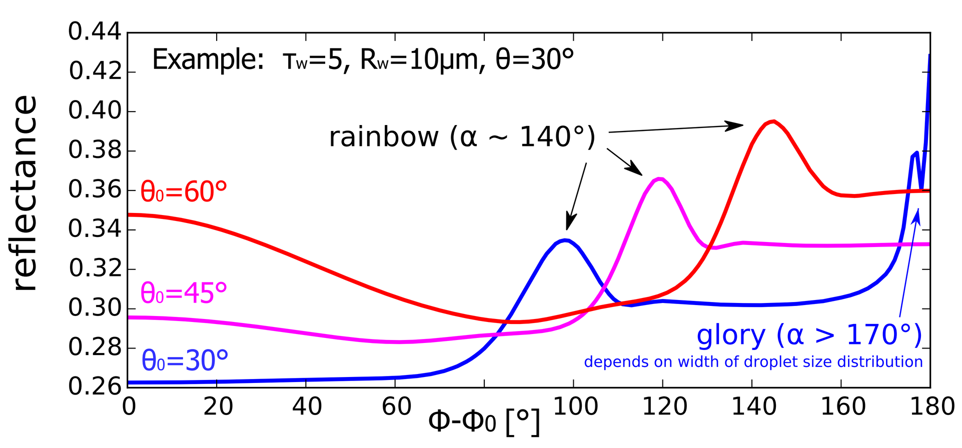
Reflectance table generation

- DISORT calculations for idealised 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)
- 4 parameters for albedo and geometry

→ 8-dimensional LUT with a size of about 12GB



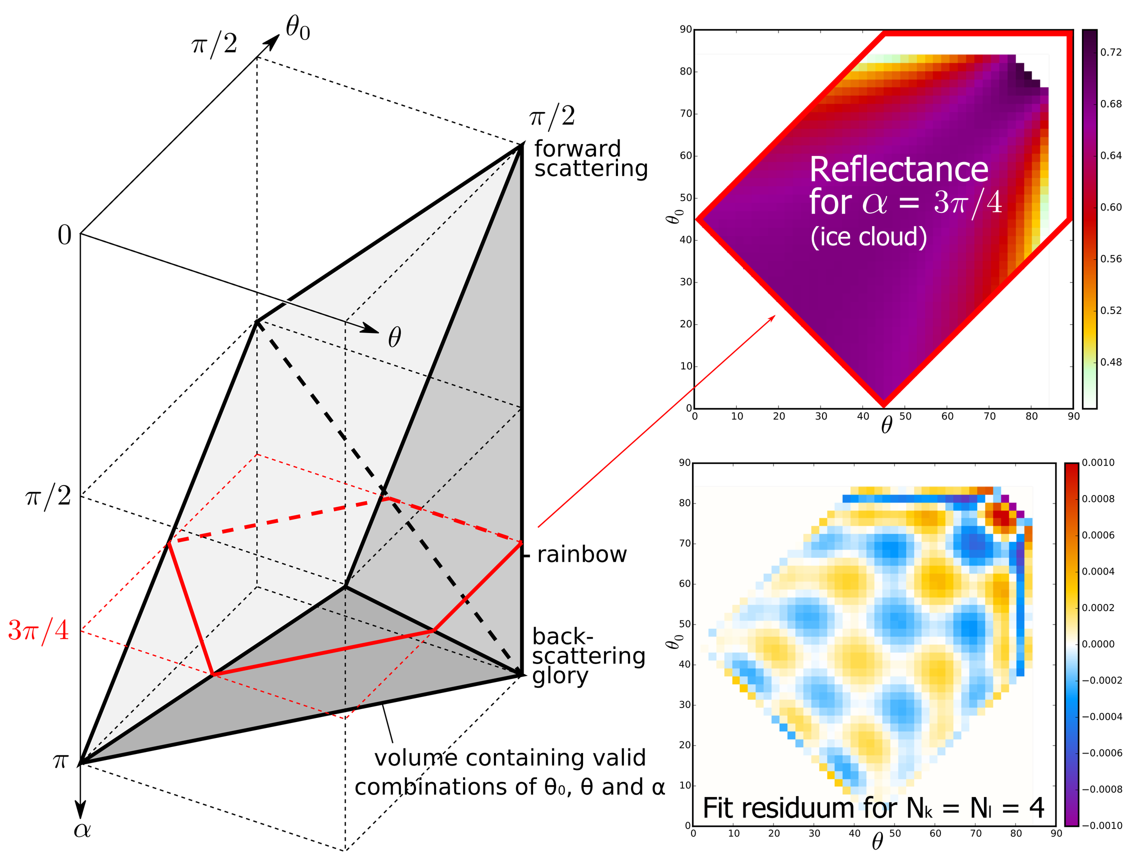
Large LUT: problematic for online operators, cache misses limit performance → need to **compress LUT**
Problematic: Small scale features in R(θ₀, θ, Φ-Φ₀)



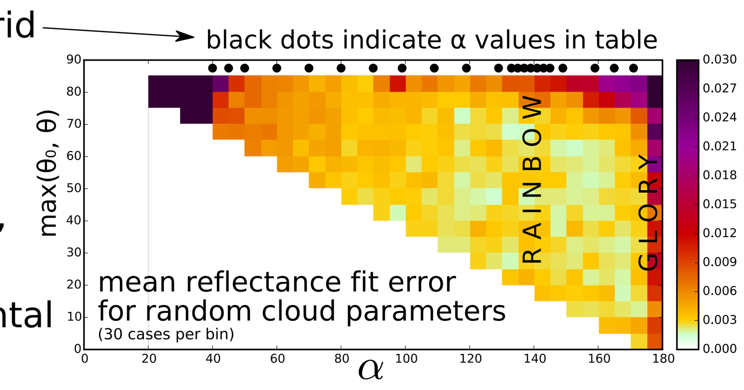
Reflectance table compression

- Reflectance as function of sun and satellite zenith angles and the difference of their azimuth angles: Complicated function, rainbow causes small scale changes in reflectance in large parts of the table → high resolution in θ_0, θ, Φ-Φ₀ required everywhere...
- It is more useful to consider reflectance as a function of the zenith angles θ_0, θ and the scattering angle α
- R(θ_0, θ) for α=const : Smooth, symmetric function that is well-approximated by a few discrete Fourier series terms:

$$R(\theta_+,\theta_-) = \sum_{k=0}^{N_k-1}\sum_{l=0}^{N_l-1}\left[C_{k,l}\cos(k\theta_+) + S_{k,l}\sin((k+1)\theta_+)\right]\cos(l\theta_-) \qquad \theta_+ = \theta+\theta_0,\ \theta_- = \theta-\theta_0$$

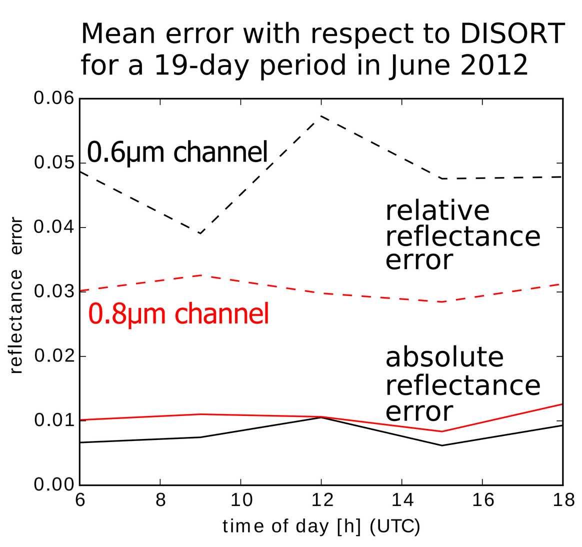


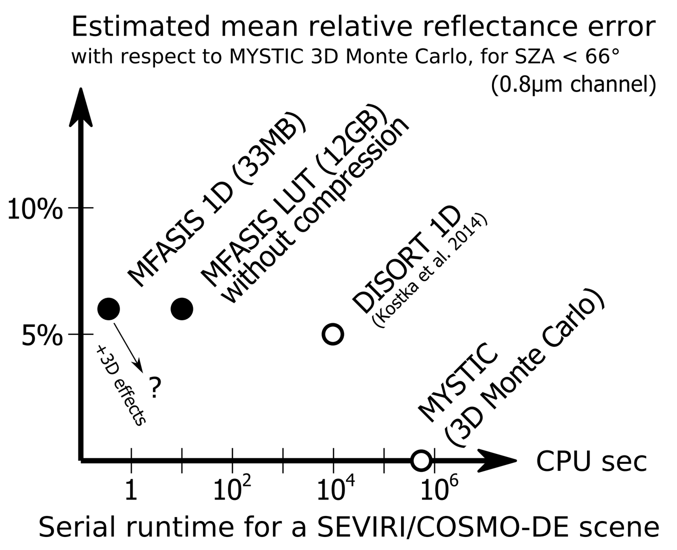
- Not all θ_0, θ, α combinations are valid (conditions: $\pi-\alpha<\theta+\theta_0$, $\pi-\alpha>|\theta-\theta_0|$) → somewhat complicated shape of θ-θ₀-domain
- Fourier coefficients $C_{k,l}$, $S_{k,l}$: Obtained by least squares fit to 12GB DISORT LUT
  → Coefficient table size: 100MB for $N_k = N_l = 4$
- Rainbow affects only α values around 140°
  → use adaptive α grid
  → further reduction of table size by factor 3 → 33MB
- Fits fails for θ_0>85°, θ>85°, α<40°
- Glory is a fundamental problem (α>170°)



Accuracy & Speed

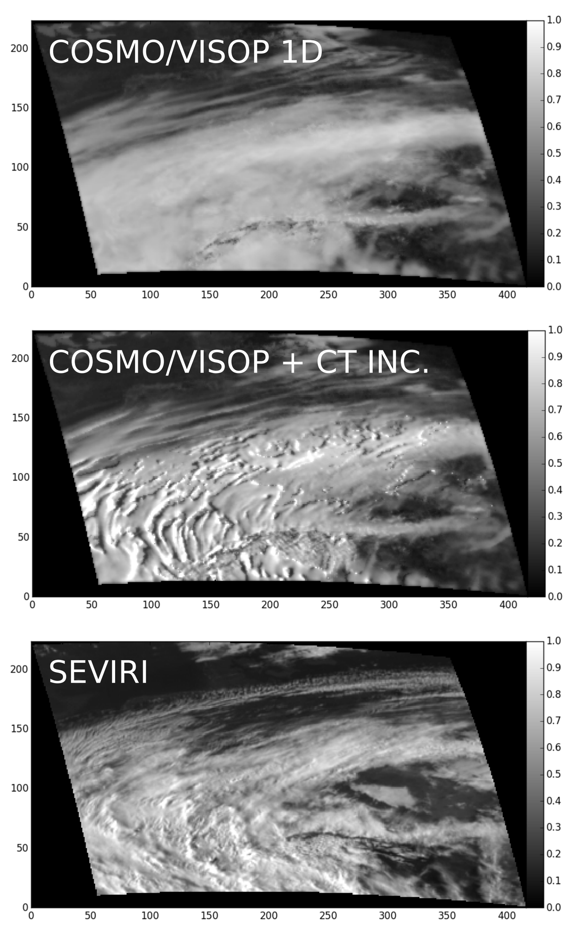
- For $N_k = N_l = 4$ the fit error is in general negligible and the error with respect to DISORT is caused by ignoring the vertical cloud structure.
- Assuming that the error between 1D DISORT and 3D Monte Carlo is not correlated with the error between DISORT and MFASIS, the mean relative reflectance **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**

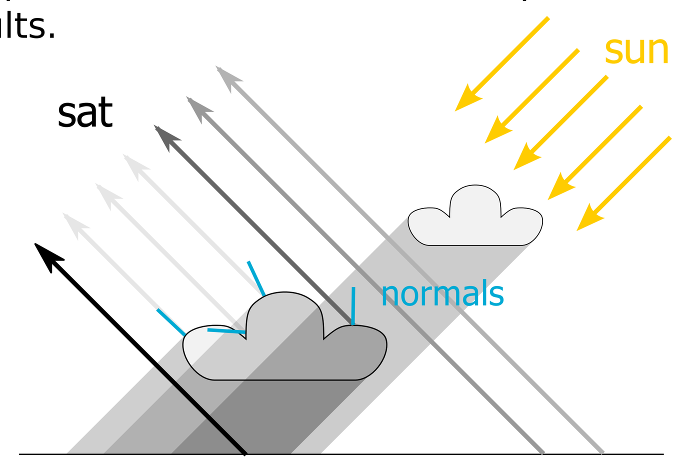




FROM 1D TO 3D: SHADOWS AND CLOUD TOP INCLINATION

Work in progress: Include fast approximations for the most important effects not present in 1D RT results.





Inclination of cloud tops:
- Fit plane to cloud top surface def. by optical depth 1, use sun & sat. angles with respect to the plane
- simple & cheap, large effect
- Still missing in implementation: Diffuse flux → shadows too dark...

Cloud shadows on ground:
- Compute reduced direct radiance, take diffuse flux into account

→ effective albedo for ground shadows

Publication: Scheck, L. and Frerebeau, P. and Buras, R. and Mayer, B., 2015, A fast radiative transfer method for the simulation of visible satellite imagery, Journal of Quantitative Spectroscopy and Radiative Transfer, submitted.

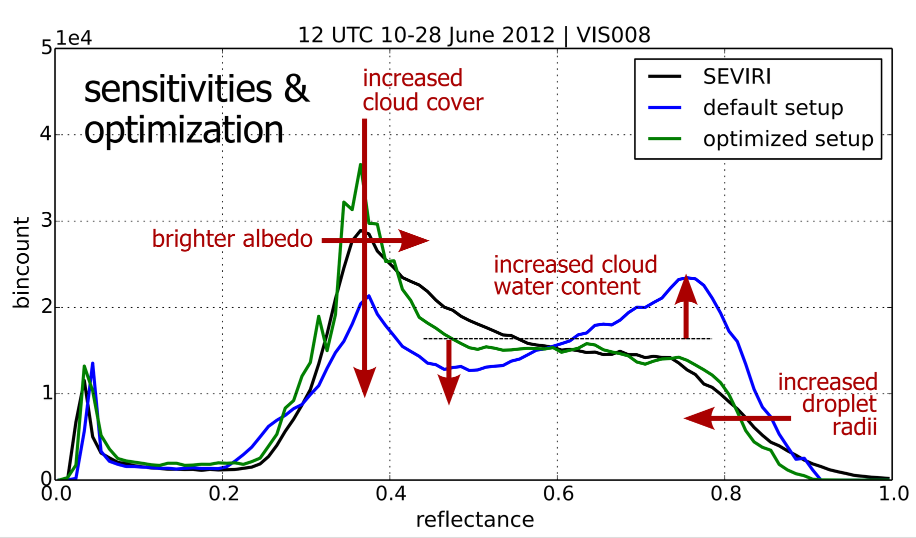
SYSTEMATIC DIFFERENCES BETWEEN OBSERVATIONS AND MODEL

The fast forward operator is used to quantify systematic differences between SEVIRI observations and operational COSMO-DE forecasts (master thesis Tobias Necker).

Goal: Identification of model and operator deficiencies

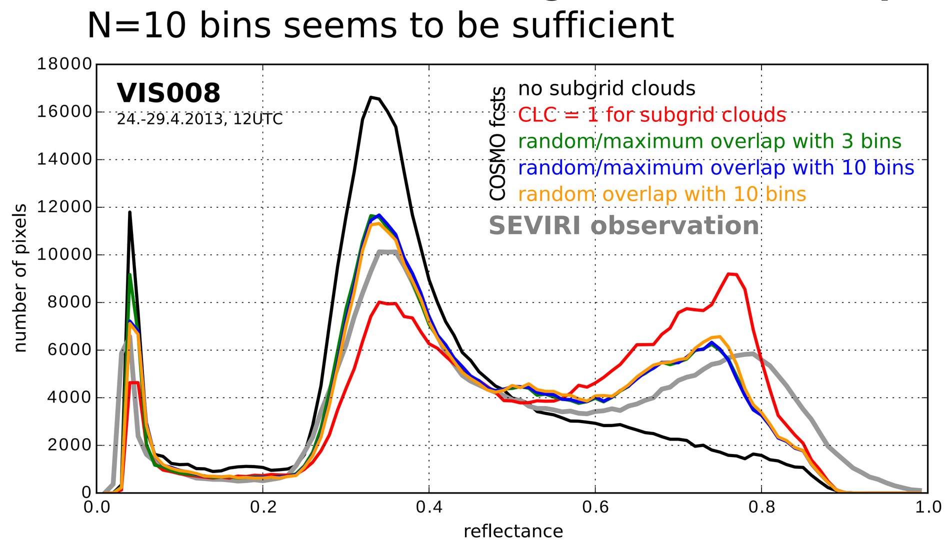
Latest development: Cloud overlap scheme for reflectance (compatible to random/maximum overlap scheme for transmittance in COSMO RT code)

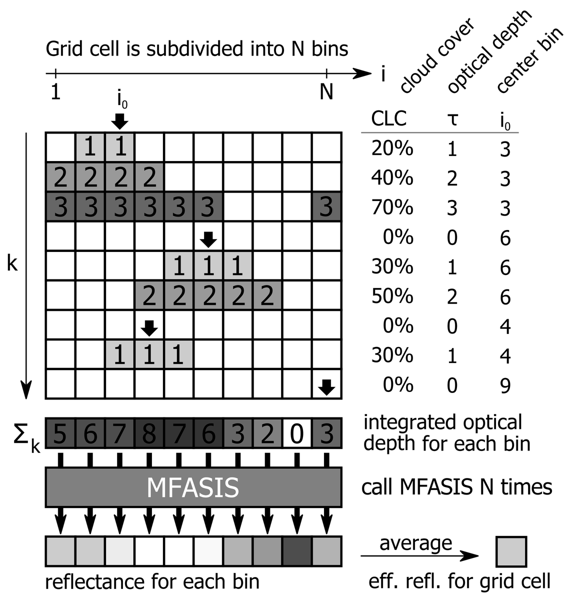
Results: Bias is strongly reduced, shape of reflectance histogram is very similar for model and observations. Work in progress: Consistent settings for all channels.



Random/maximum subgrid cloud overlap

N=10 bins seems to be sufficient





DATA ASSIMILATION EXPERIMENTS

KENDA setup for SEVIRI assimilation experiments:
- 1-hourly LETKF assimilation, analysis ensemble with 40 members
- 20 member ECMWF EPS boundary conditions (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.
- Superobbing with 3px radius

Preliminary results:
- Conventional observations are not able to reduce reflectance error
- With SEVIRI: Ensemble is drawn towards observations, RMSE reduced
- Larger ensemble or relaxation to prior spread improve results
- Independent GNSS humidity observations show reduced error and bias
- Challenge: Strongly non-Gaussian first guess departures