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DWD

Evaluation of ICON's model cloud fields using simulated and observed satellite images

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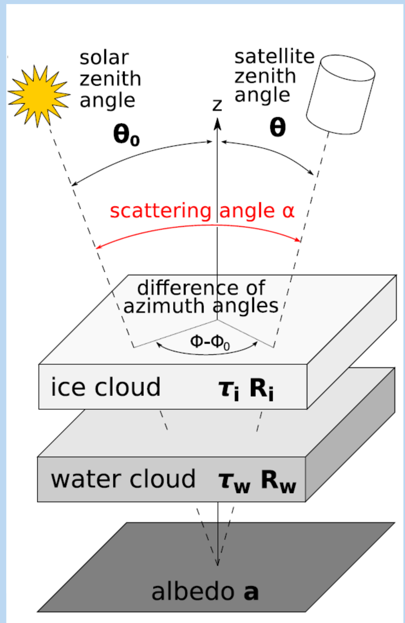
This work aims at a systematic uncertainty quantification of MFASIS, a fast forward operator for simulating visible satellite images, and its application to evaluating ICON model clouds through comparison of simulated and observed reflectances. Understanding such cloud-related biases is an important step for developing a situation-dependent bias correction and for paving the way to an assimilation of visible satellite channels in the global ICON model. Experiments on assimilating SEVIRI's 0.6µm channel in the convection-resolving ICON-LAM have demonstated its value by improving the representation of clouds as well as cloud-related processes (see L. Bach et al., 2p.01). We present how different resolutions in observations and NWP models are handled and provide first results of ICON model biases in certain cloud situations.

1 Visible satellite image simulation using RTTOV-MFASIS

Method for FAst Satellite Image Synthesis

1.1 General concept



MFASIS (Scheck et al., 2016) is a fast 1D radiative transfer model based on a lookup table (LUT) approach. MFASIS assumes a simplified atmospheric profile described by a minimal parameter set:

- satellite viewing geometry (θ, θ_0, α)
- homogeneous water cloud with optical depth τ_w and effective radius R_w
- homogeneous ice cloud with optical depth τ_i and effective radius R_i
- surface albedo a

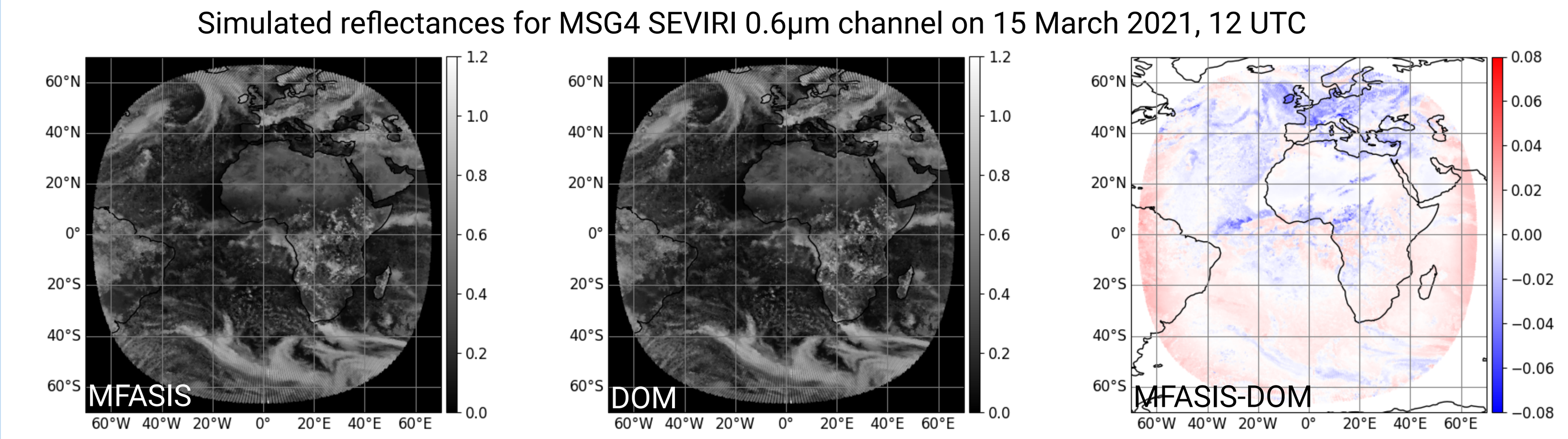
The reflectance LUTs are precomputed for all parameter combinations using the Discrete Ordinate Method (DOM) implementation available in RTTOV. The LUTs are compressed using a Fourier series decomposition, with 18 Fourier coefficients describing R(θ, θ_0, α) well and reducing the required memory from ~8GB to ~20MB.

→ MFASIS is fast approximation for the more accurate, but slower DOM.

- Direct as well as TL/AD/K models available in RTTOV since version 12.2 with subsequent updates
- For more details see RTTOV-13 Science and Validation Report and https://nwp-saf.eumetsat.int
- Major upgrade planned: Neural-network version for MFASIS (see L. Scheck, 2.05)

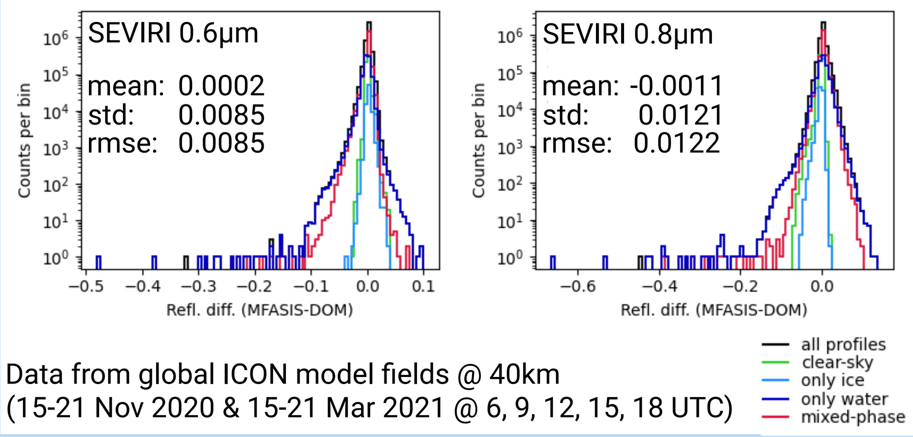
1.2 Accuracy and performance

Simulated reflectances for MSG4 SEVIRI 0.6µm channel on 15 March 2021, 12 UTC



- Runtime for Meteosat disk (single-threaded on Intel Xeon @ 2.6 GHz processor): ~13h DOM (16 streams) versus ~2min MFASIS (further speed-up with upcoming NN version)
- Generally very good agreement between MFASIS and DOM
- MFASIS-DOM reflectance differences
  - mostly below 0.01
  - depend on viewing geometry
  - ring-like structure due to Fourier series decomposition in zenith angles
  - depend on cloud situation; mixed-phase clouds have largest errors
    → ongoing study
  - vary with channel wavelength

MFASIS-DOM reflectance differences for MSG4 SEVIRI



Data from global ICON model fields @ 40km (15-21 Nov 2020 & 15-21 Mar 2021 @ 6, 9, 12, 15, 18 UTC)

- Errors due to forward operator assumptions are smaller than typical observation-simulation errors

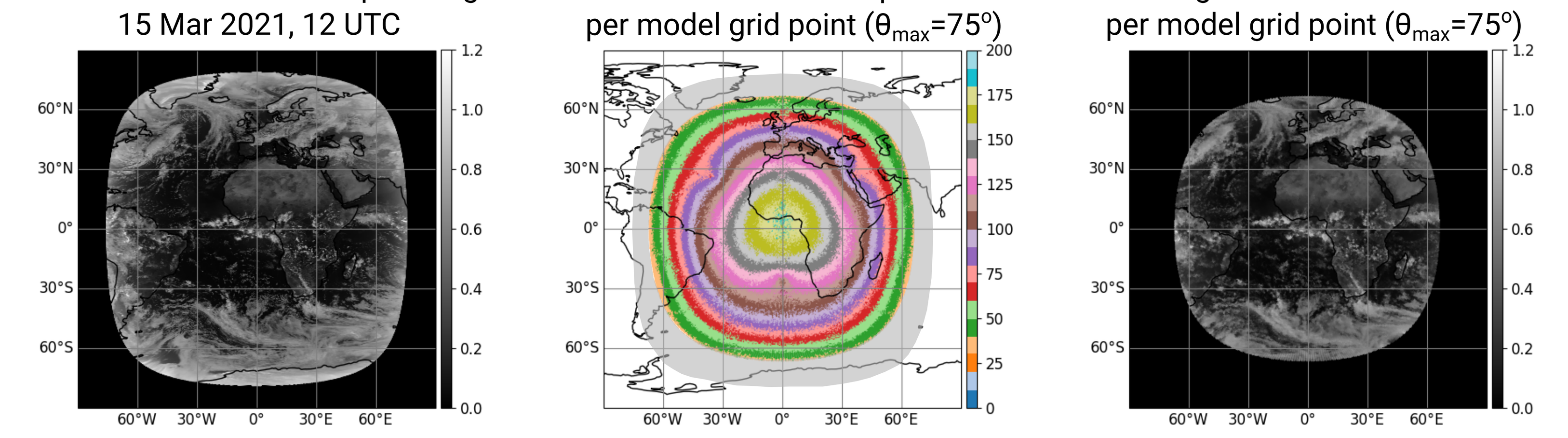
→ Use MFASIS to study model biases!

2 Observed reflectances and scale matching with model fields

Imagers observe reflectances, i.e., the percentage of reflected solar radiation by clouds and the Earth's surface. Reflectances provide added and complementary information to infrared sounders because they 'see' low clouds and are more sensitive to cloud water and cloud ice contents.

A fair comparison with global ICON model fields requires that both model and observation data reside on grids with similar resolution. We use SEVIRI 0.6µm channel images at 3 km nadir resolution and compare with simulations based on ICON fields at 40 km (ensemble resolution, shown here) and full 13 km resolution. SEVIRI pixels are averaged to match the respective model resolution.

Full-resolution SEVIRI 0.6µm image 15 Mar 2021, 12 UTC | Number of SEVIRI pixels per model grid point (θ_{max}=75°) | Averaged SEVIRI observation per model grid point (θ_{max}=75°)



We correct for a negative bias of SEVIRI observations (~8% and ~6% for the 0.6µm and 0.8µm ch.) compared to MODIS on Aqua by scaling the observations accordingly (Meirink et al., 2013).

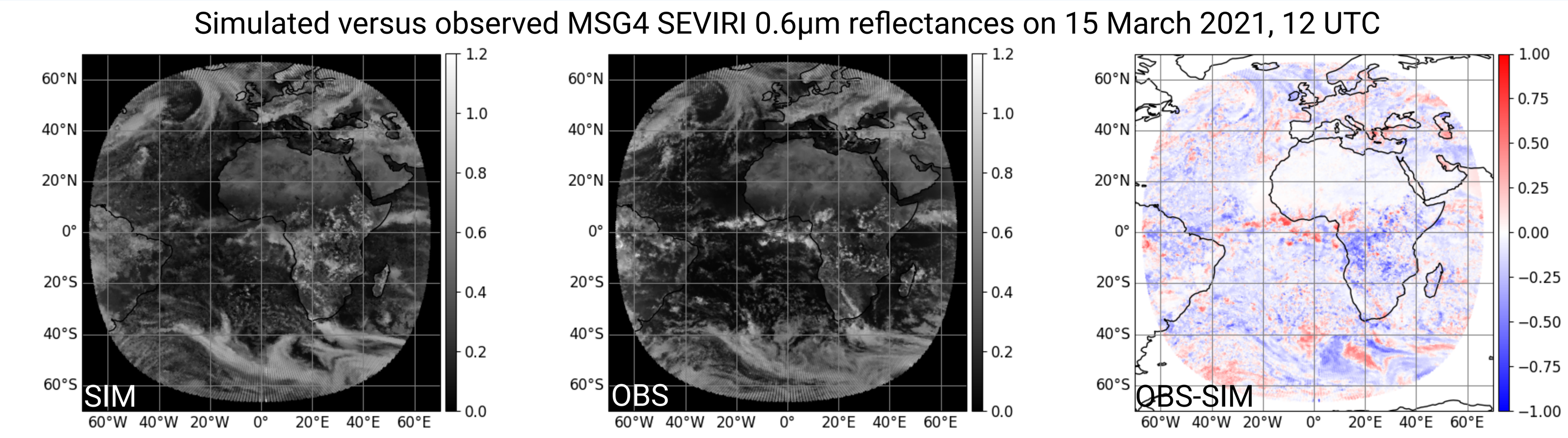
3 ICON cloud field evaluation

3.1 Comparison of simulated and observed satellite images

Simulation and observation show similar cloud patterns.
The differences are due to

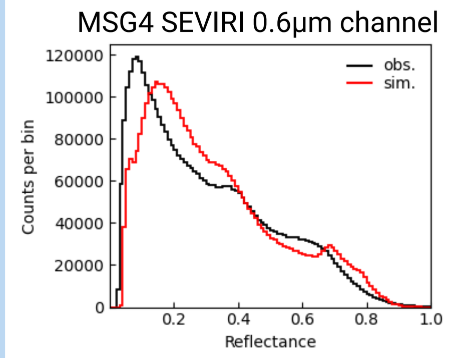
- deficiencies in model cloud location or cloud representation
- 3D effects (esp. large viewing angles) and subgrid scale variability not captured by forward operator or model
  → improvements on this are planned for a future RTTOV version

Simulated versus observed MSG4 SEVIRI 0.6µm reflectances on 15 March 2021, 12 UTC



For investigating model biases, we collect data from 15-21 November 2020 and 15-21 March 2021, each at 6, 9, 12, 15 and 18 UTC.
→ Variety of atmospheric situations and different local times covered

- Overall shape of observed reflectance histogram is reproduced in the simulation
- Differences: peak at low reflectances, overestimated reflectances in simulation

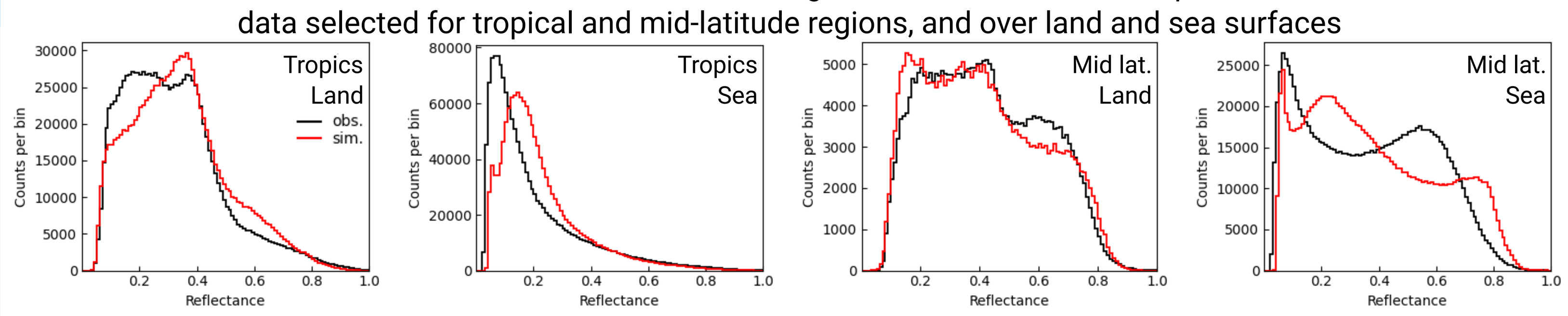


3.2 Towards understanding situational biases - Outlook

For a better understanding of the model biases, we compare simulated and observed reflectances under certain conditions:

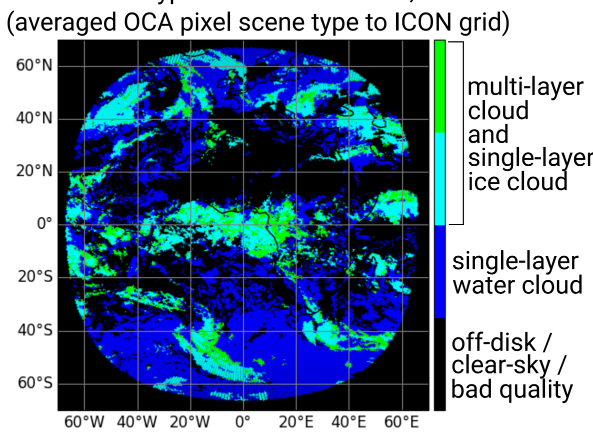
- Resctrict data to certain regions, e.g., by latitude, or surface type. We expect that clouds over land are predominantly of continental nature, while clouds over sea are mainly of maritime origin.

Simulated and observed reflectance histograms for MSG4 SEVIRI 0.6µm channel data selected for tropical and mid-latitude regions, and over land and sea surfaces



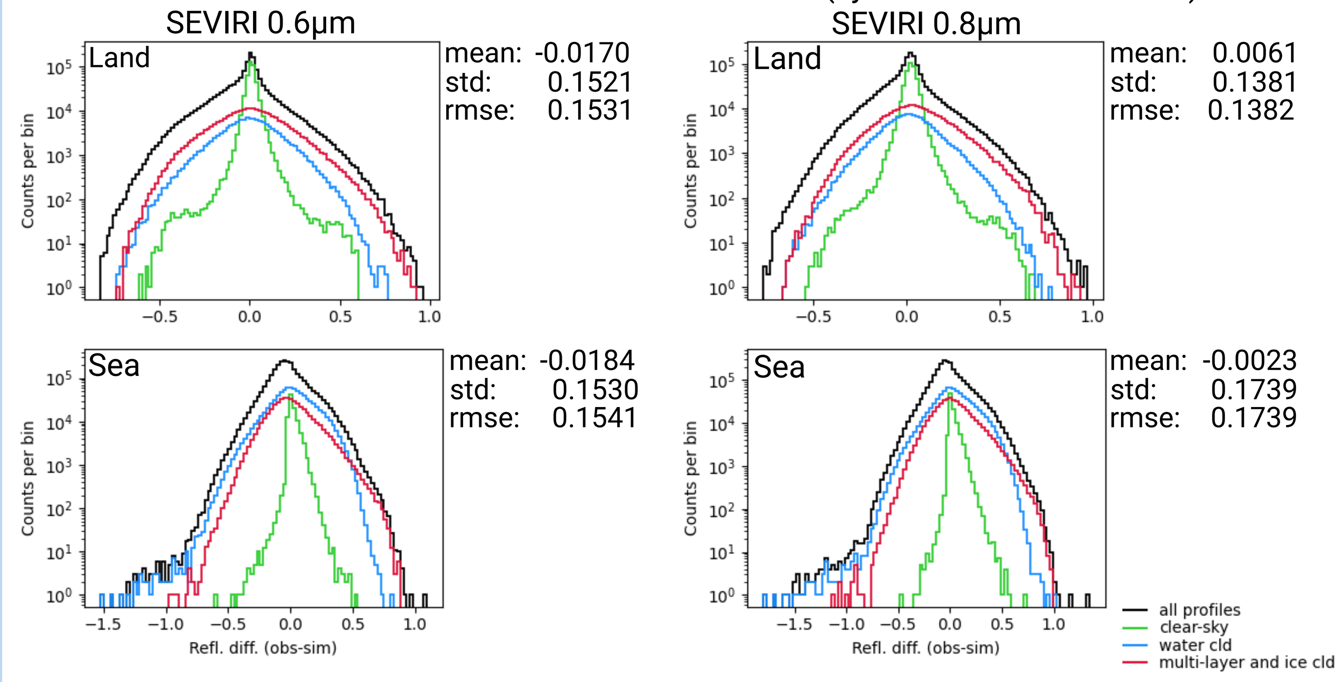
- Cloud type classification:
  - Model fields:
    Apply limits on the total optical depths or effective particle sizes for water and ice per atmospheric profile
  - Observations:
    Use Optimal Cloud Analysis (OCA, Eumetsat product) averaged in the same way as SEVIRI observations
    → principal cloud parameters: phase, pressure, optical thickness, effective particle radii

Main scene type for 15 March 2021, 12 UTC (averaged OCA pixel scene type to ICON grid)



- Different applications by selecting the clouds in the model and observation
  → separately: compare the number of clouds of a given type in the model and observation
  → symmetrically: better understand model errors for similar cloud types in the model and observation

Observed-simulated reflectances for MSG4 disk (symmetric data selection)



→ Biases of observed-simulated reflectances for land, sea and different cloud situations provide the basis for future situation-dependent observation errors and bias correction.

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