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COSMO/KENDA EXPERIMENTS USING VISIBLE SATELLITE OBSERVATIONS

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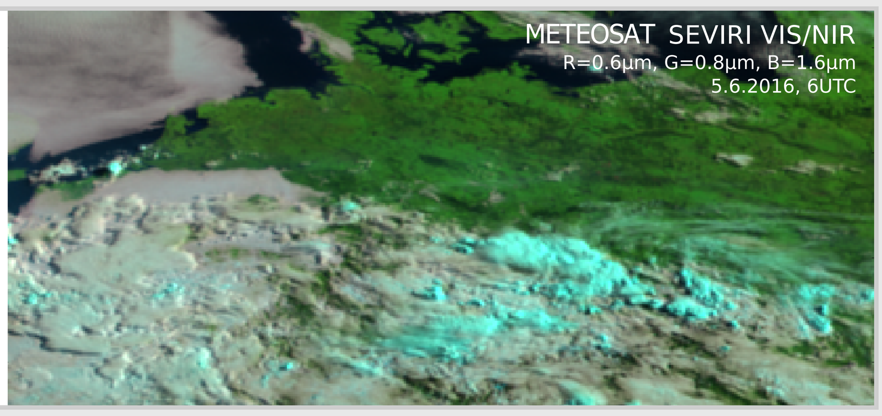
MOTIVATION

- **Visible (VIS) and near-infrared (NIR) satellite** images provide information on **cloud distribution and cloud properties**
- **High spatial resolution** (MODIS 250m, Himawari8, GOES-16, MTG 500m) and/or **high temporal resolution** (minutes)
- Complementary to IR information (mainly sensitive to clouds, low clouds clearly visible, IR-opaque ice clouds often transparent)
- Well-suited for high-resolution model evaluation and data assimilation, but no sufficiently fast and accurate forward operator was available.
  Challenge: Multiple scattering dominates and makes radiative transfer (RT) complicated and slow (1D RT method DISORT: CPU-hours / image)

→ **Development of fast VIS/NIR forward operator** that is sufficiently accurate for model evaluation and data assimilation



VIS/NIR FORWARD OPERATOR

MFASIS (Method for FAst Satellite Image Simulation)

Standard 1D RT solvers: too slow for operational DA and high-resolution model evaluation.
→ new, fast, look-up table based RT method

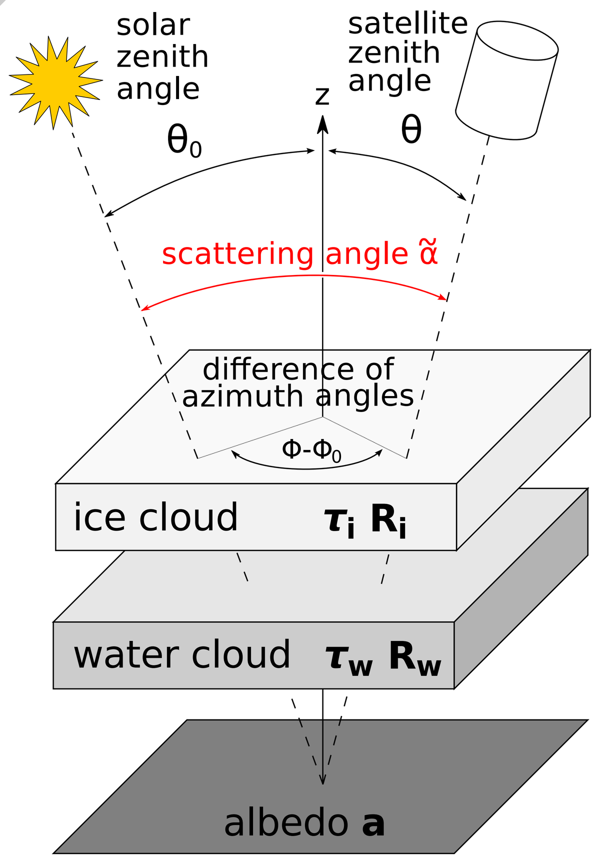
Basic strategy

- 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 1D RT calculations for idealised scenes: Two homogeneous clouds at fixed heights, defined by only 4 parameters per column: optical depths and effective particle radii for water and ice clouds
- Vertical structure of clouds (e.g. cloud top height) has only weak influence on VIS/NIR reflectances
- 4 more parameters for albedo and geometry

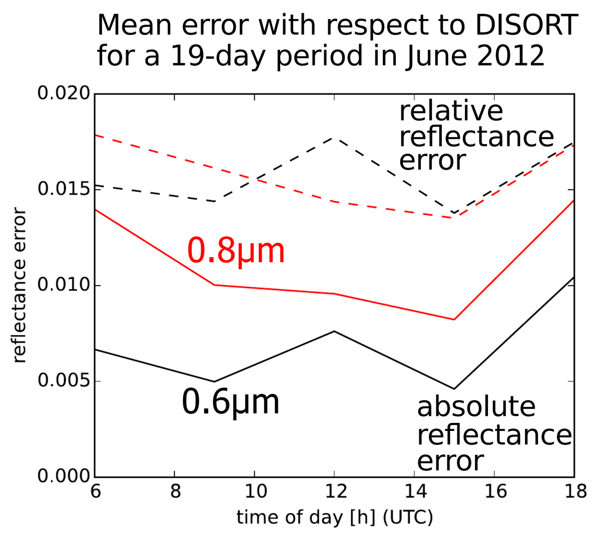
→ 8-dimensional LUT with a size of about **8GB**



lossy compression of LUT
(truncated Fourier series)
→ LUT reduced to 21MB

Accuracy & Speed

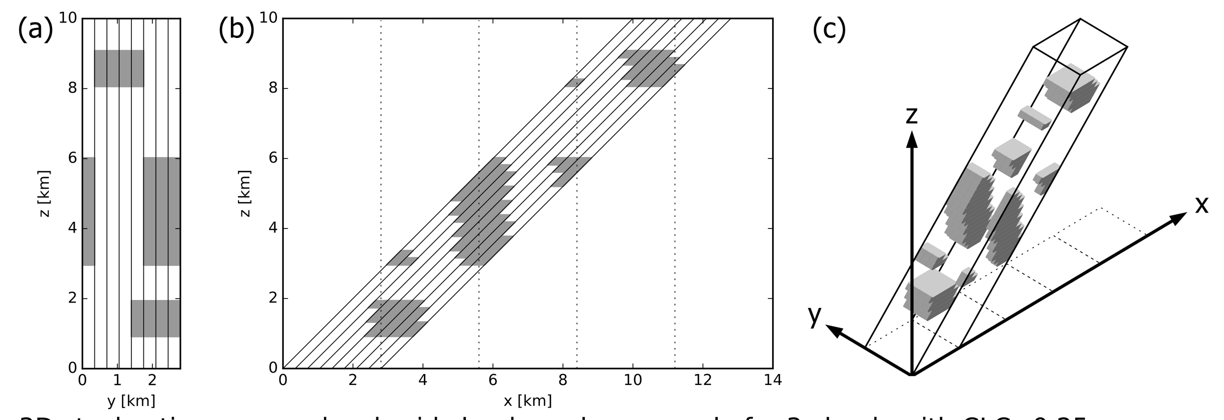
- **Error with respect to DISORT < SEVIRI calibration error**
- Does not include 3D effects...
- **MFASIS is ~10^4 times faster**



Integration of MFASIS into RTTOV (DWD NWP-SAF contribution)

- Work is under way at DWD and MetOffice (supported by HErZ-DA) and should be finished soon...

A STOCHASTIC CLOUD OVERLAP SCHEME ACCOUNTING FOR THE SLANT VIEWING ANGLE



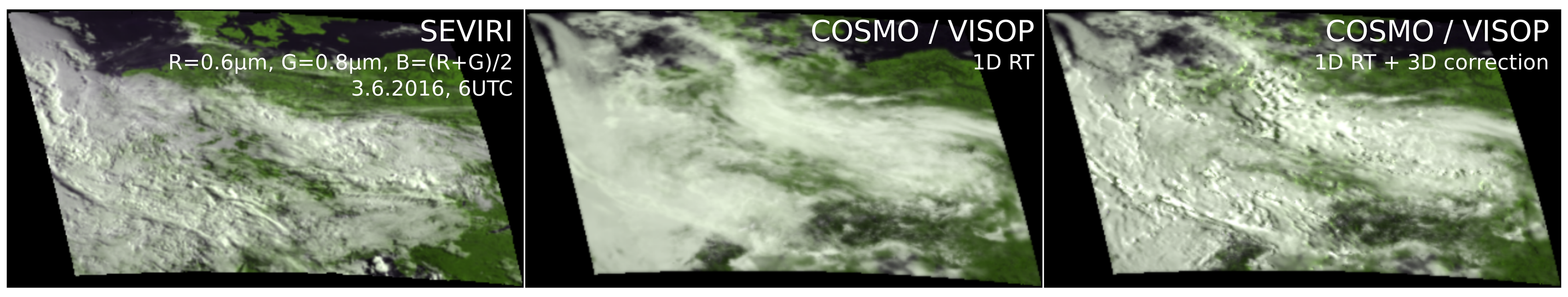
3D stochastic max.-rand. subgrid cloud overlap example for 3 clouds with CLC=0.25.

- Parameterized **subgrid clouds** are important at km scales
- Internal RT code makes assumptions about **overlap** of the clouds (e.g. random, random-maximum) that apply for **vertical columns.**
- **Slant satellite viewing angle:** Tilted column cloud cover is not the same as for vertical column (cloud sides become visible)
- This effect is taken into account in a new **stochastic 3D cloud overlap scheme** (not more expensive than 2D schemes)

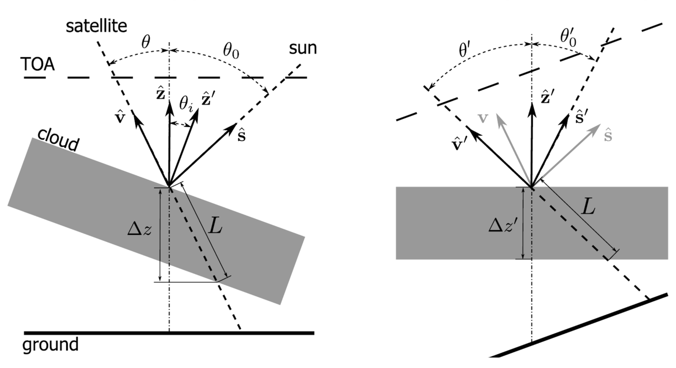
Evaluation: MSG / COSMO-DE images computed with the new maximum-random 3D resemble more those computed with random 2D than those computed with maximum-random 2D

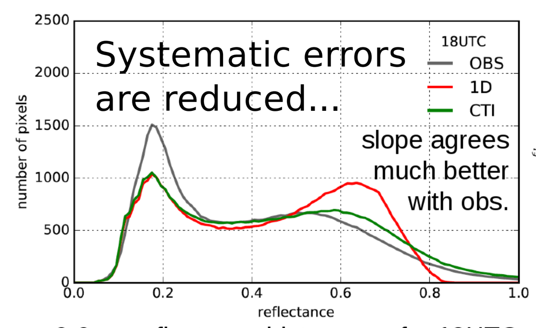
A COMPUTATIONALLY EFFICIENT 3D RT CORRECTION

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

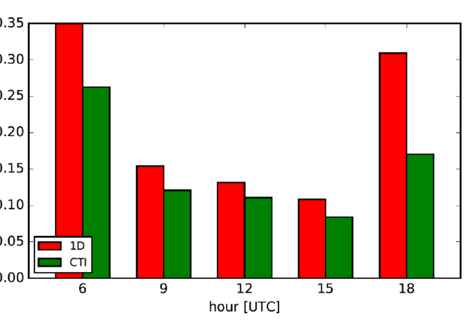


Efficient approximation: Solve quasi-1D problem in rotated frame of reference, transform back.





0.6mu reflectance histograms for 18UTC



area between obs.& model histogram

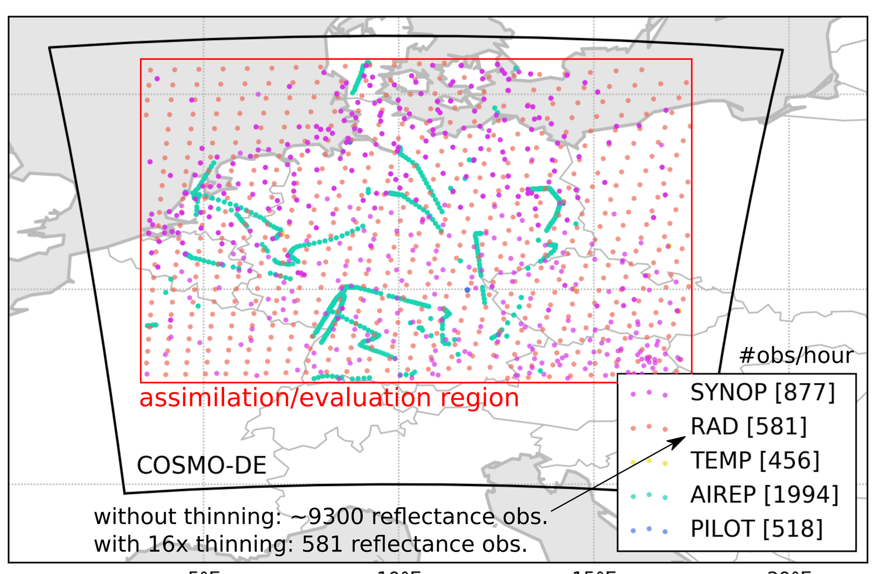
$$R_{3D}(\alpha,\theta,\theta_0,A,\tau,\theta_i,\phi_i) \approx R_{1D}(\alpha,\theta',\theta'_0,A\sigma^{-1},\tau\sigma)\times\sigma_0 \quad \theta' \text{ and } \theta'_0\text{: functions of } \alpha,\theta,\theta_0,\theta_i,\phi_i; \quad \sigma=\frac{\cos\theta'}{\cos\theta}, \quad \sigma_0=\frac{\cos\theta'_0}{\cos\theta_0}$$

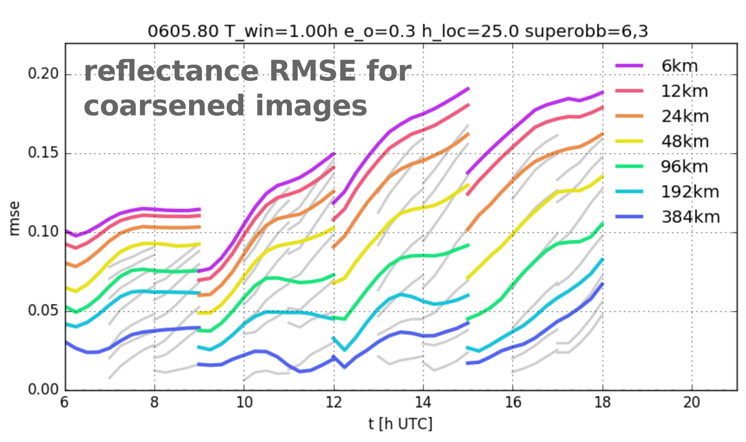
Publications: Scheck, Frerebeau, Buras-Schnell, Mayer (2016): A fast radiative transfer method for the simulation of visible satellite imagery, Journal of Quantitative Spectroscopy and Radiative Transfer, 175, 54-67.
Scheck, Hocking, Saunders (2016): *A comparison of MFASIS and RTTOV-DOM*, NWP-SAF visiting scientist report, http://www.nwpsaf.eu/vs_reports/nwpsaf-mo-vs-054.pdf
Scheck, Weissmann, Mayer (2018): Efficient methods to account for cloud top inclination and cloud overlap in synthetic visible satellite images, Journal of Quantitative Spectroscopy and Radiative Transfer, accepted.

ASSIMILATION EXPERIMENTS WITH COSMO/KENDA

ASSIMILATION SETUP

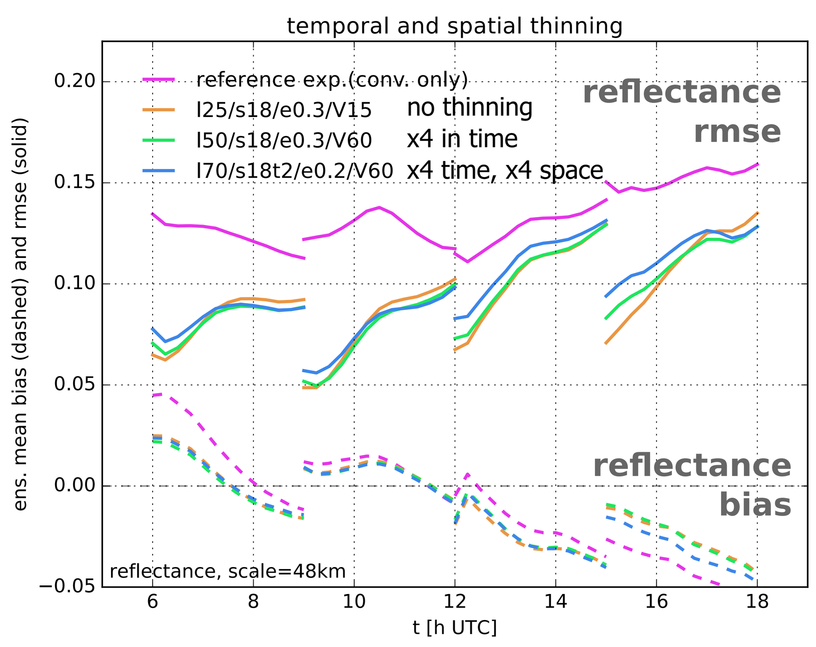
- Codes: KENDA (LETKF) + COSMO-DE (2.8km grid)
- Case: 5 June 2016, reflectances assim. for t >= 6UTC
- Conventional obs. or conv. obs. + 0.6mu reflectances
- 40 members, 1h assimilation window
- Additive and multiplicative covar. inflation + RTPP
- conventional observations: lh=80km localization, ~4000 active obs. per hour
- reflectances: error 0.2 - 0.3, superobbing 18-48km, no vertical localization, hor. loc. 25-100km





For information on assimilation of visible satellite images at DWD **see talk by Lilo Bach...**

Brightness: Probability of cloudiness →
= fraction of ensemble members exceeding reflectance 0.3. White pixels = all members have a cloud, black pixels = no members has a cloud.
Blue shading: observed clouds →
(observed reflectance of pixel > 0.3)



Average relative change in RMSE with respect to "conv. only" experiment for 3h forecasts