Assimilation of visible and near-infrared SEVIRI observations in KENDA/COSMO

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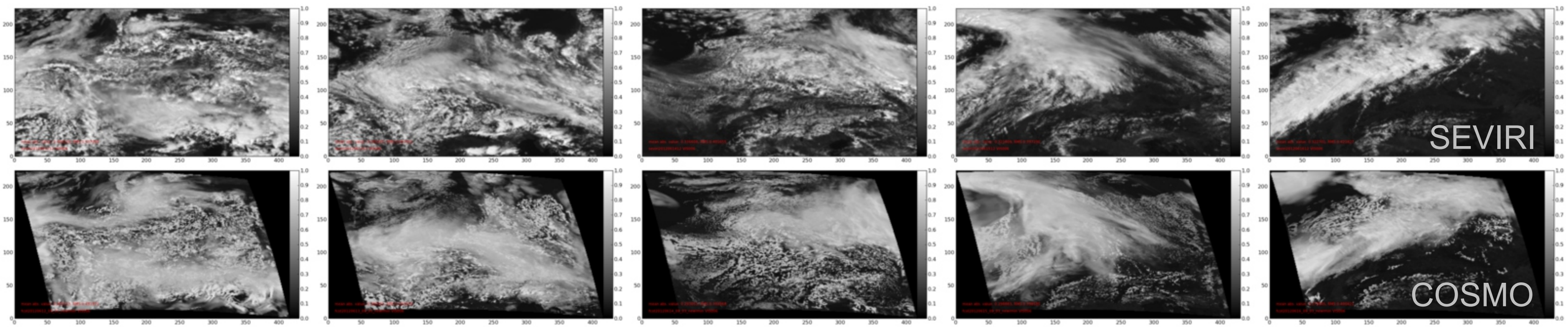
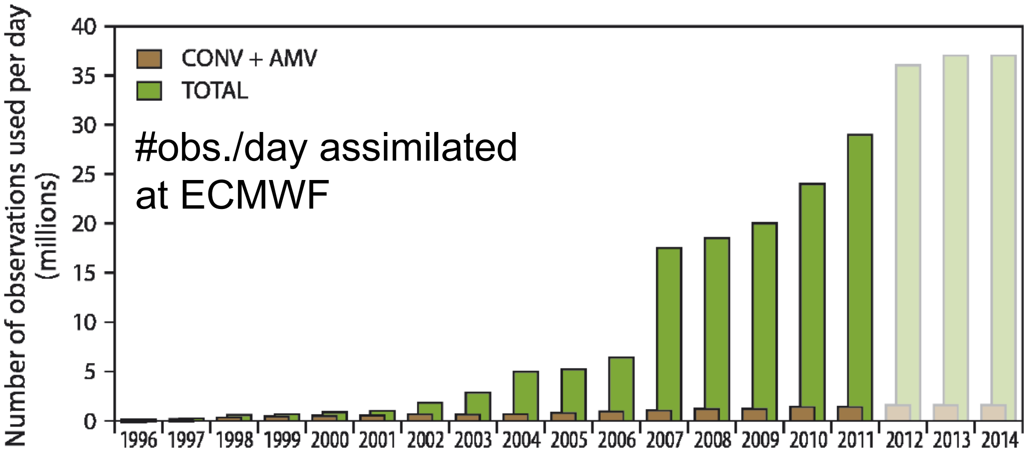
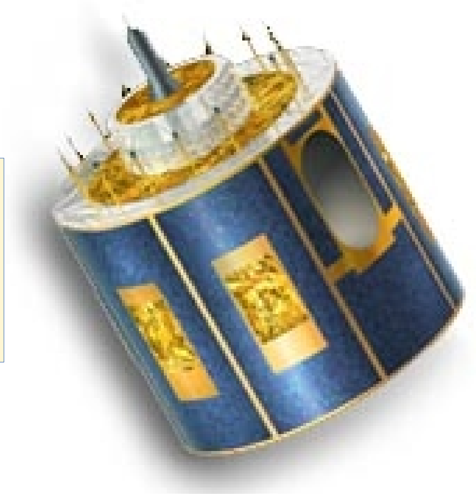


MOTIVATION



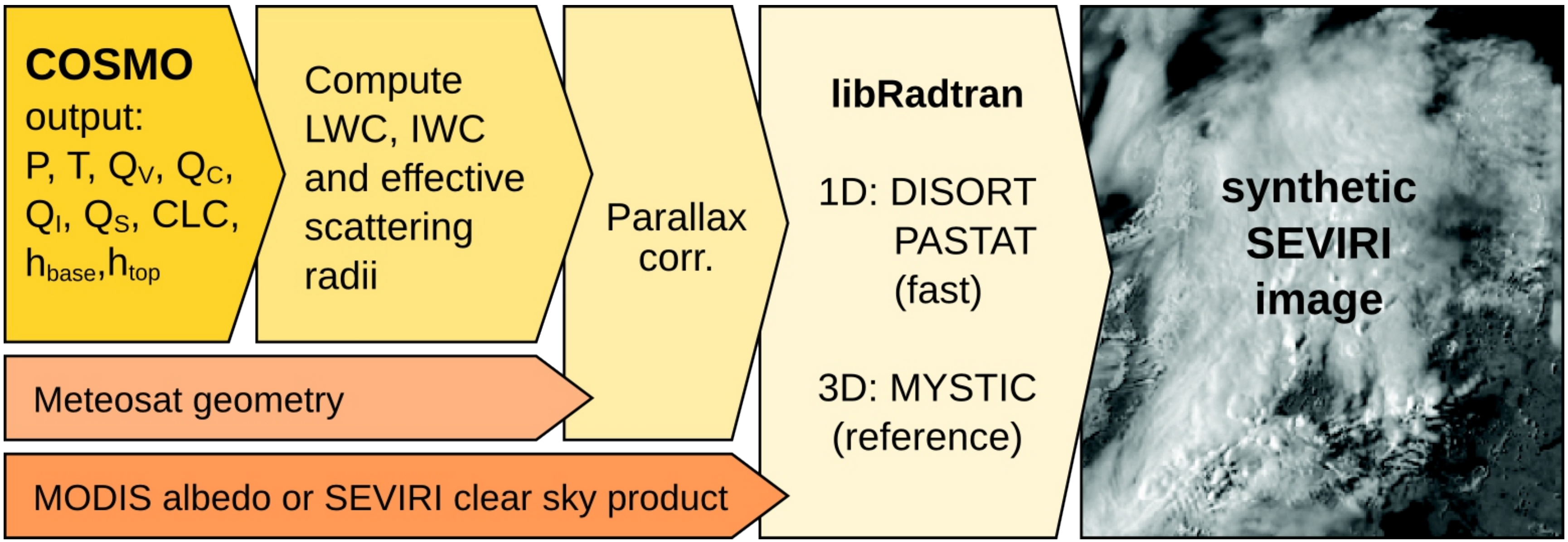
- Satellites dominate number of assimilated observations and have contributed strongly to improvements in NWP
- Visible and near-infrared obs.: information on cloud properties
- Not used operationally, mainly because no fast forward operator exists (scattering complicates radiative transfer)

Goals: Development of fast VIS/NIR forward operator, Direct assimilation of radiances (cloud information) in convective scale ensemble DA system



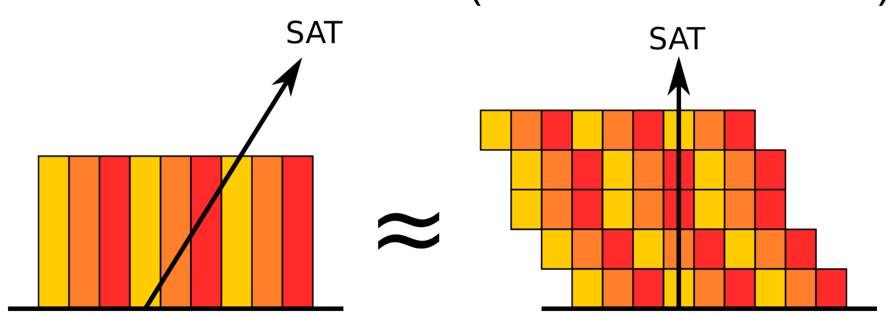
- Instrument: SEVIRI on Meteosat second generation 600nm, 800nm, 1600nm images every 15min, 2-5km res.

A fast forward operator for SEVIRI

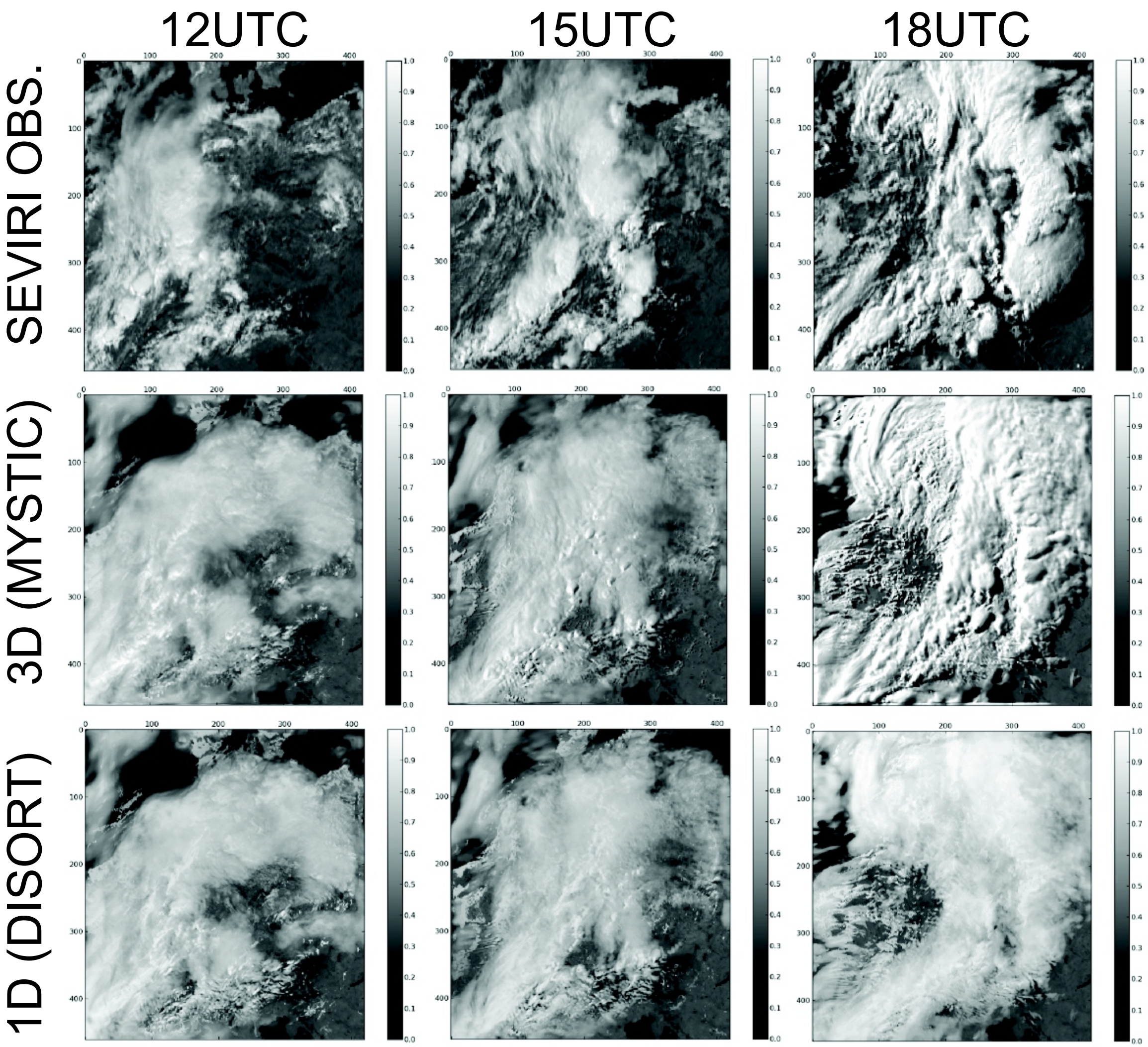


COSMO (Consortium for Small-scale Modeling) **model:**
nonhydrostatic limited-area NWP model
convection-permitting, grid length 2.8km

Parallax correction (1st order 3D effect)



Kostka et al. „Observation Operator for Visible and Near-Infrared Satellite Reflectances", 2014, J. Atmos. Oceanic Technol., 31, 1216–1233



22 June 2011

OPERATOR RESULTS

Observation vs. Model:
Realistic structures. Significant differences, mainly due to discrepancy between forecast and reality

1D vs. 3D:
Agreement quite good for 06-15 UTC (RMS Error < 5% with parallax correction)

Computational effort:
MYSTIC: O(CPU-days)
DISORT: O(CPU-hours)
→ **too much for operational DA...**

A fast replacement for DISORT: PASTAT (PhD thesis Pascal Frerebeau)

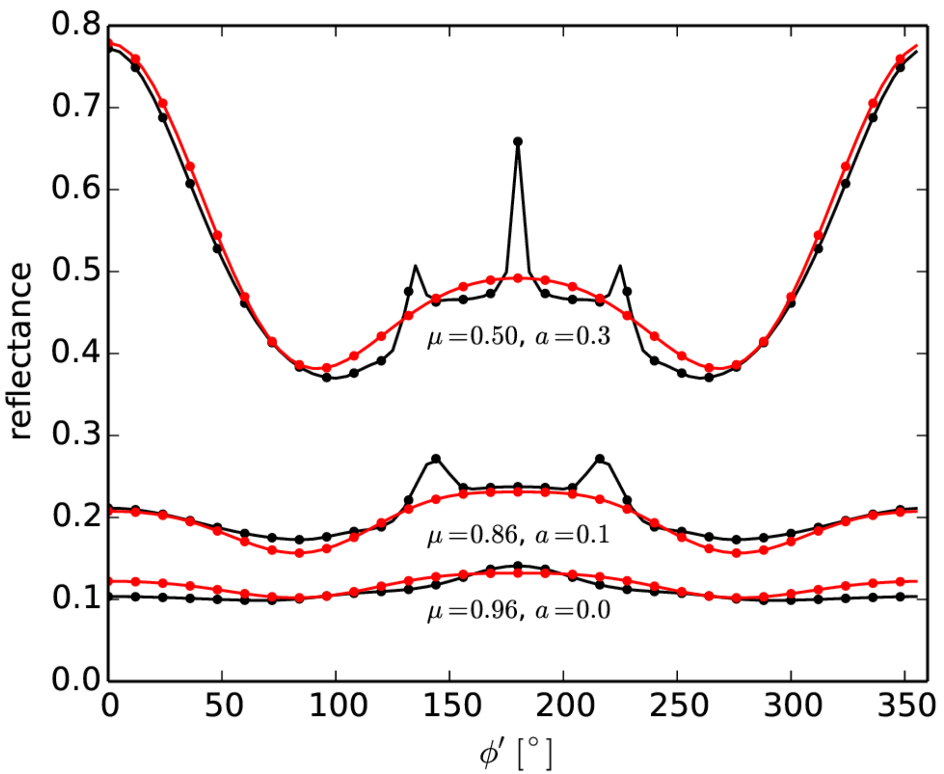
Strategy:
- Describe atmosphere and sun/sat geometry by a few parameters
- Compute look-up tables with DISORT for all parameter combinations
- Computing reflectance = calculate parameters from model output, interpolate in look-up tables

Parameters: satellite angles, SZA, albedo, water & ice optical depths, eff. radii for water and ice particles.

Reflectance varies more strongly and nonlinearly with satellite angles than with the other parameters

Idea: Instead of tabulating reflectance Directly for many satellite angles, use Fourier series & Taylor expansion of the reflectance and tabulate only a few coefficients

reflectance(azimuthal angle) and fit with 4 Fourier terms



A fast replacement for DIS... th

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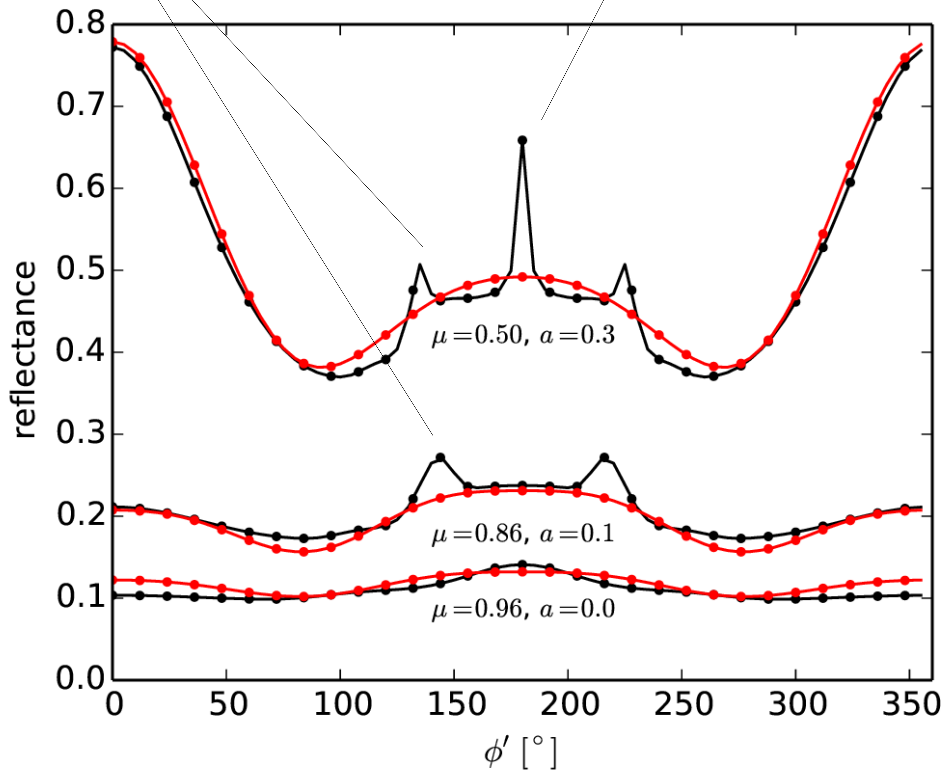

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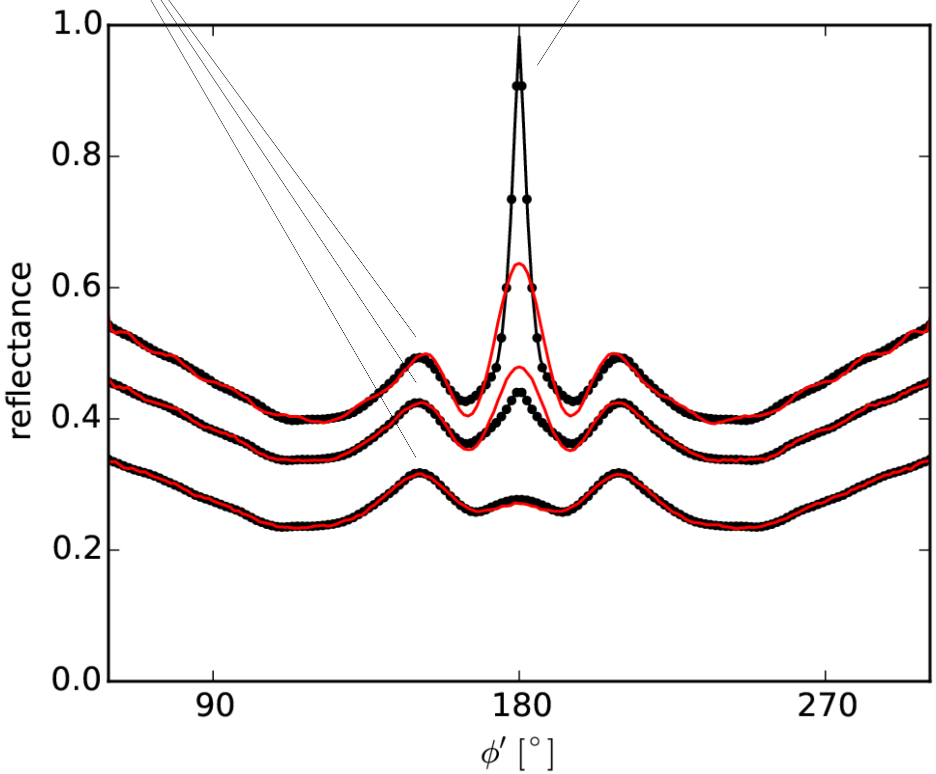
reflectance(azimuthal angle) and
fit with 15 Fourier terms



$$I_{\mathrm{toa}}(\mu, \phi', \mathbf{p}) = \sum_{k=0}^{n_k-1} \mu^k I_k(\mathbf{p}) \left[1 + (1-\mu) \sum_{l=1}^{n_l} c_{k,l}(\mathbf{p}) \cos(l\phi') \right]$$

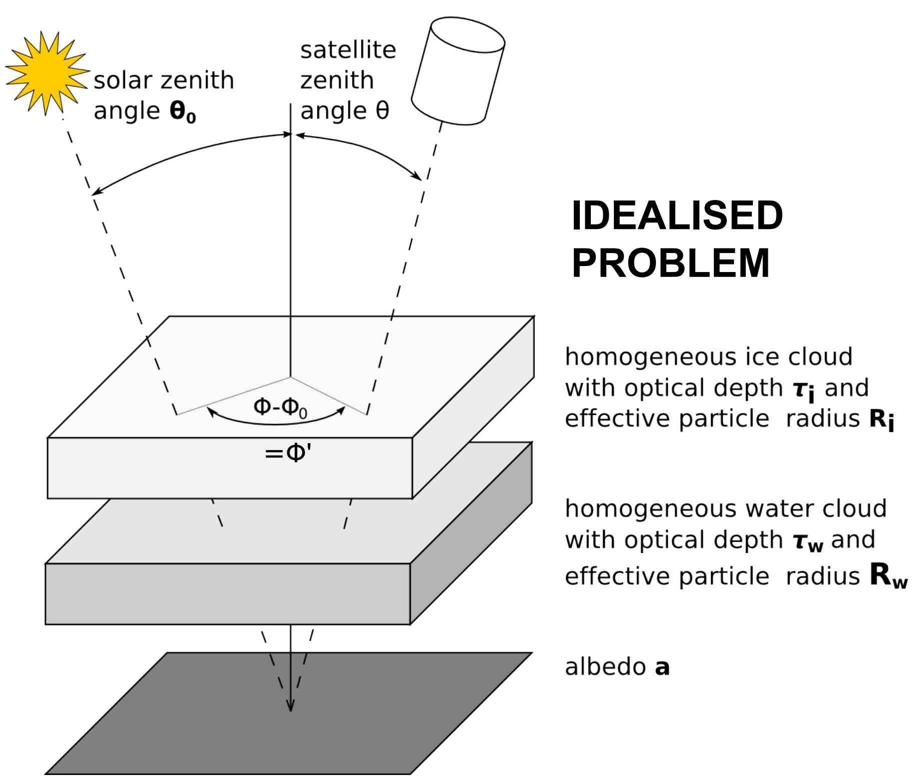
sat angles: (μ, ϕ')

top of atmosphere: toa

parameters: $\mathbf{p}$

Coefficients for Taylor expansion in $\mu=\cos(\mathrm{SZA})$: $I_k(\mathbf{p})$

Coefficients for Fourier series in Φ': $c_{k,l}(\mathbf{p})$



Generation of coefficient tables:

1. **Run DISORT** for idealised problems described by $\mu, \Phi', \mathbf{p}$

   $\rightarrow \quad I_{\mathrm{DISORT}}(\mu, \Phi', \mathbf{p})$

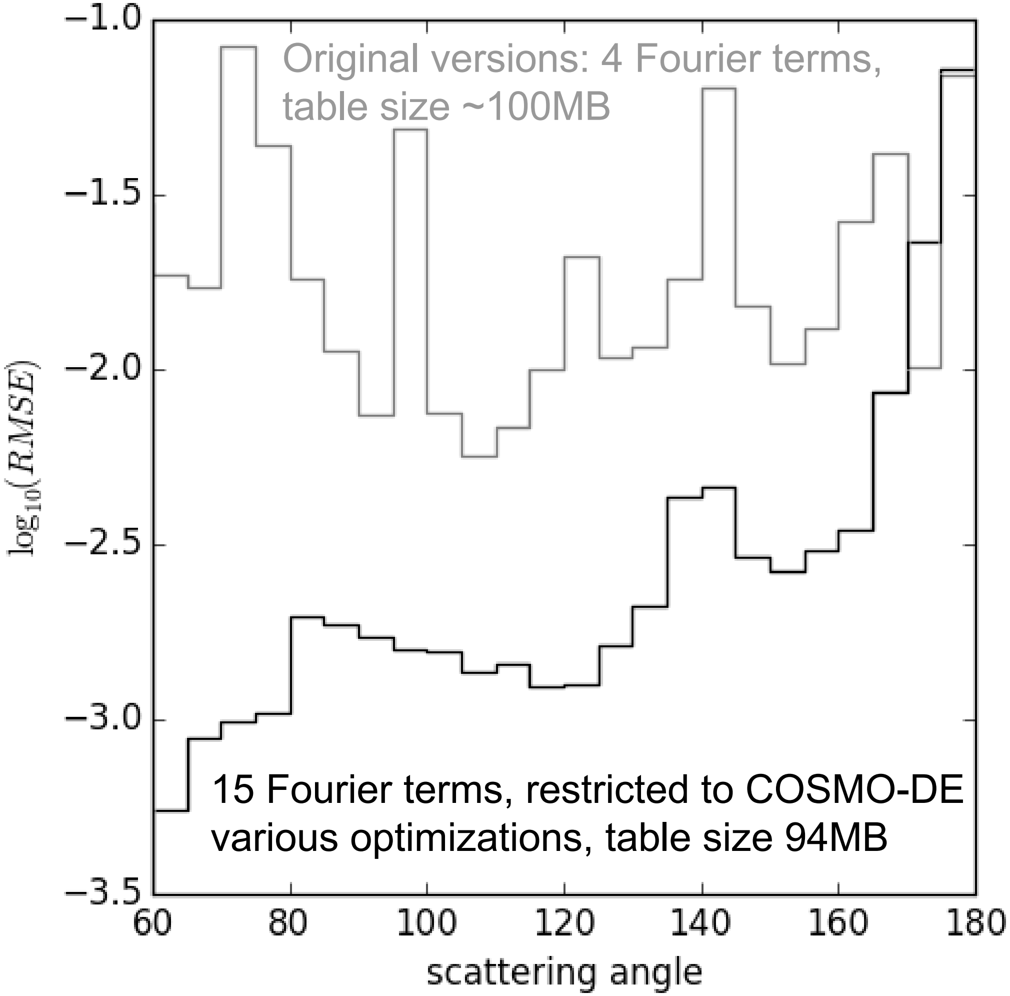
   for all $\mu, \Phi', \mathbf{p}$ combinations

2. **Perform least squares fit** for each **p** minimize

   $$\sum_i \sum_j \left| I_{\mathrm{toa}}(\mu_i, \Phi'_j, \mathbf{p}) - I_{\mathrm{DISORT}}(\mu_i, \Phi'_j, \mathbf{p}) \right|^2$$

   $\rightarrow$ coefficients $I_k(\mathbf{p})$, $c_{k,l}(\mathbf{p})$

Fit quality



Sort table points in scattering angle bins, compute RMSE wrt DISORT for 600nm channel

Glory and rainbows cause local Maxima at ~140°, 180°

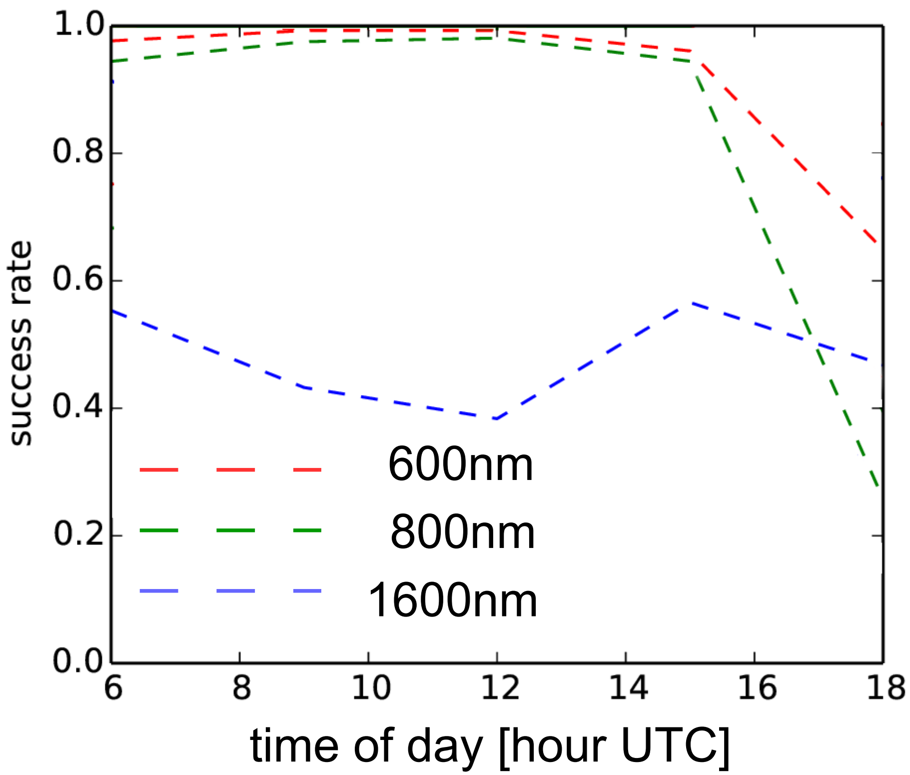
For scattering angles < 170°: RMSE < 1%

6 parameters **p** do not describe atmosphere fully → additional errors

→ tests with realistic atmospheric states necessary...

Comparison with DISORT for a COSMO/SEVIRI scene in June

Data: 3-hourly operational COSMO-DE forecasts for June 15-20, 2012



Success rate R_5:

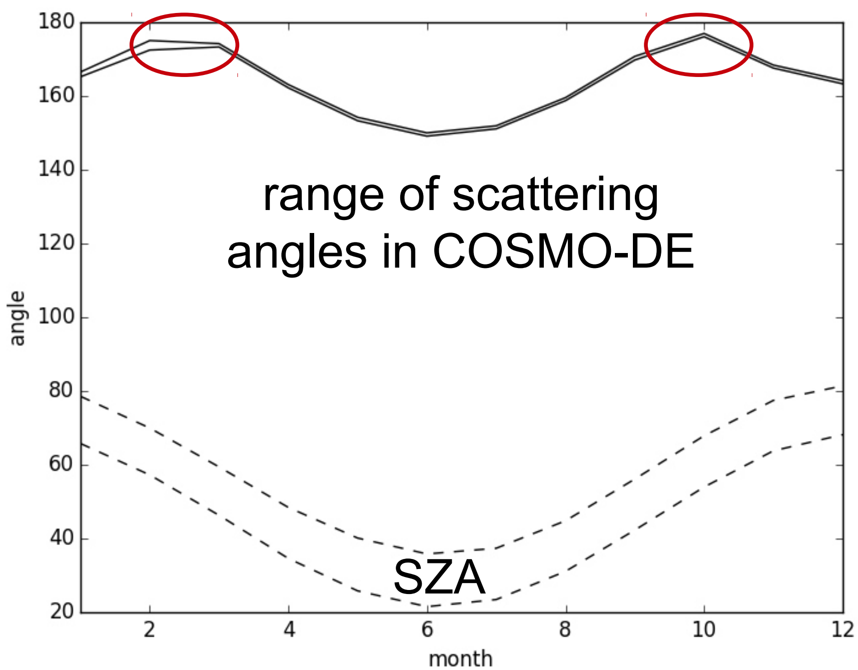
Number of pixels with relative reflectance error of less than 5% percent (compared to DISORT) / total number of pixels

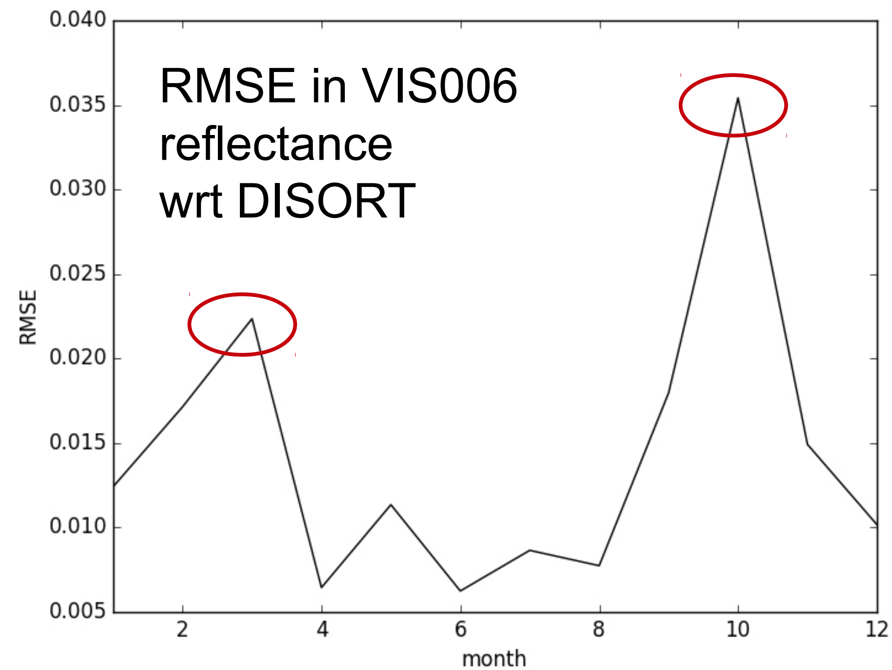
> 95% of the pixels have less than 5% error between 6 UTC and 15 UCT for the 600nm and 800nm channels. RMSE in reflectance is about 1%.

- 18 UTC worse: large solar zenith angle
- 1600nm: Absorption becomes important, strong dependence on vertical profile of particle radius – problematic...

Accuracy for other months

Experiment: Compare PASTAT to DISORT at 600nm for atmospheric state from operational forecast for June 15, 2012, 12 UTC + sun position from other months





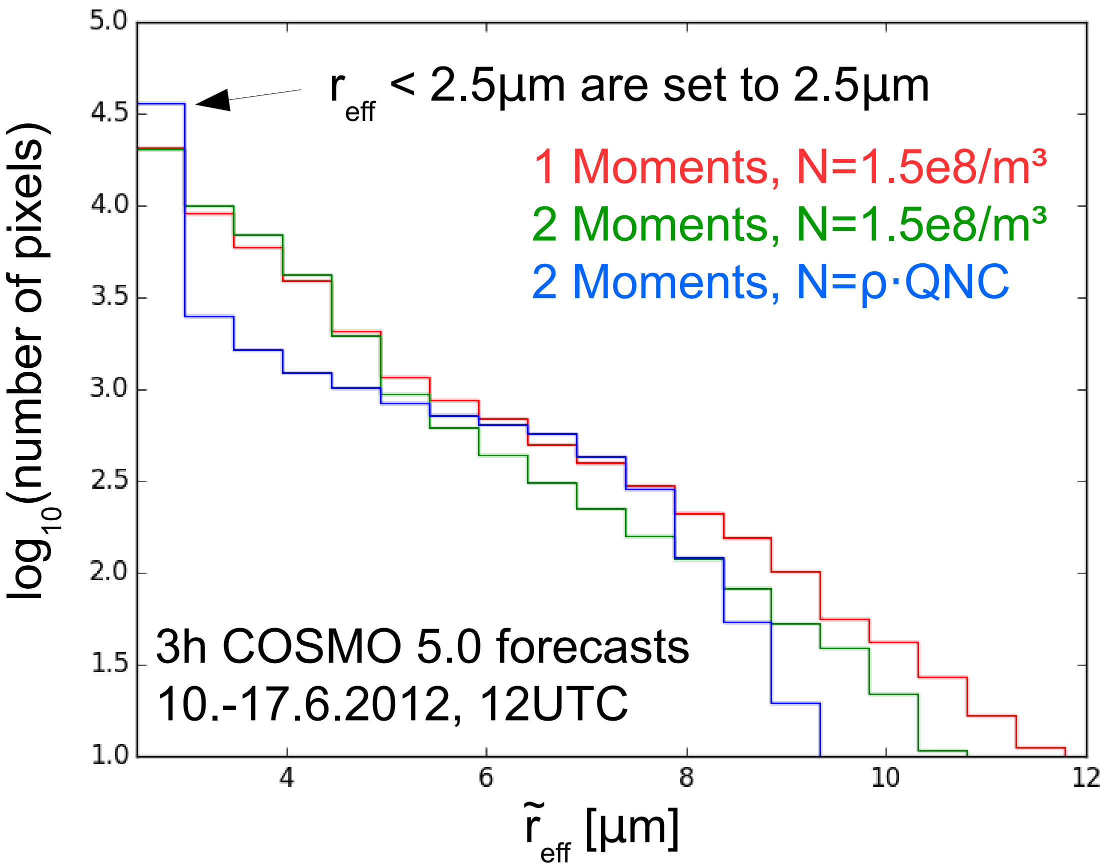
April to September: Basically same accuracy as for June

Scattering angle >170° in March and October → Glory problems, enhanced RMSE (could still be useful for DA)

Further problems in winter: Large SZA, snow

Using two moments in the Operator

Two-moment scheme: Information about number density → more realistic profiles for particle radii (important for NIR)? Improved LWC and IWC distributions?



Parameterization for effective radius of water droplets (Bugliaro et al. 2011, Martin et al. 1994):

$$r_{\mathrm{eff}} = \left(0.75 \cdot \left(\frac{\mathrm{LWC}}{\pi \cdot k \cdot N \cdot \rho}\right)\right)^{1/3}$$

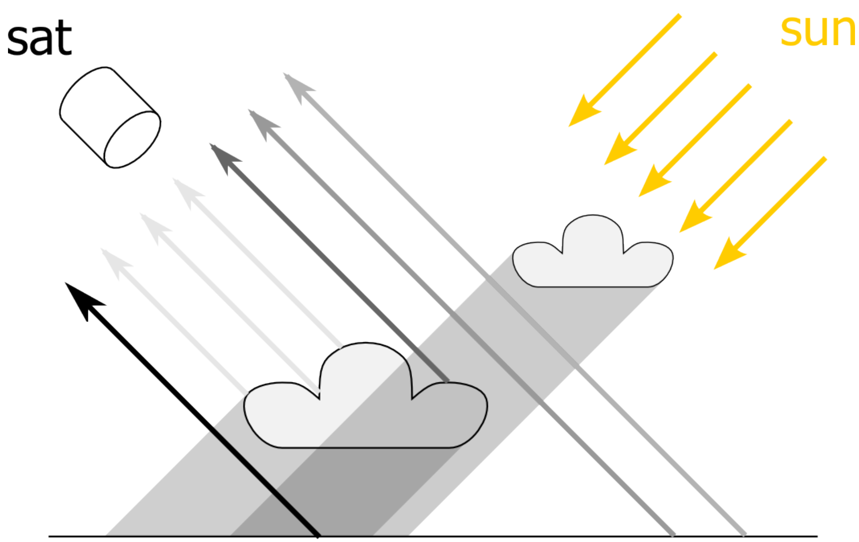
Using information from second moment → more small particles → higher reflectances (which are already too high)

Impact of modified LWC: weak (see talk by Tobias Necker)

Further Development in HD(CP)²-O3

Online Version for ICON:
- based on MESSy interface (P.Jöckel, DLR)
- massively parallel machines → strong restrictions for inter-column communication
  → in first step only 1D without parallax correction
- strong restrictions regarding memory use: table is too big...
  → compute only parameters **p** online (3d→2d data reduction), perform interpolation in postprocessing step

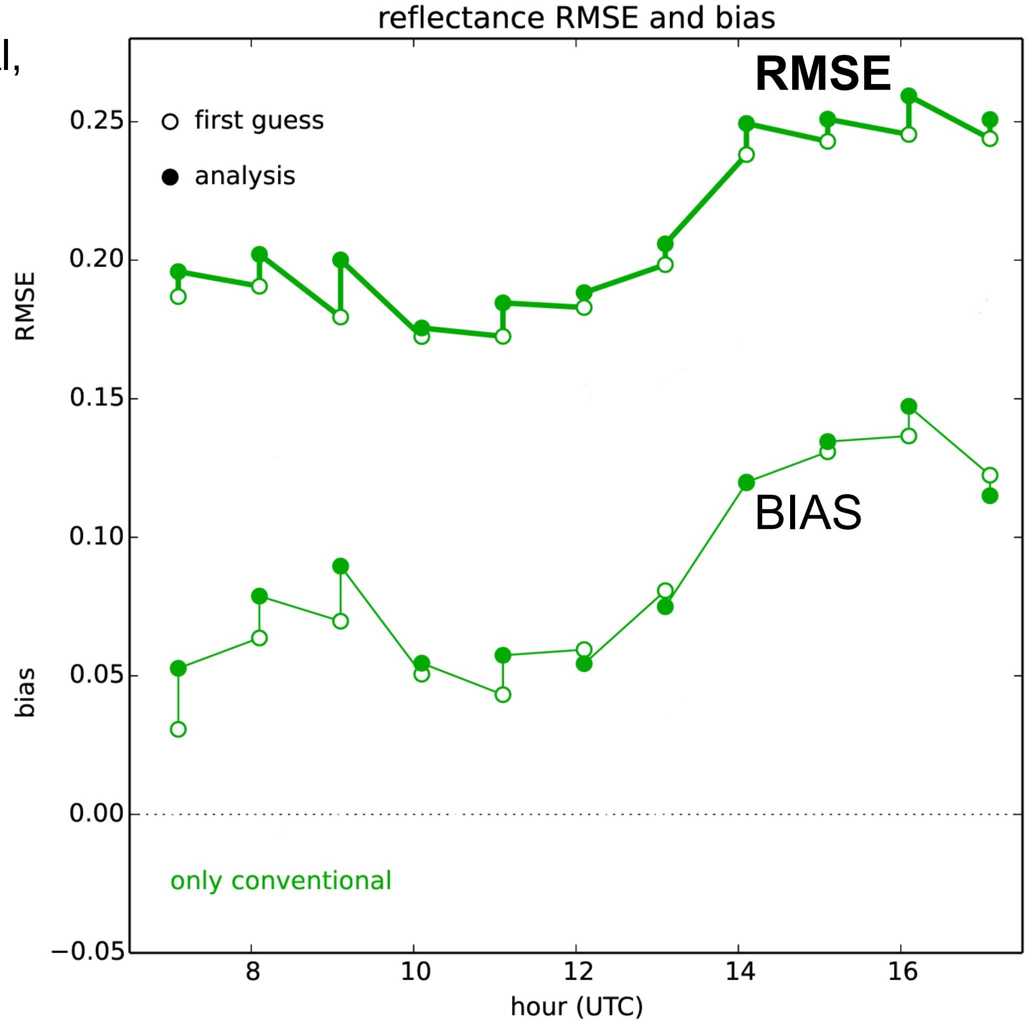
Offline version for PALM, UCLA-LES:
- regular grid facilitates implementation of more 3D effects (e.g. cloud shadows)
- will allow us to investigate methods to reduce communication



First assimilation results

Assimilation of conventional and/or SEVIRI observations in COSMO/KENDA

Setup: LETKF, 40 members, 1h interval, 600nm observations, obs. error 0.2, superobbing (radius 3 pixels), localization 100km (hor.) / none (vert.)



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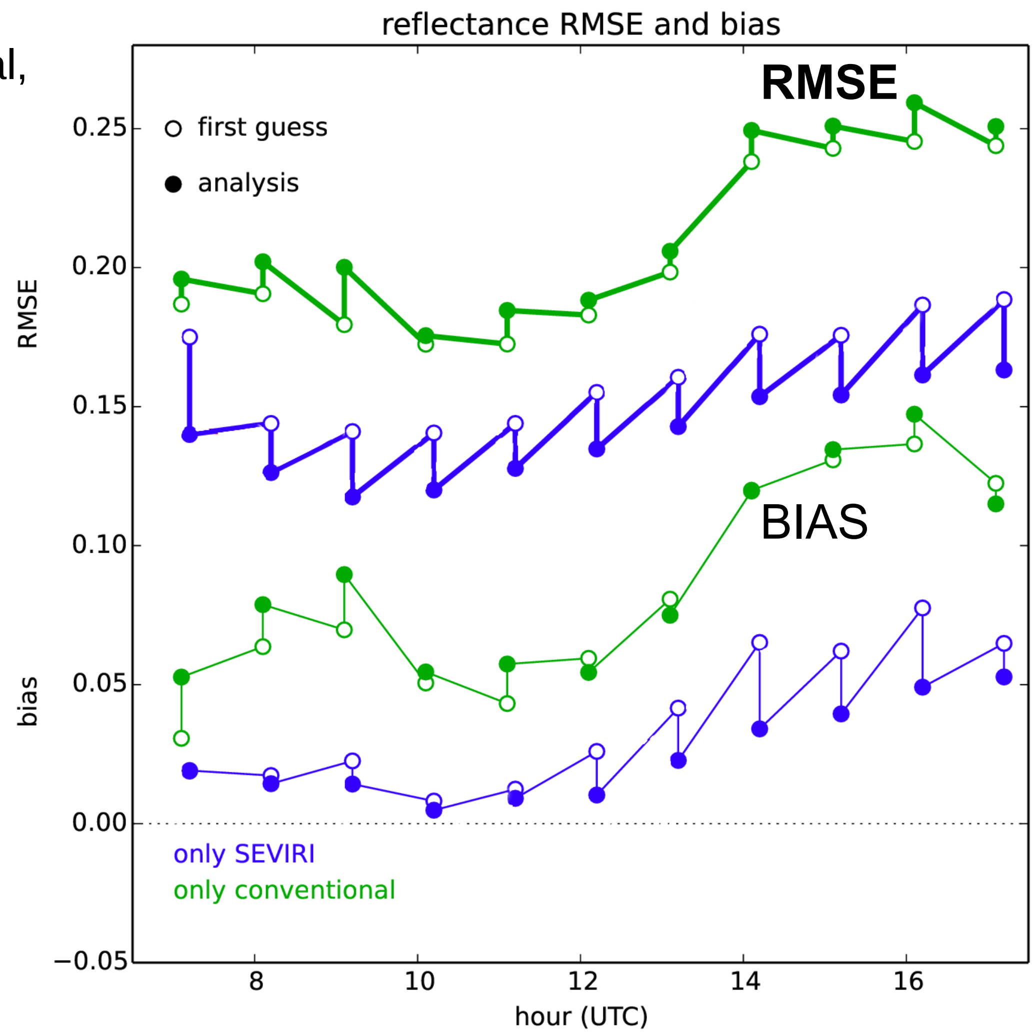
- Assimilation of SEVIRI observations:
  → lower reflectance RMSE and bias



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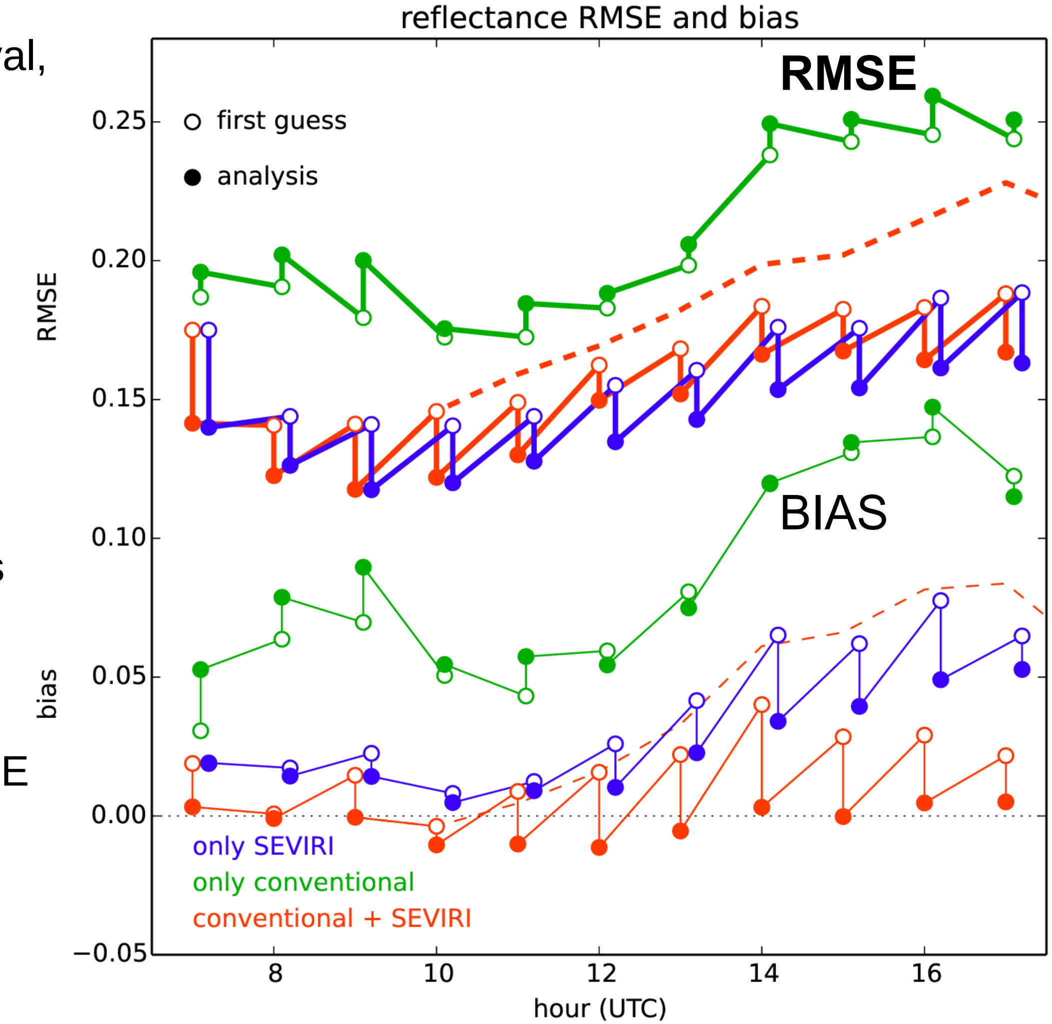
- Conventional observations cannot reduce reflectance error, but lead together with SEVIRI to reduced bias

- Forecast (dashed line) started from assimilation experiment with SEVIRI and conventional observations: RMSE and bias remain smaller than in the analysis ensemble with only conventional observations



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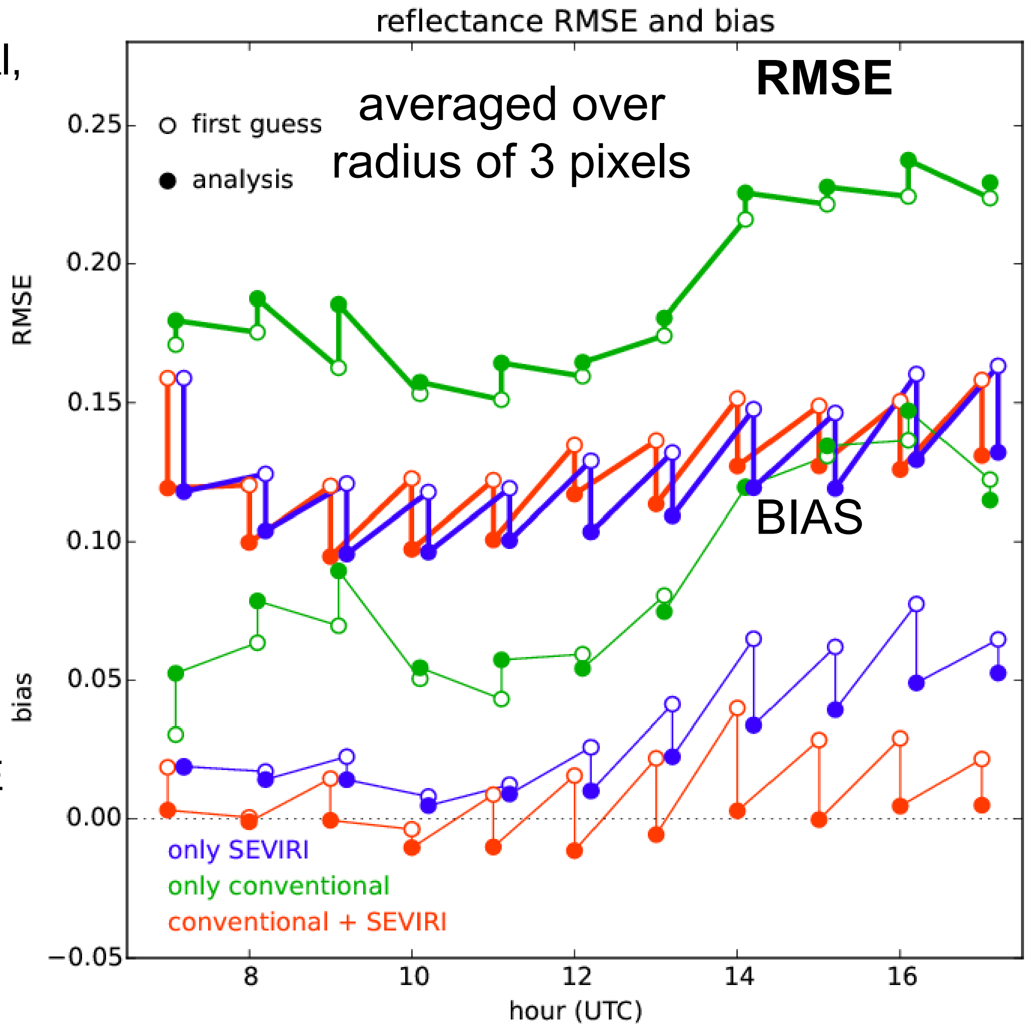

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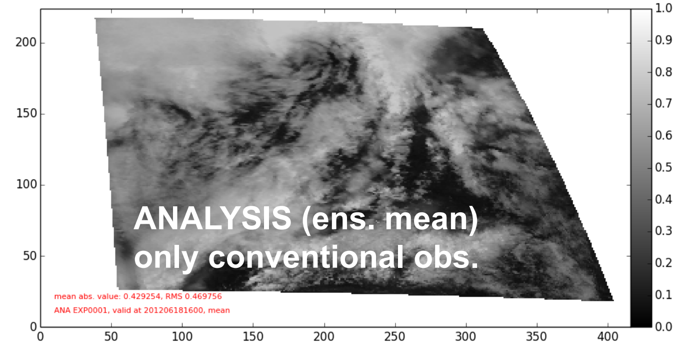
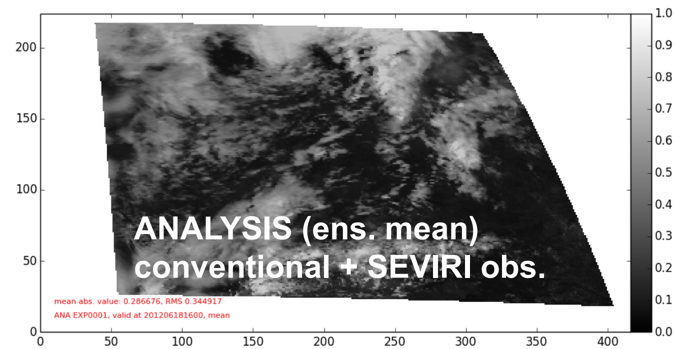
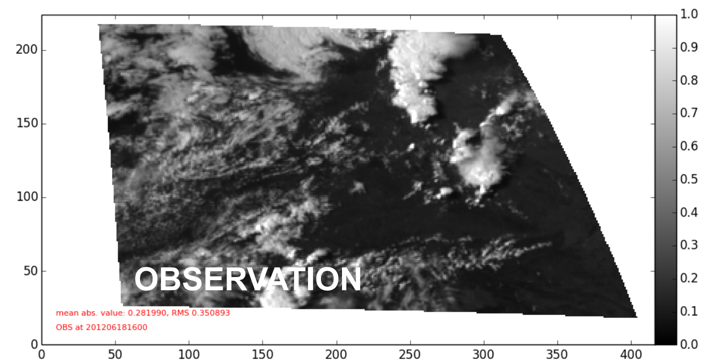
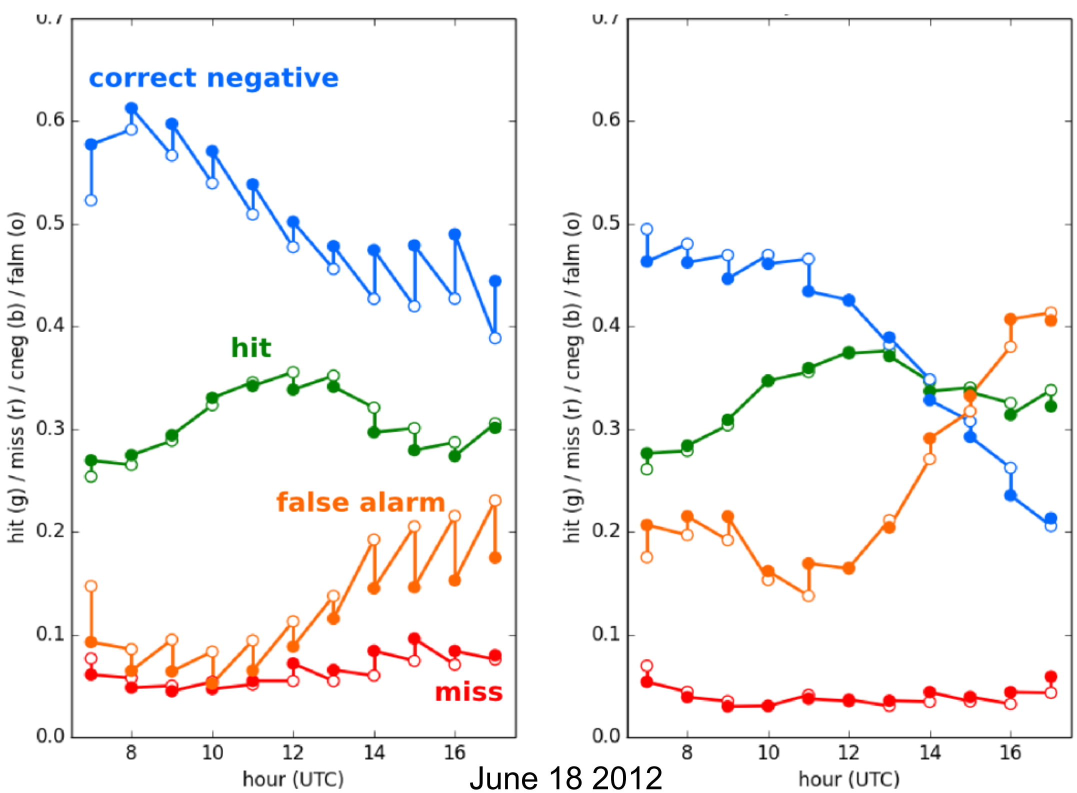






Contingency table entries for cloudy / cloud free



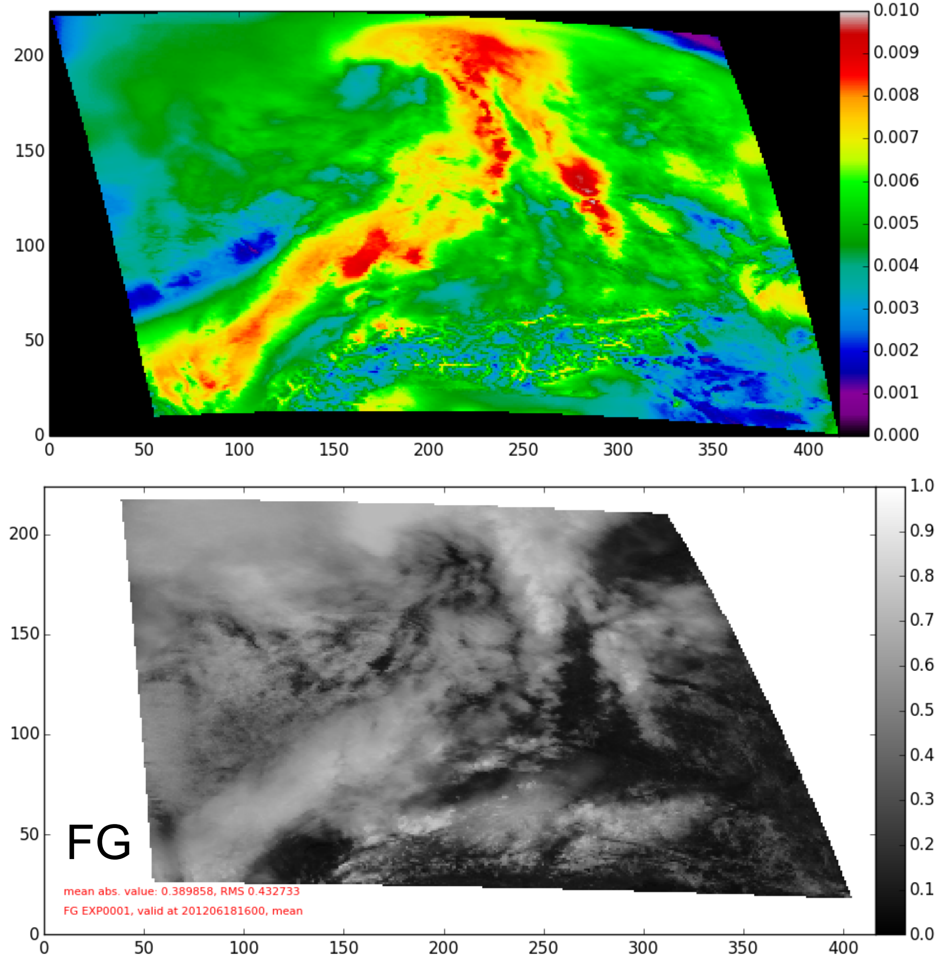
→ False alarm clouds strongly reduced!

First assimilation results

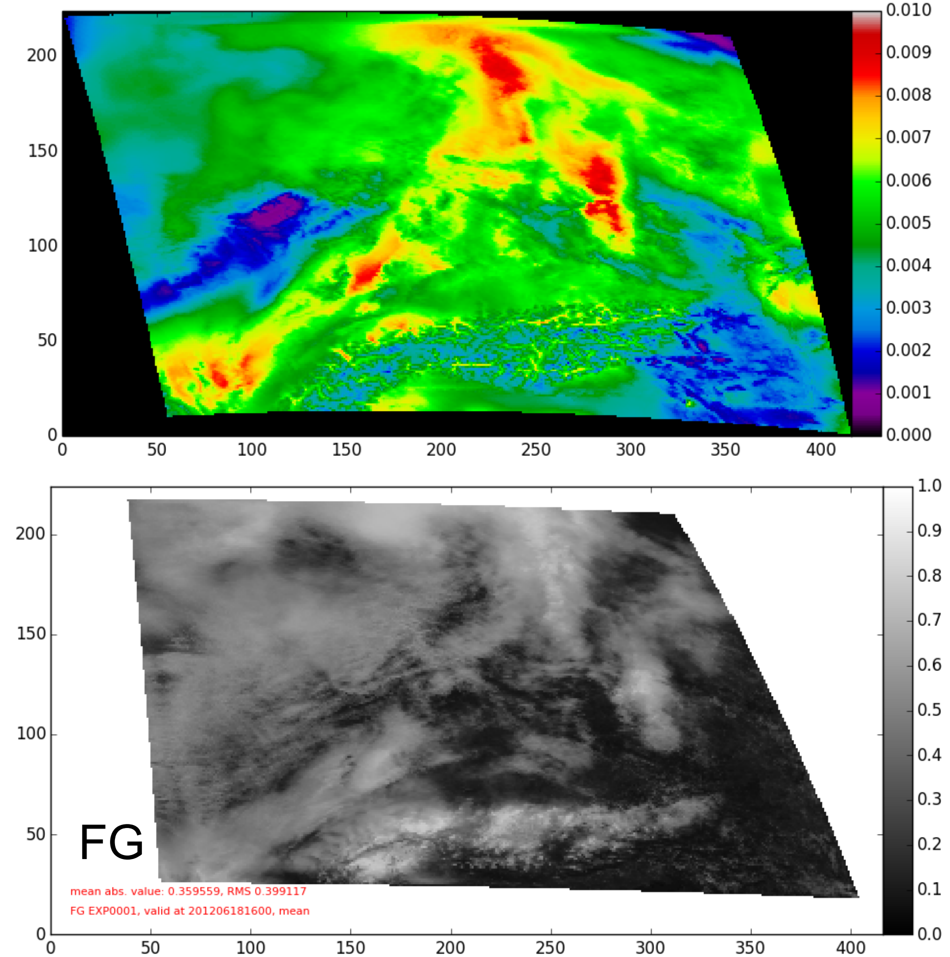
Impact on moisture

specific humidity on model level 33

conventional obs.



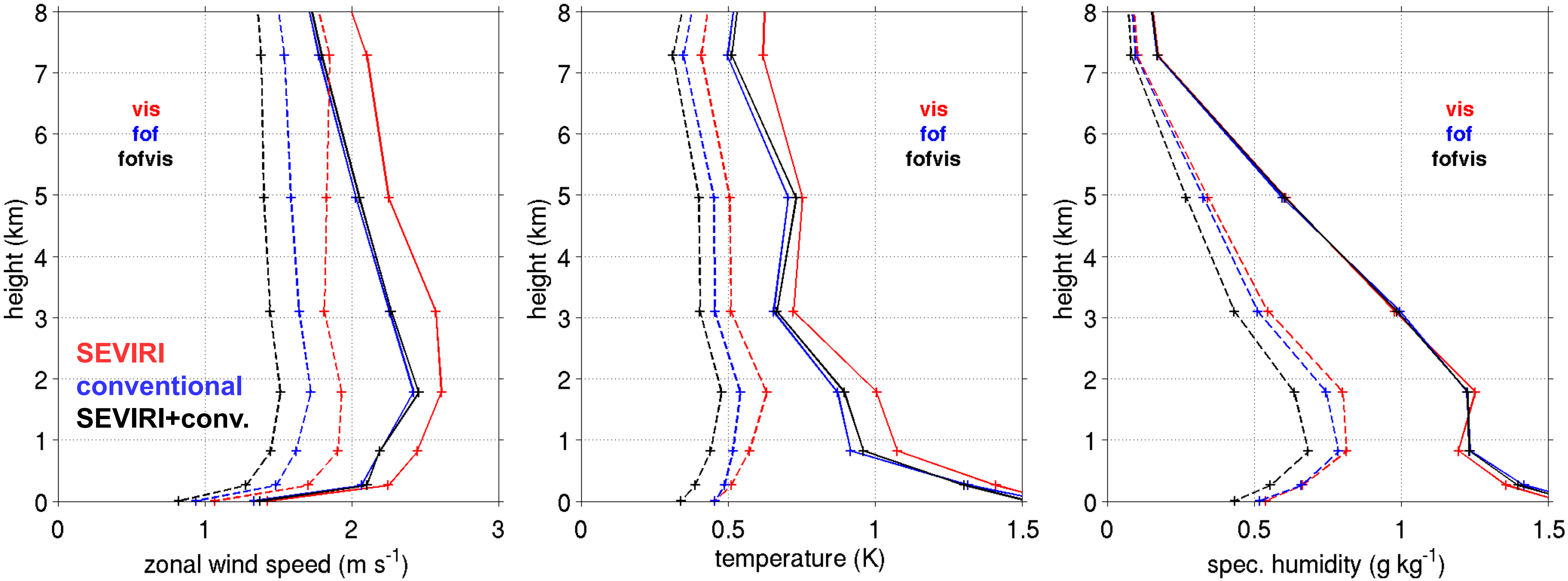
SEVIRI 600nm



First assimilation results

Comparison with operational analysis

Solid: 1h FC RMSE Ensemble Mean wrt. COSMO-DE analysis
Dashed: 1h FC Ensemble Spread



Next step: Verification with observations

SUMMARY

- We developed a **forward operator for VIS/NIR satellite images**:
  - **sufficiently fast** for use in operational data assimilation system
  - **sufficiently accurate** (with some limitations)
- First assimilation experiments with KENDA LETKF:
  - RMS **reflectance error is significantly reduced**
  - prediction of cloudy / cloud-free situations strongly improved

OUTLOOK

- **Operator refinements** (3D effects in HD(CP)2, glory, NIR)
- **Systematic errors in model clouds** (see talk T.Necker)
- **Optimization of assimilation settings** (ensemble size, localization, ...)
- **Assessment of forecast impact** of SEVIRI observations