Uncertainties in ice-affected Synthetic Brightness Temperatures

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Introduction

Problems

- synthetic satellite images used in model verification and data assimilation
- systematic biases do exist and make quantitative application complicated, for instance for
  - object-based verification methods
  - assimilation of cloudy radiances
- inconsistencies between parameterizations of cloud microphysics and their interaction with radiation as well as assumptions in retrieval algorithms make interpretation of observation-model differences difficult

Goals

- identification of systematic deficits in a current operational scheme for derivation of synthetic satellite images
- quantification of uncertainties in synthetic satellite images

Origins of Uncertainties

- methodic error in RTTOV (regression method)
  - for clear sky: said to be below instrument error interpolation error
- uncertainties due to subgrid-scale parameters
  - water / **ice cloud microphysics**
    - connection to radiative properties is uncertain, e.g. shape dependence
    - inconsistencies in assumptions on the ice microphysics between RTTOV and COSMO
    - ice vs. snow problem
  - subgrid cloud cover
  - turbulent fluctuations: to be closer to observation?

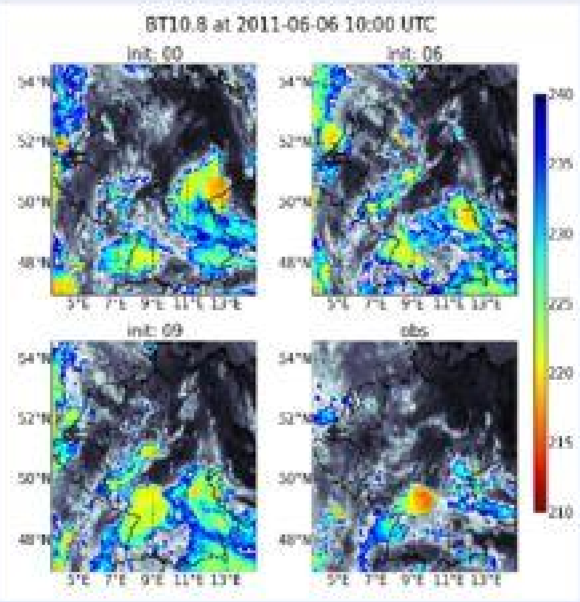

Fig. 1: Synthetic vs. observed brightness temperature of the SEVIRI IR10.8 channel for three COSMO-DE runs started at init time 0, 6, and 9 UTC.

→ Systematic errors in the handling of different solid water categories (cloud ice and snow) will have an effect on the amount of cold BTs.

Ice-optical Properties in RTTOV

RTTOV

- very fast radiative transfer model *(long history in data assimilation of sat.-radiances)*
- simulates infrared radiances of MSG- SEVIRI from model forecast *(no visible + NIR yet!)*

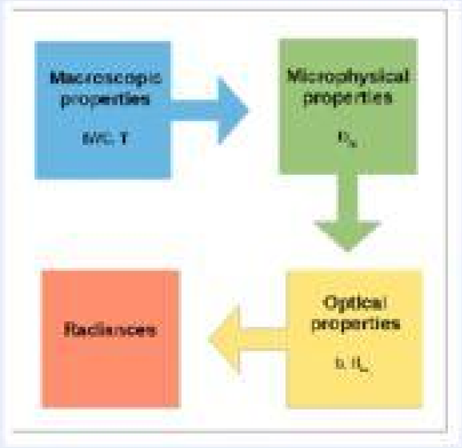

Fig. 2: RTTOV scheme for the calculation of cloud-affected radiances. Macroscopic cloud properties are converted into microphysical and then optical properties, which are at the end used for radiance calculations.

Uncertainties in the McFarquhar scheme

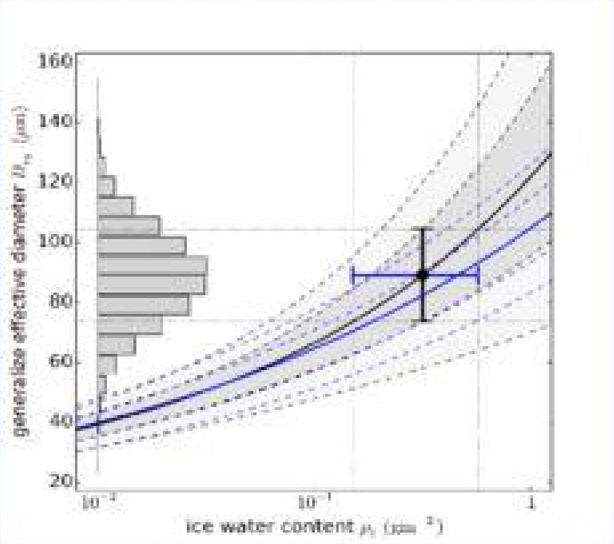

Fig. 3: McFarquhar relation used in RTTOV of IWC to D_{eg} conversion. Based on a large set of Insitu observations. Uncertainty intervals are given based on the statistical uncertainty of their fitted relations.

- McFarquhar (2003) gives a relative uncertainty of the IWC to D_{ge} conversion of ca. 5 % (10 %) at 1σ (2σ) level

Simplified ice cloud calculations

- Uncertainty in ice-affected brightness temperatures is largest for semi-transparent clouds
- clouds with optical thicknesses between 0.5 and 3 are mainly influenced
- effect does mainly depend on surface transmissivity
- ice aggregates have lower optical thickness than hexagonal ice crystals for equal ice water path
- uncertainties of about 5 % in the generalized effective diameter lead to maximum variations of 5 K in 10.8 µm brightness temperature

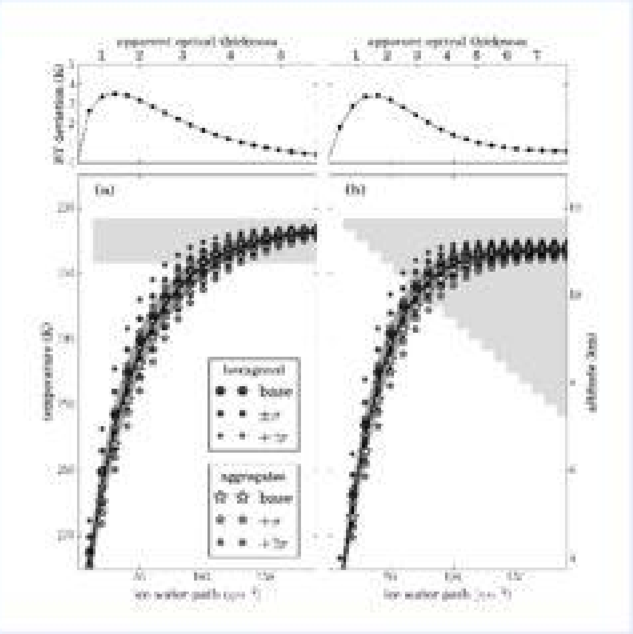

Fig. 4: Simplified RTTOV calculations using clouds with constant IWC and increasing geometrical depth.

COSMO-DE Ice - Microphysics

Ice vs. Snow

- non-precipitating
- hexagonal plates
- mono-disperse distribution

effective diameter:

$$D_{max}^{ice} = \left(\frac{IWC}{a_i N_i(T)}\right)^{1/3}$$

with $N_i = 100\, e^{0.2(T_0 - T)}$

- precipitating
- rimed aggregates
- exponentially distributed

effective diameter:

$$D_{eff}^{snow} = \frac{9\alpha}{2}\left(\frac{SWC}{2a_s N_s(T)}\right)^{1/3}$$

with $N_s = 7.6\, 10^6\, e^{0.107(T_0 - T)}$

Generalized Effective Diameter of Ice and Snow

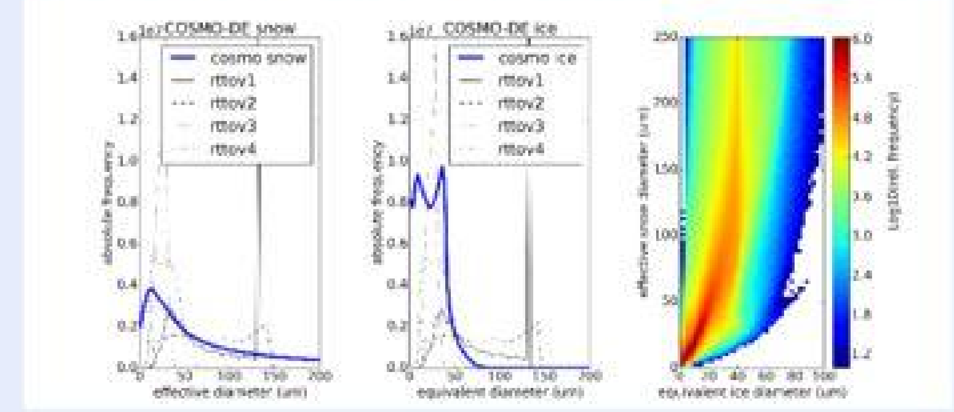

Fig. 5: Distribution of the generalized effective diameter of model ice and snow in comparison with parameterization of D_{ge} taken from RTTOV.

Extinction weighted effective diameter

- use size information from COSMO-DE microphysics explicitly in RTTOV
- add extinction from ice and snow and calculate an extinction weighted effect. diameter used in instead

$$D_{ge} = F^{-1}\left((\beta_{ext}^{ice} + \beta_{ext}^{snow})/SIWC\right)$$

with $\beta_{ext}^{ice}/IWC = F(D_{ge}^{ice})$
and $\beta_{ext}^{snow}/SWC = F(D_{ge}^{snow})$

f_{ice} : ice fraction
f_{snow} : snow fraction

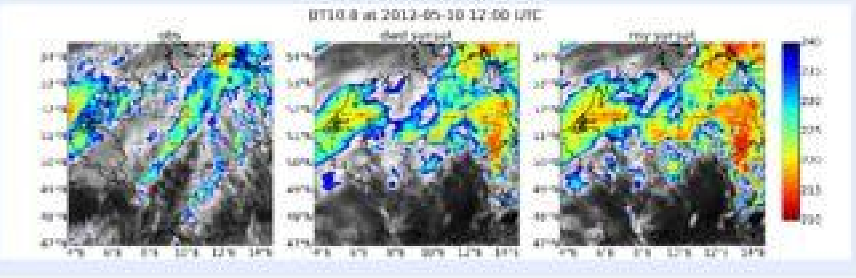

Fig. 6: Color-enhanced BT108 (K) for observation (left), operational DWD synSat (middle) and recalculated synSat with COSMO-DE microphysics information used in RTTOV.

Spatial Distribution

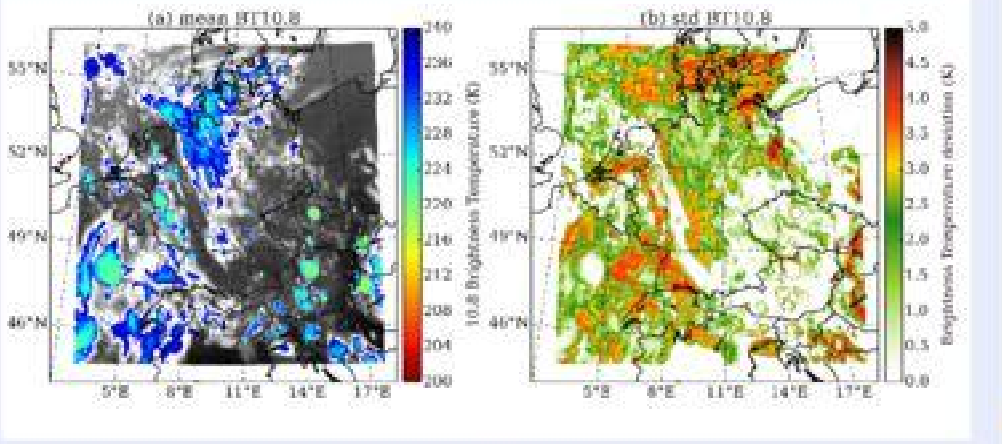

Fig. 7: Example for the spatial distribution of BT10.8 uncertainties for the 5 July 2012 at 12 UTC. The situation is characterized by developing deep moist convection and other high-level clouds.

Simple Predictors of Uncertainty

One example case

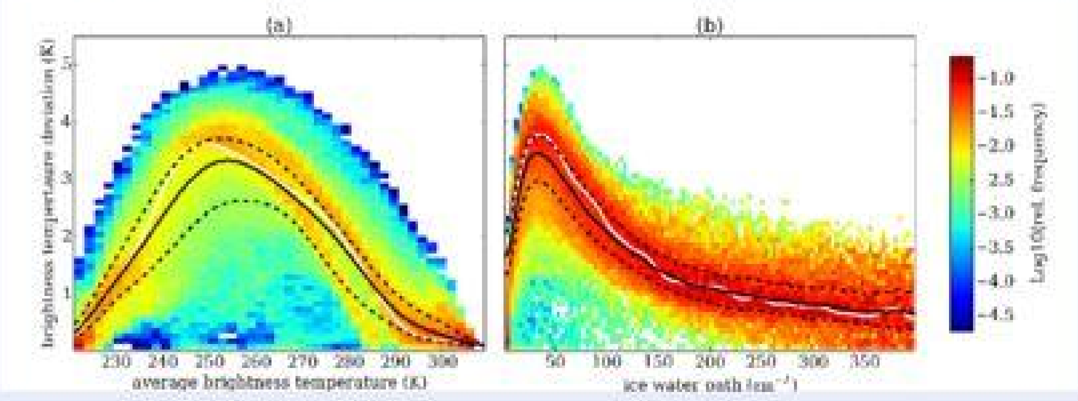

Fig. 8: 2d conditioned histograms of the occurrence frequency of a certain brightness temperature deviation conditioned on the simultaneous occurrence of (a) an average brightness temperature and (b) an model-derived ice path water for the case shown in Fig. 6.

Many cases

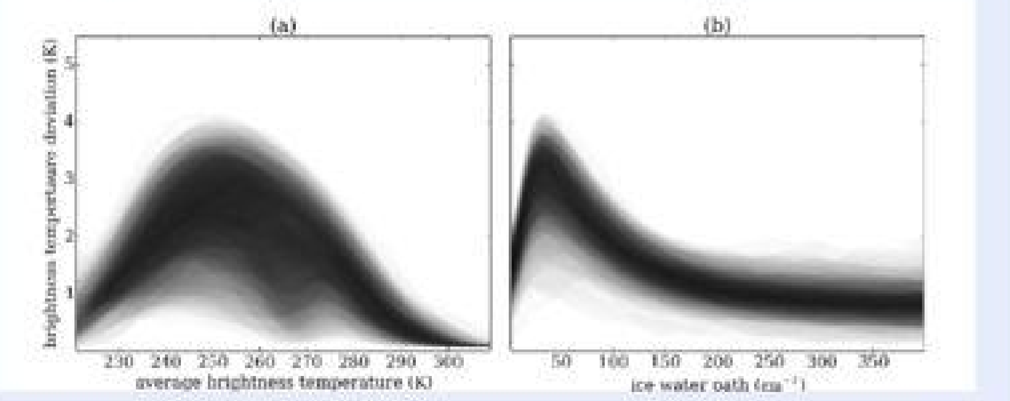

Fig. 9: The inter quartile range of the 2d conditioned histograms in plotted for many forecasts with light gray. The gray tones add when inter quartile intervals overlap. Black regions mean that 50 % or more of these interval overlap.

Conclusions

- inconsistencies between model microphysics and assumptions in the derivation of synthetic satellite images complicate the comparison of satellite-observed and model clouds
- forecast verification should deal with synSat uncertainties
- more consistent treatments of radiation – microphysics – interaction helps to address model deficits
- uncertainties in synthetic satellite images are non-negligible; espec. for τ ~ 0.5 - 3

Future Challenges

- How can we estimate the uncertainty in synthetic satellite images based on a few simple forecasted parameters like e.g. IWP?
- How can the estimates of synSat uncertainty be used in data assimilation and forecast verification esp. for object-based methods?
- How propagates error from uncertain synthetic satellite images to derived synthetic satellite products?

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