Using solar satellite channels for convective-scale data assimilation

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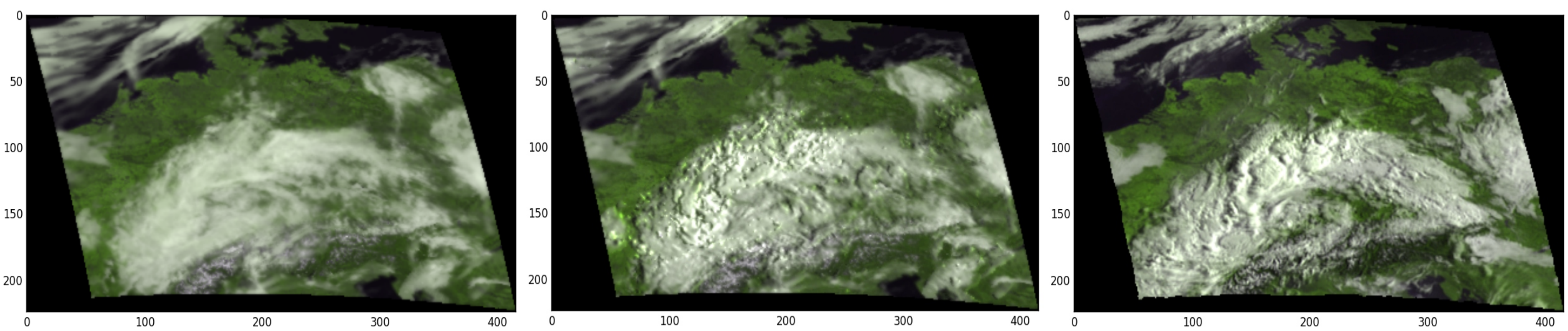
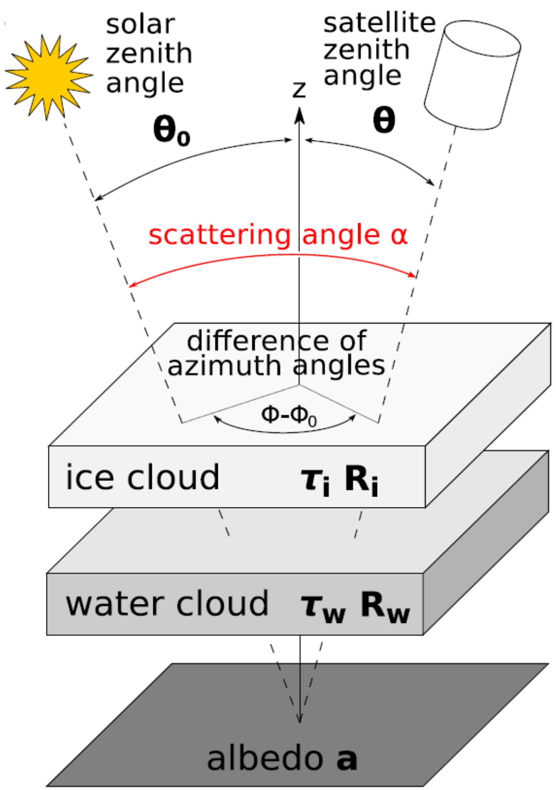


Solar satellite channels and radiative transfer

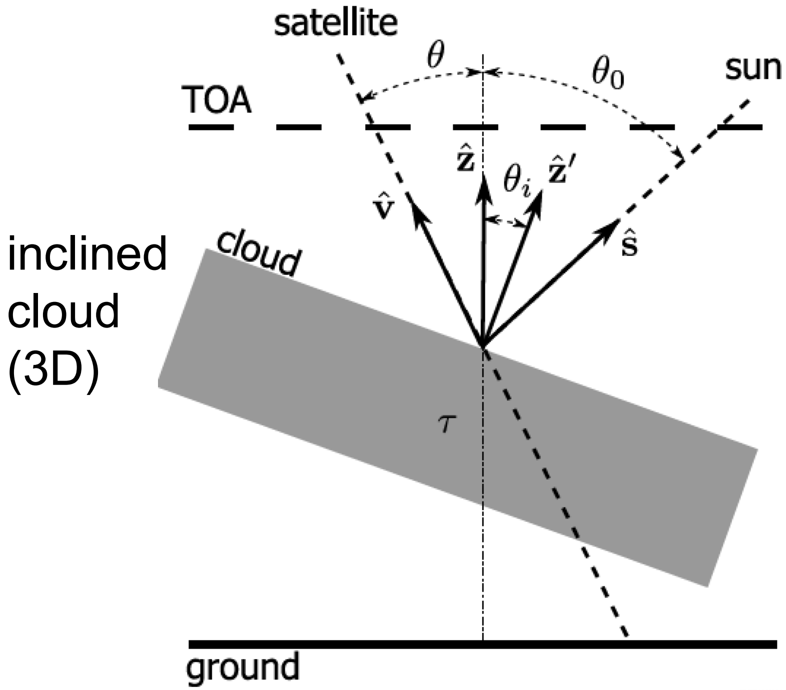
- Solar channels (λ<4µm,visible+IR): **high-resolution information on clouds**
- Multiple scattering makes radiative transfer (RT) complex → sufficiently fast forward operators for convective scale data assimilation (DA) not available

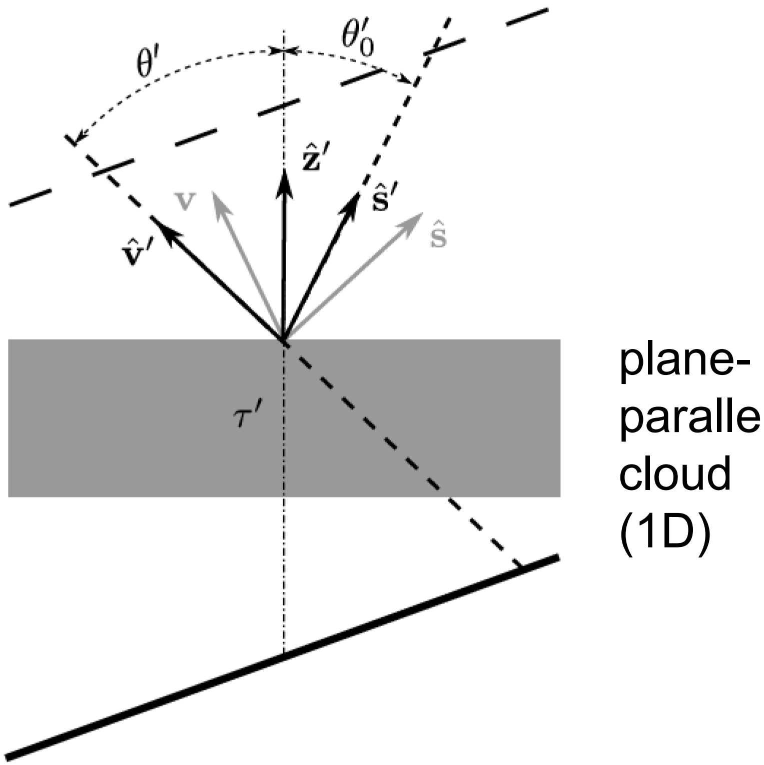


→ development of **MFASIS** (Method for Fast Satellite Image Synthesis), a 1D RT method based on look-up tables computed with standard methods

- Key ideas: **simplification of vertical structure** (8 parameters to define clouds & geometry), **lossy LUT compression** (8GB→ 21MB, Fourier coeff. for constant scattering angle)
- **4 orders of magnitude faster** than discrete ordinate method (DISORT) → fast enough for operational DA
- **SEVIRI 0.6µm: Relative error wrt. DISORT: < 2%** (calibration error 4%). Does not include 3D RT errors...
- Will be included in next **RTTOV** release (as a part of DWDs contribution to NWP-SAF, work in progress)

Accounting for 3D RT effects: Cloud top inclination

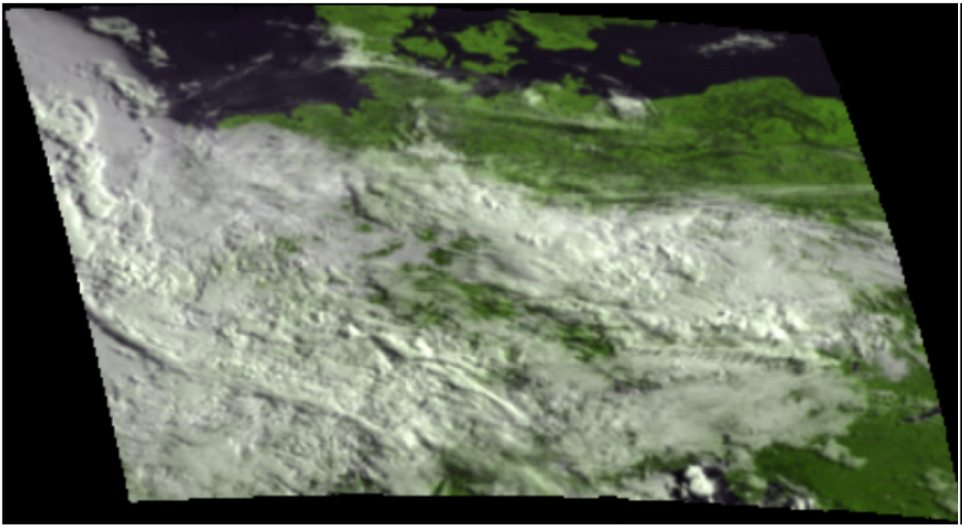




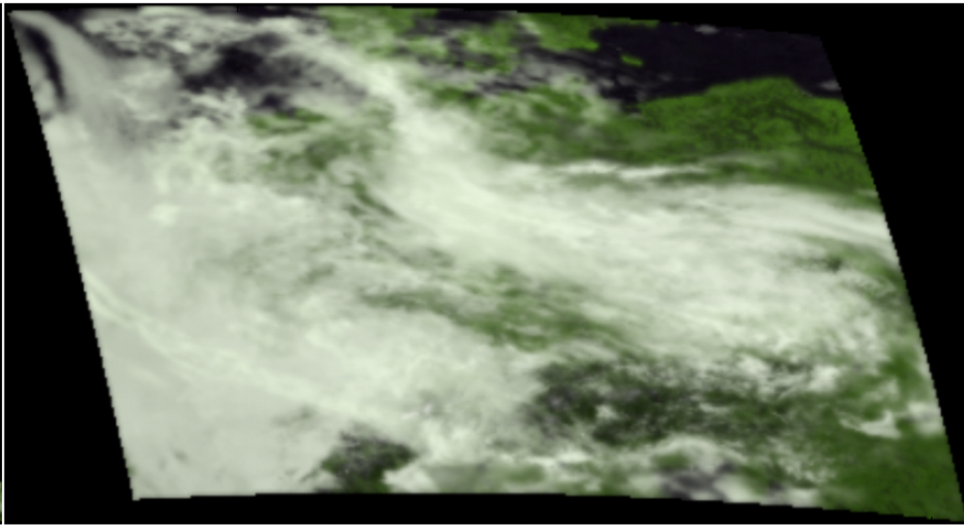
$$R_T(\theta, \theta_0, \alpha, A, \tau, \theta_i) = R(\theta', \theta_0', \alpha, A', \tau \cos\theta_i) \frac{\cos\theta_0'}{\cos\theta_0}$$

Rotated frame of reference with ground-parallel cloud → nearly a 1D problem (inclined ground is taken into account by using a modified surface albedo)
→ Solve modified 1D problem, transform back to non-rotated frame.

Cloud top inclination



SEVIRI 0.6mu+0.8mu, 3 June 2016, 6UTC

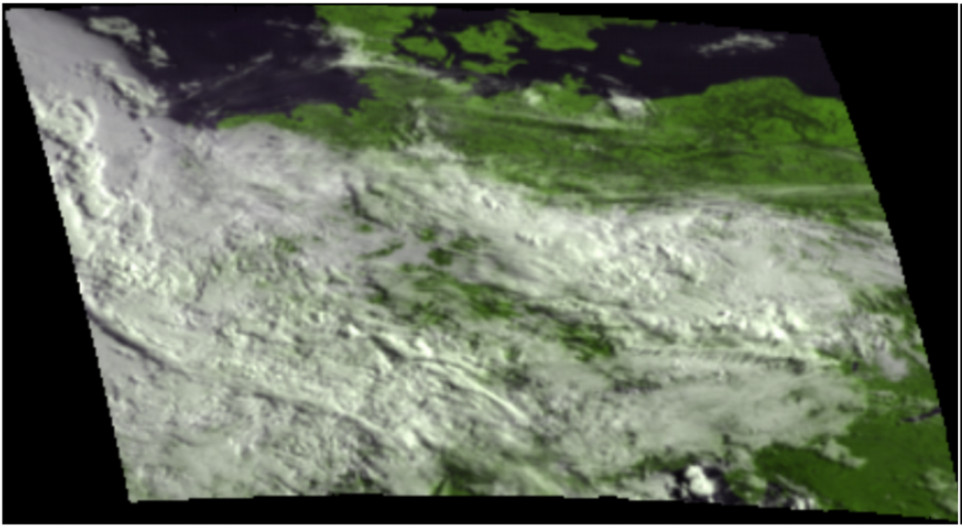


3h COSMO fcst **without 3D correction**

Cloud top definition : optical depth 1 surface
(detect tau=1 in all columns, fit plane to column and 8 neighbour columns)

Cloud top inclination correction → Increased information content
Much more cloud structure is visible, in particular for larger SZAs
For instance, one can distinguish convective from stratiform clouds

Cloud top inclination



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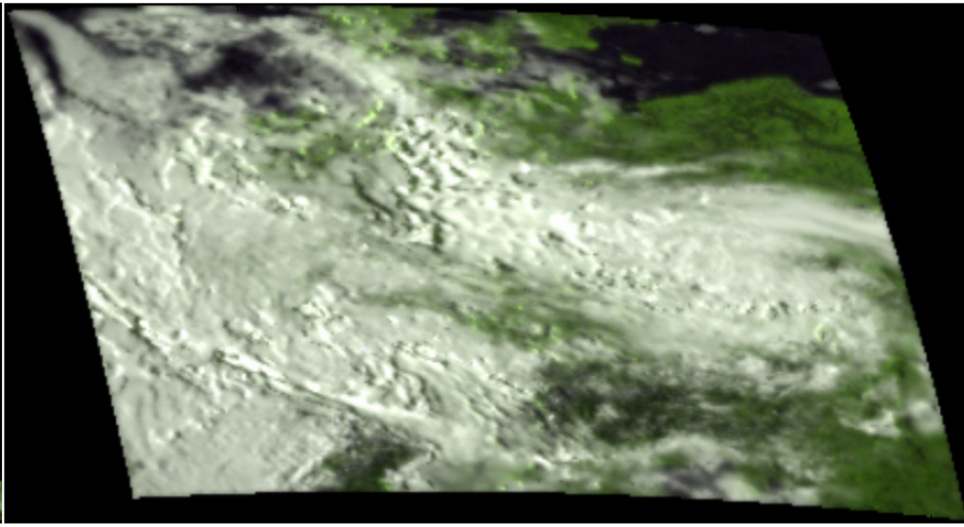

3h COSMO fcst **with 3D correction**

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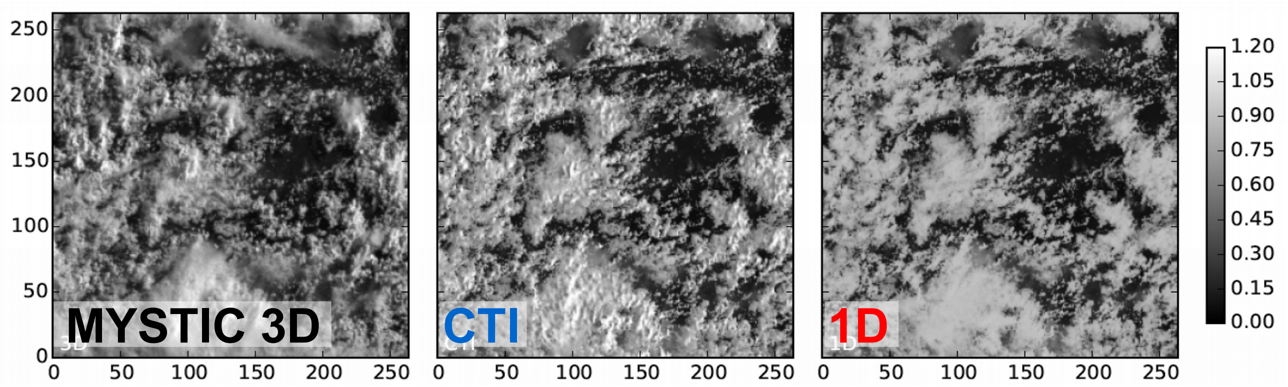
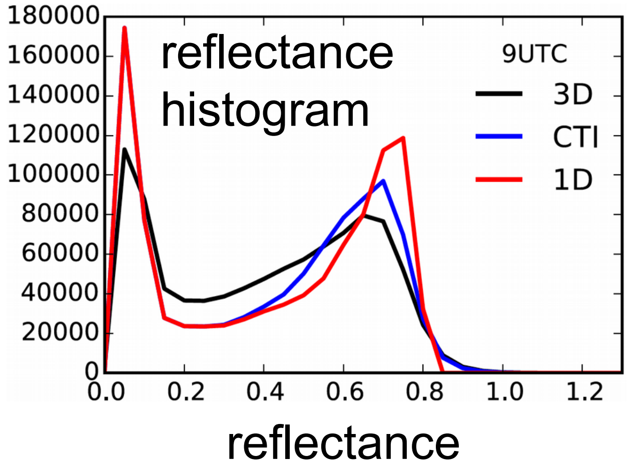
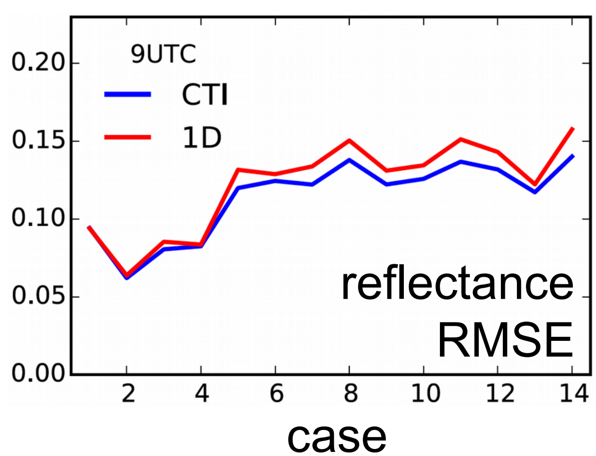
Comparison with 3D Monte Carlo RT calculations

"Does it just look prettier, or are the errors really reduced?"



Clean comparison (only RT errors, no model errors) based on 156m ICON runs from HD(CP)2 project:

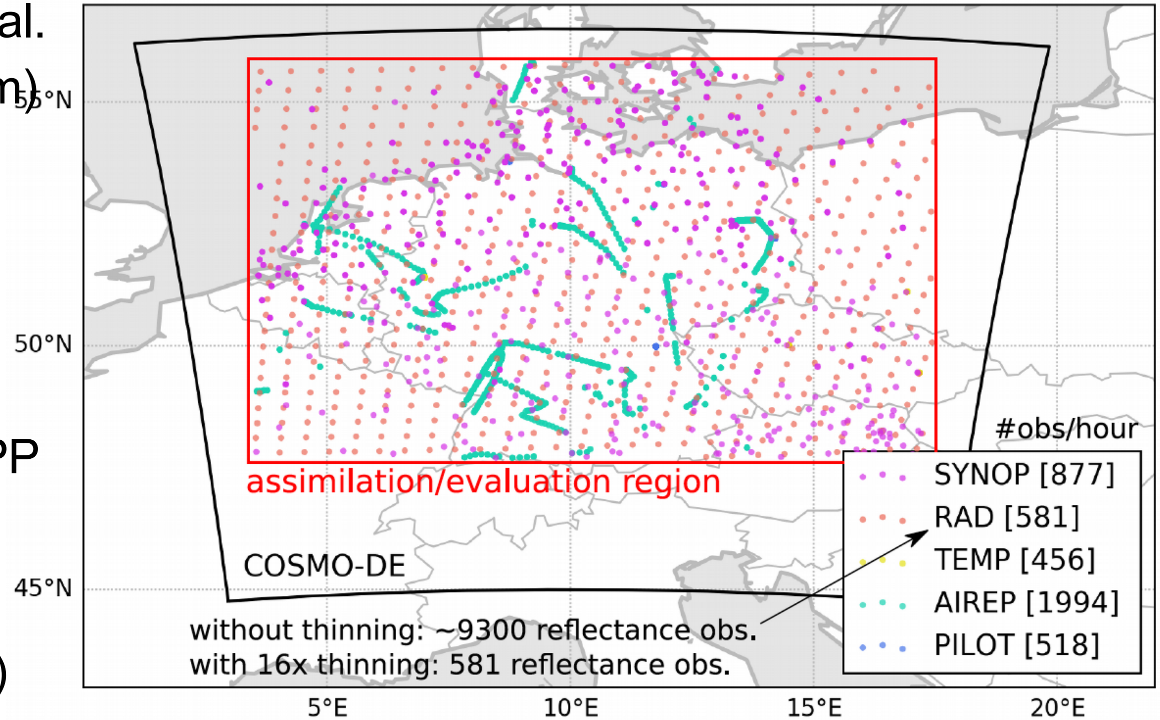




- RMSE is reduced
- Histogram shape is improved
- Other 3D effects are still missing (e.g. shadows, flux through cloud sides)

LETKF Assimilation experiments

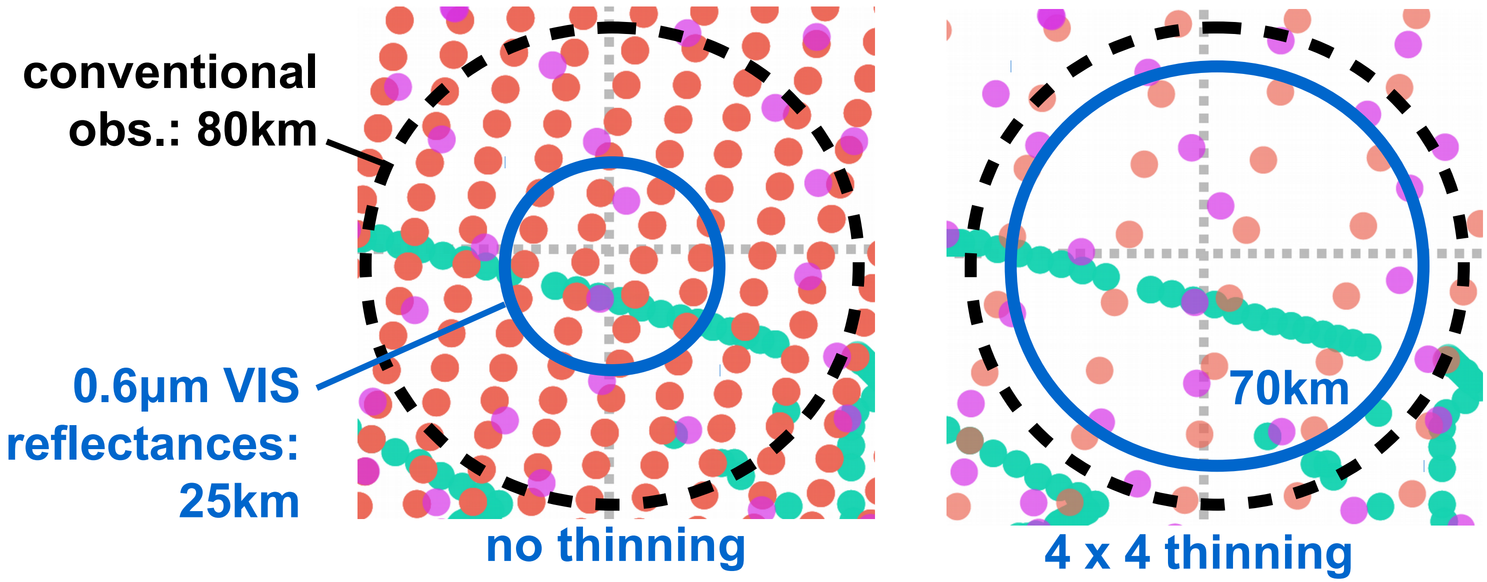
- **Codes:** KENDA (Schraff et al. 2016) + COSMO-DE (2.8km)
- **Case:** 5 June 2016
- **Ensemble:** 40 members
- **Assimilation window:** 1h
- **Covariance inflation:**
  Additive + multiplicat. + RTPP
- **Conventional obs.:**
  SYNOP, TEMP, Profiler, AMDAR (no MODE-S, LHN)
  ~5000 observations/hour



- **Reference runs:** Cycling with conv. obs. from June 4th, 21UTC - June 5th,18UTC
- **Runs with conventional obs. + 0.6µm VIS SEVIRI channel:**
  Branched from ref. run at 5UTC → first analysis at 6UTC

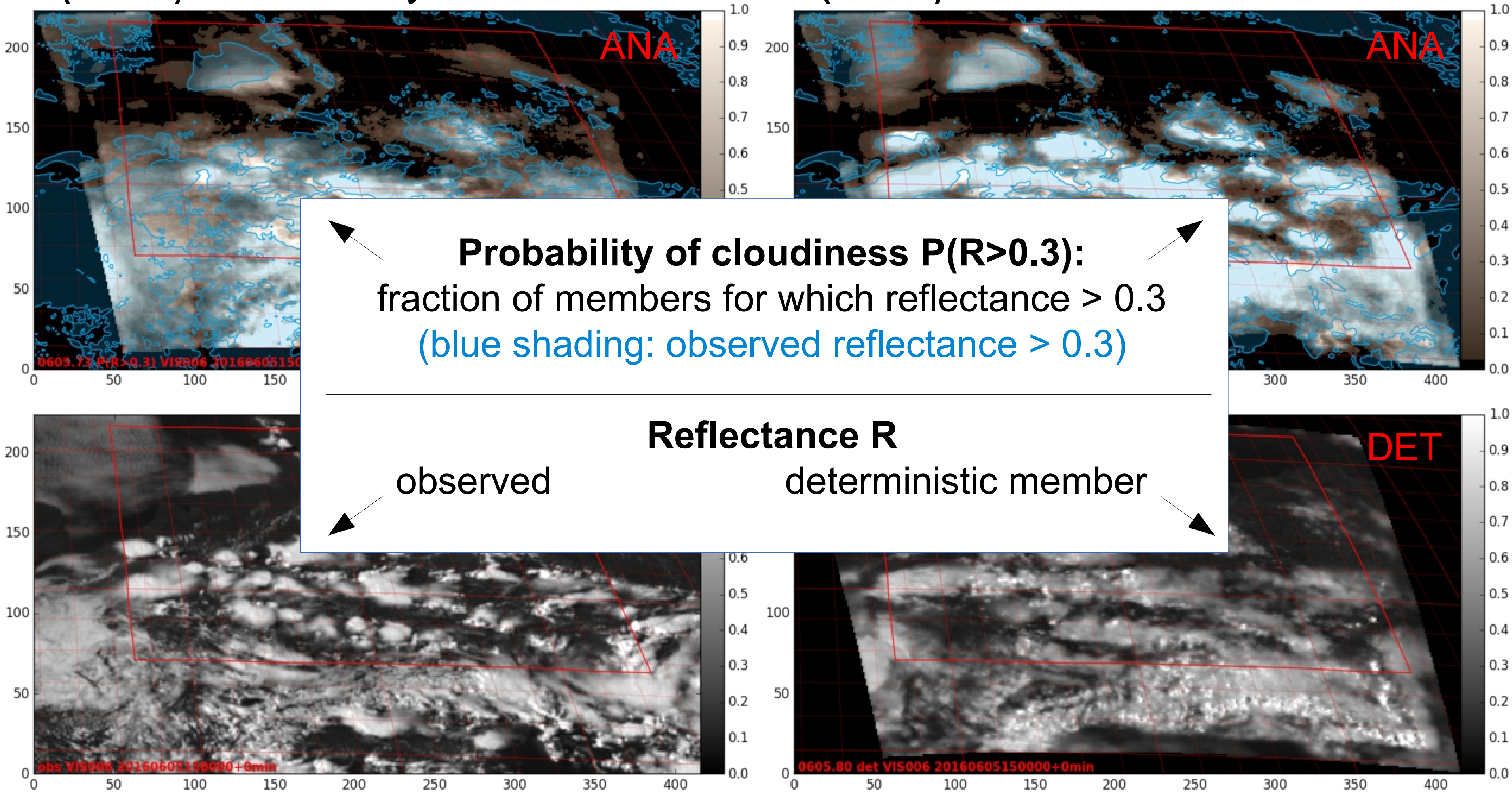
Superobbing, Thinning and Localization

- **Superobbing:** 3 x 6 pixels → 18 x 18 km² in model space, O(eff. model resolution)
  Reflectance obs. every 15min → 9255 reflectance superobs. per hour (> conv. obs.)
- **Thinning**, e.g. factors 4 in space & time → 581 superobs. per hour (< conv. obs.)



- **Different localizations** (to avoid that VIS overwhelms conv. or vice versa)
  - Aim for both conv. and VIS: **#obs. / grid point ~ O(ensemble size)**
  - Reflectances: **No vertical localization** (→ see talk by Lilo Bach…)

P(R>0.3) only conventional obs. **P(R>0.3)** conventional + SEVIRI 0.6mu

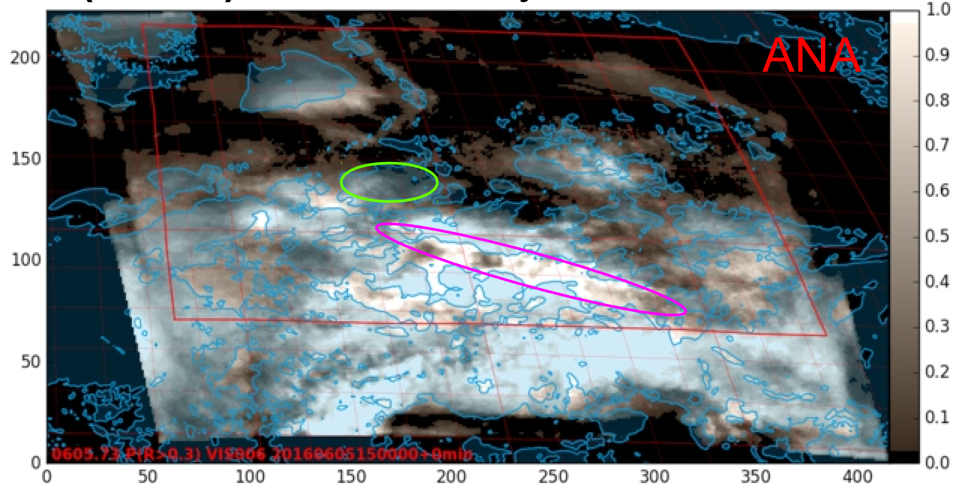


Probability of cloudiness P(R>0.3):
fraction of members for which reflectance > 0.3
(blue shading: observed reflectance > 0.3)

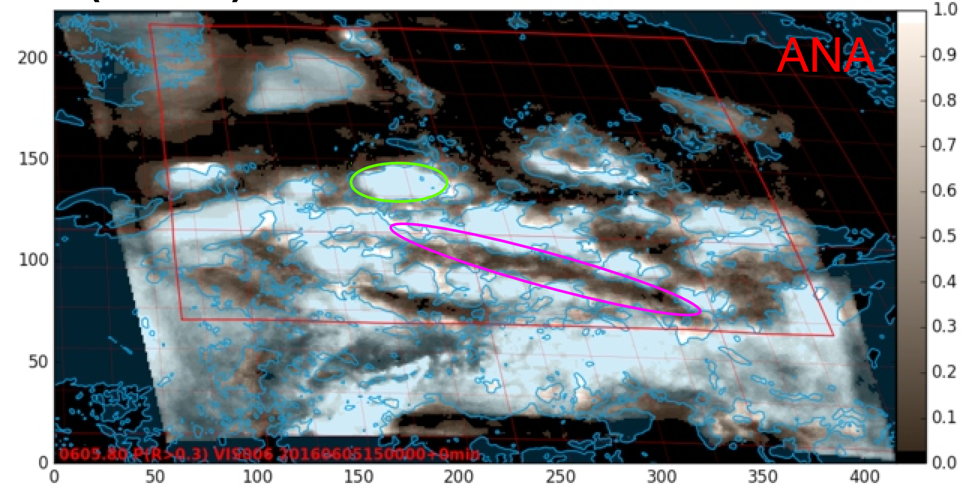
Reflectance R
observed deterministic member

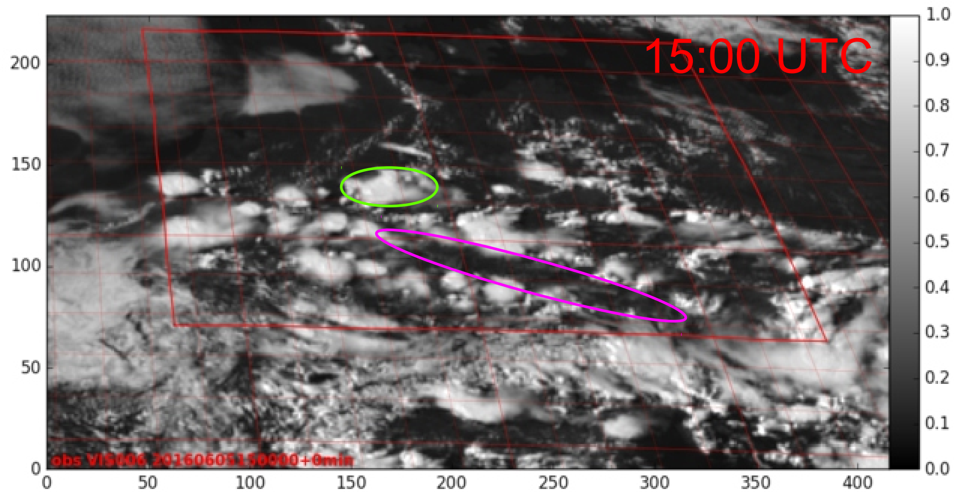
R SEVIRI 0.6mu observation **R** det. member from conv. + SEVIRI

P(R>0.3) only conventional obs.

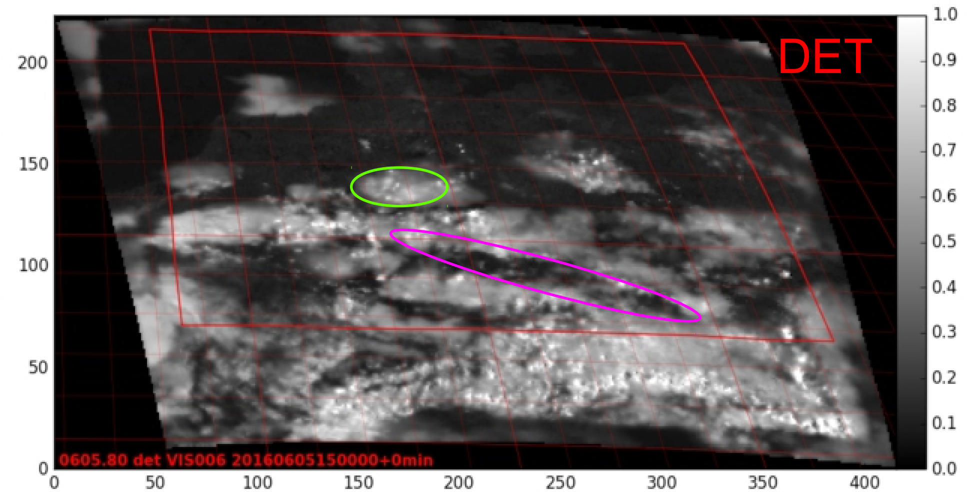


P(R>0.3) conventional + SEVIRI 0.6mu



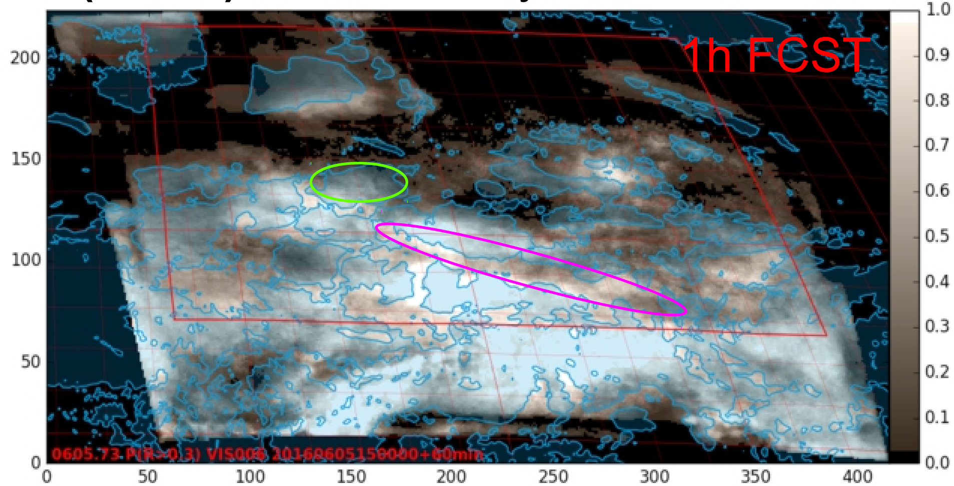


R SEVIRI 0.6mu observation



R det. member from conv. + SEVIRI

P(R>0.3) only conventional obs.



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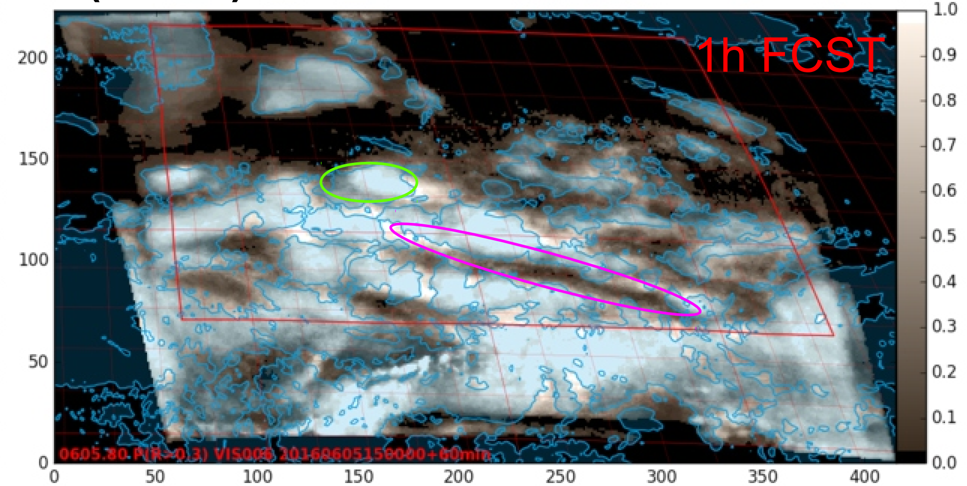

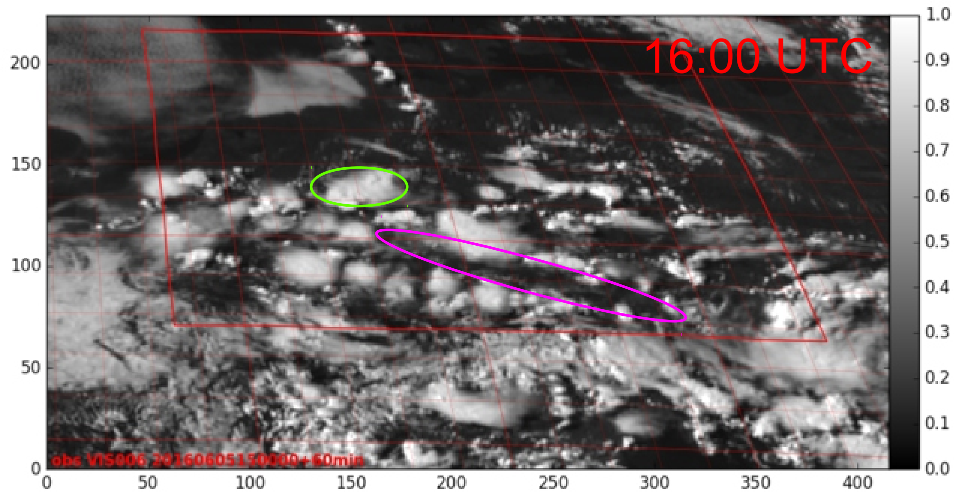

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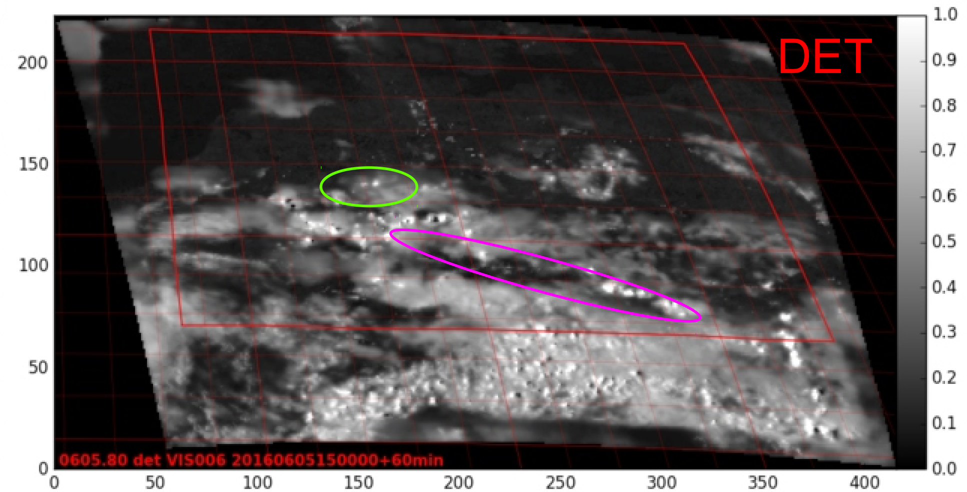

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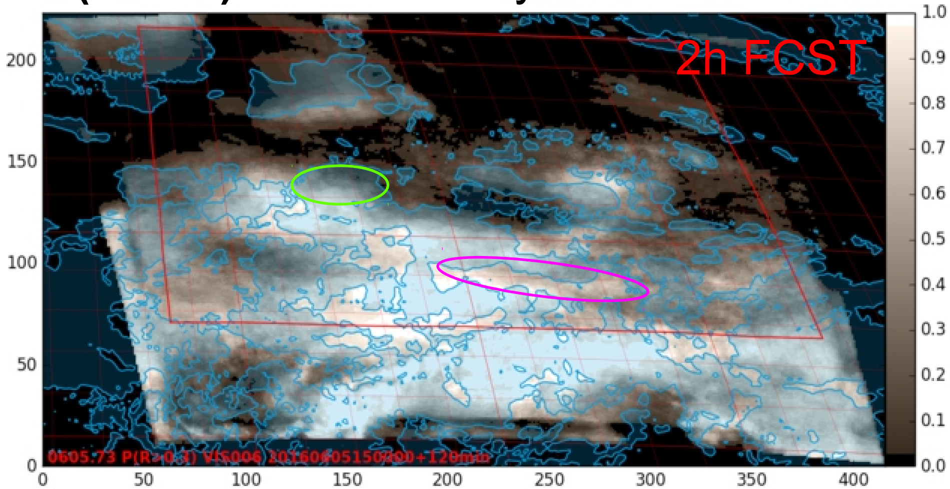

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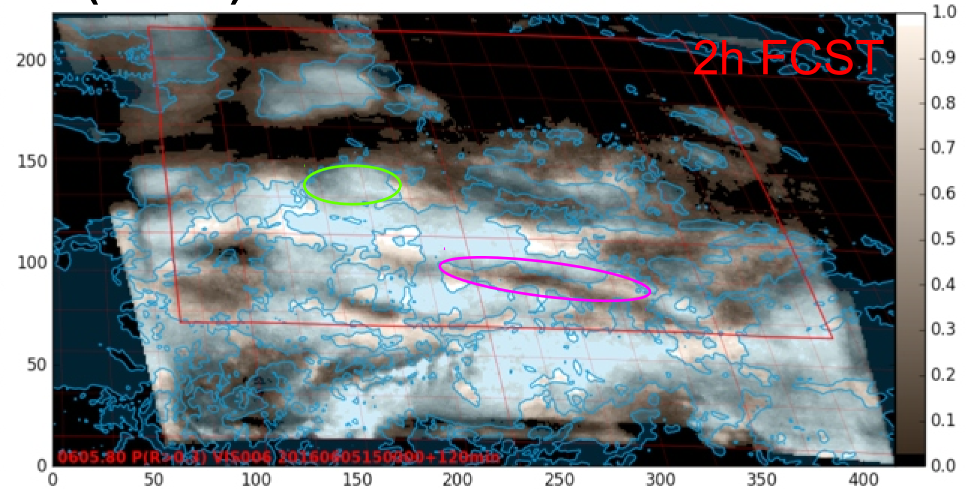
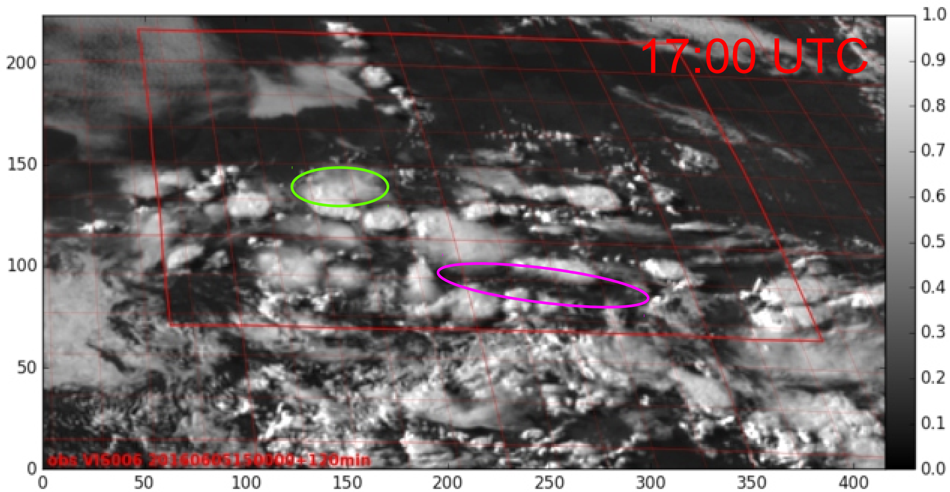
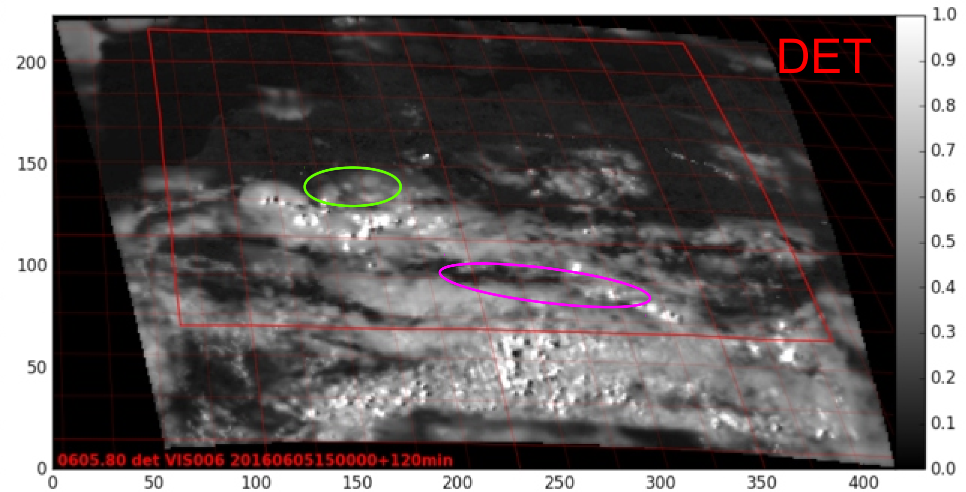


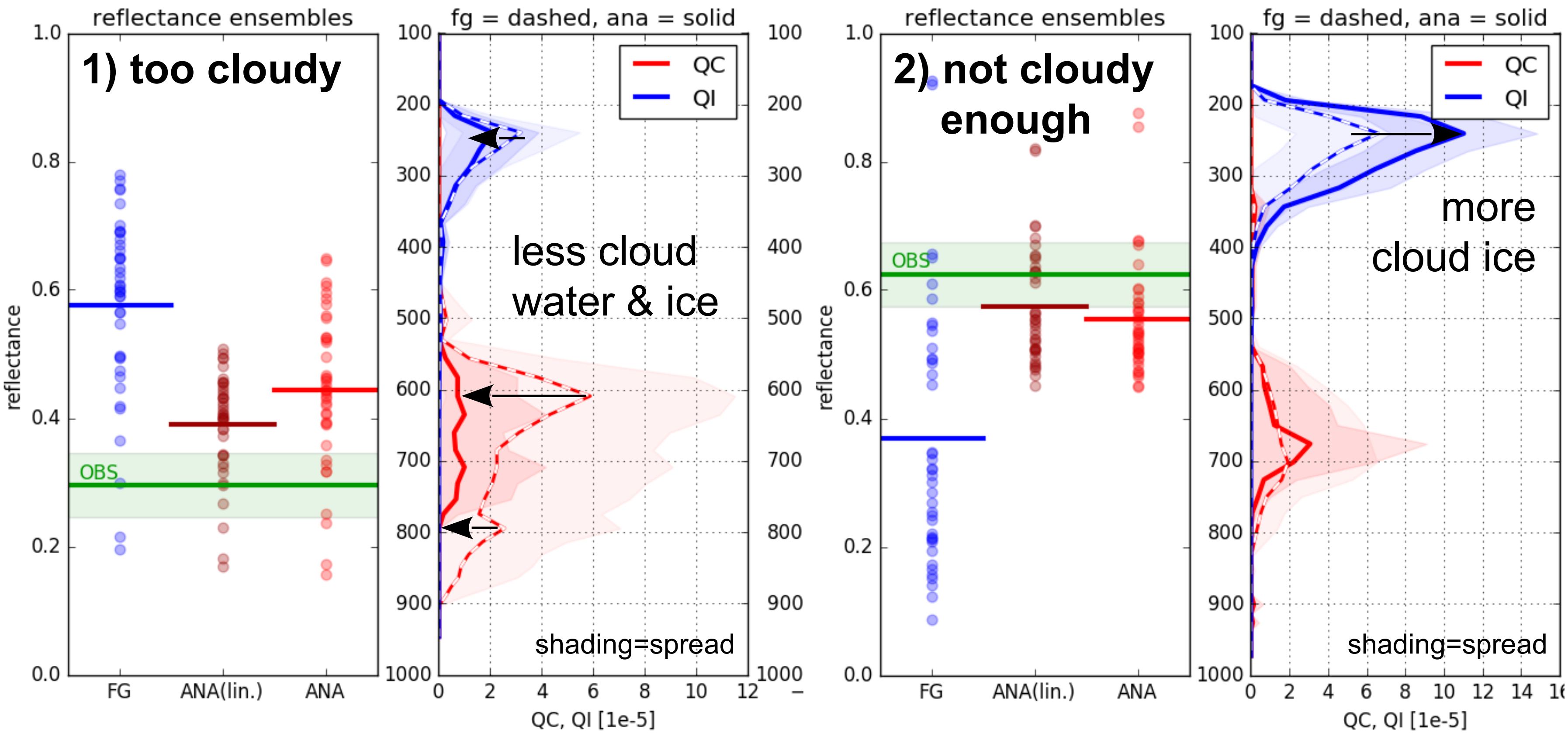


R SEVIRI 0.6mu observation



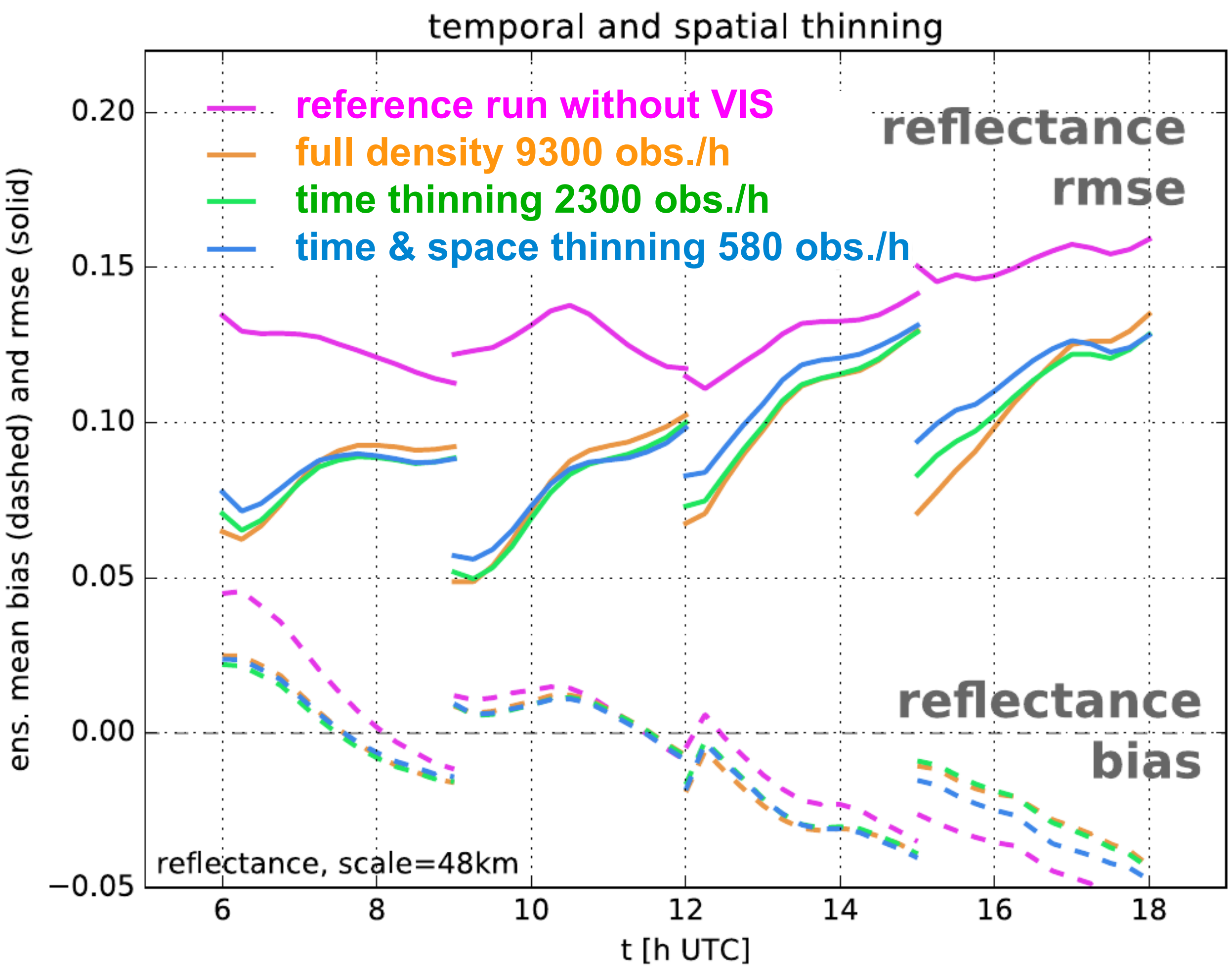
R det. member from conv. + SEVIRI

Single observation experiments



- Model equiv. computed with **nonlinear** operator differ from LETKF estimate
- **Ambiguity** of VIS: LWC, IWC, RH are modified → resolve using other channels?
- More single observation experiments -> talk Lilo Bach...

Reflectance error evolution for different assimilation settings



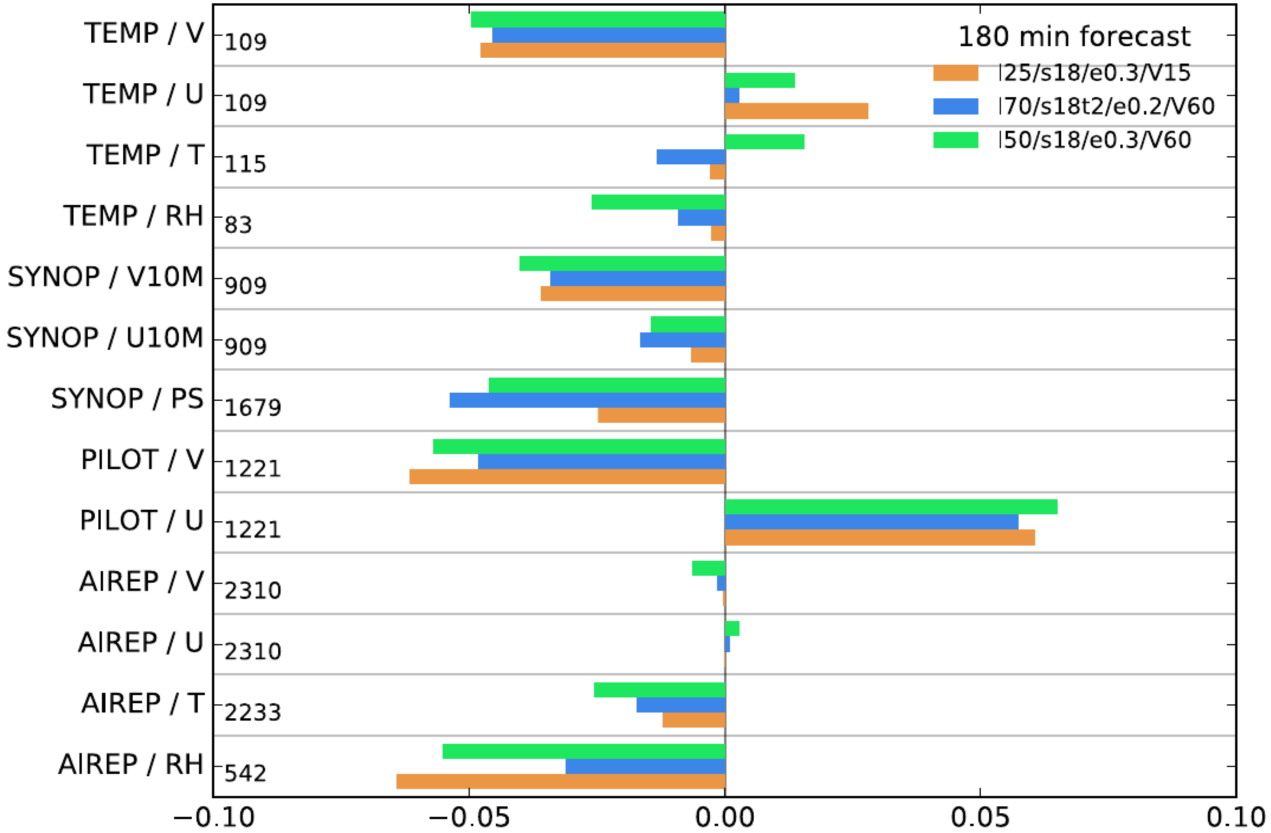
RMSE is smaller than in **reference run** for all settings even after >3 hours.
Bias evolution: some clouds dissolve

Full obs. density: (~9300 obs./hour), obs. error 0.3 is better than 0.2 (corr. err.?)

Temporal thinning improves 3h fcsts

Temporal & spatial thinning: similar 3h fcst results

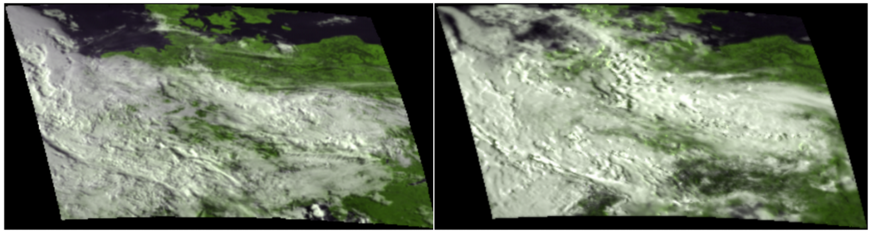
Impact on conventional observations

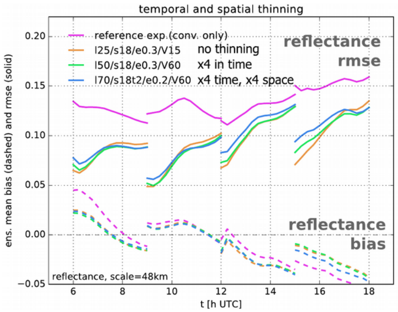


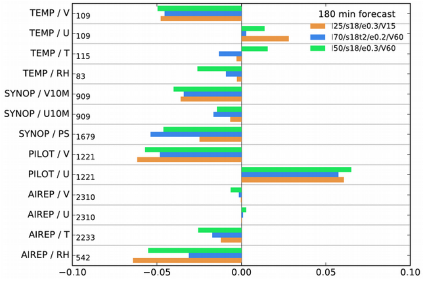
Relative change in RMSE of 3h forecasts caused by VIS assimilation: Mostly beneficial. But this is for only one day… → talk by Lilo Bach!

Summary

- MFASIS is sufficiently fast for the operational assimilation of visible satellite images
- Computationally efficient cloud top inclination parameterizations reduces the systematic error
- Assimilation experiments with KENDA: improved reflectances forecasts for > 3h, mostly beneficial impact on conventional observations

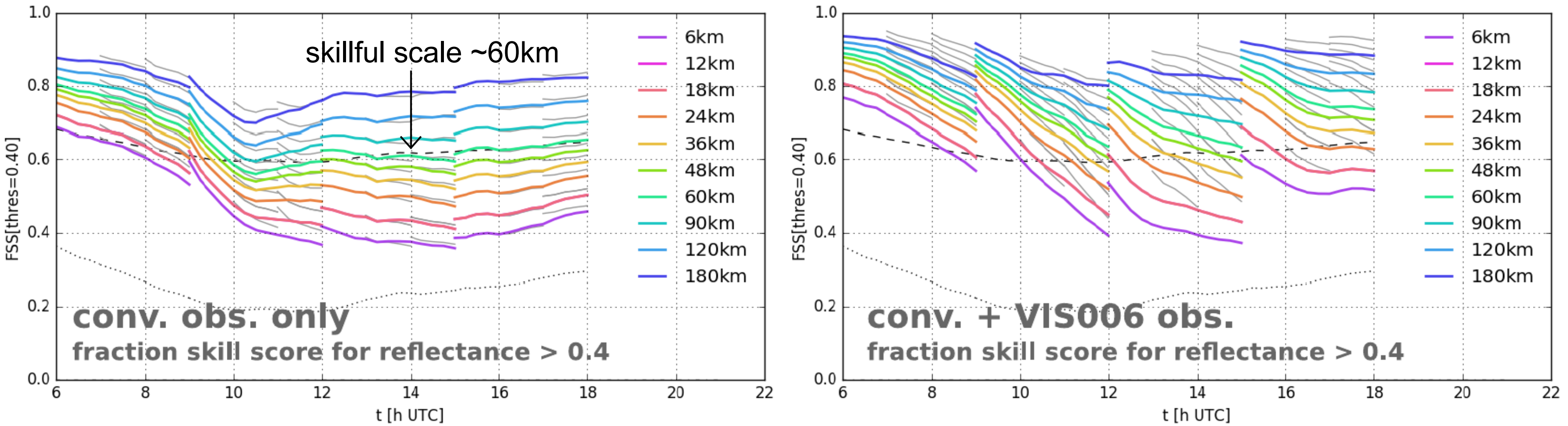






Publications:
Scheck, Frerebeau, Buras-Schnell, Mayer (2016): *A fast radiative transfer method for the simulation of visible satellite imagery*, Journal of Quantitative Spectroscopy and Radiative Transfer, 175, 54-67.
Scheck, Hocking, Saunders (2016): *A comparison of MFASIS and RTTOV-DOM*, NWP-SAF 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*, JTECH, accepted

Evolution of skill / error growth



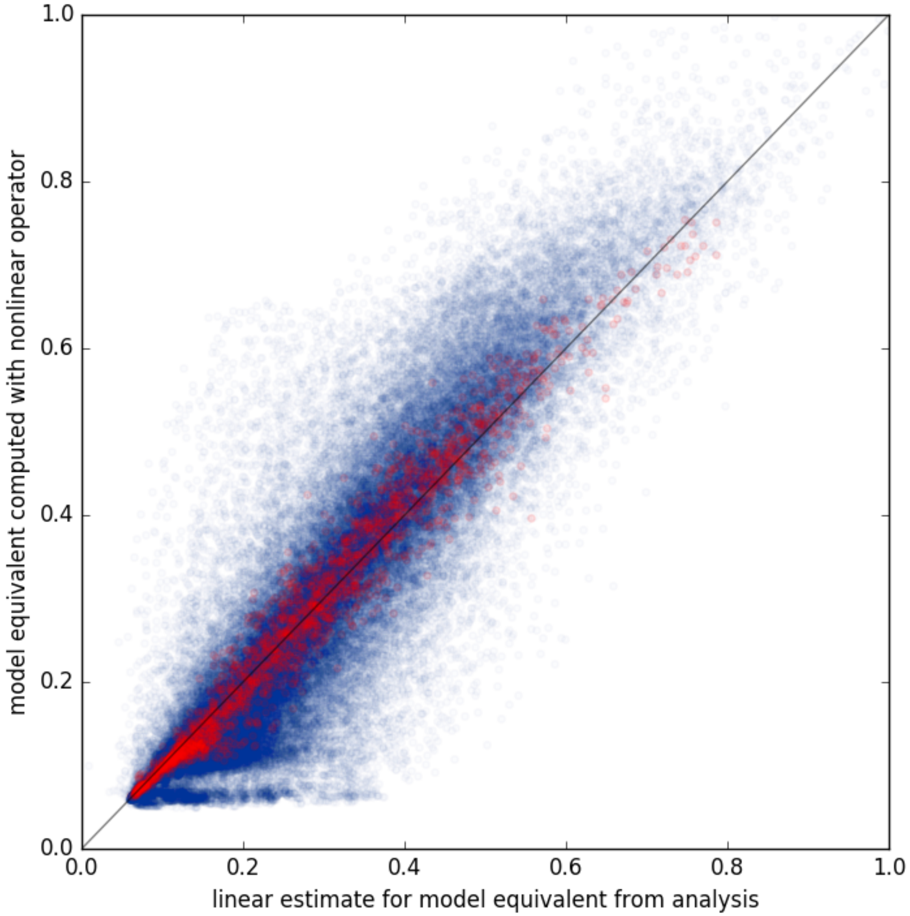
Ensemble FSS for reflectance > 0.4 (for 3h forecasts):

- Without VIS “skillful scale” (dashed line) ~60km after convection sets in analysis does not improve skill significantly
- With VIS assimilation: Skill is improved in each analysis for all scales, skillful scale reaches 60km only after 3h or longer

Error growth mechanisms:

- Decorrelation (could be reduced by improving wind field)
- Imbalanced or inconsistent analysis state (e.g. LWC > 0, RH < 100%)

Nonlinearity of the operator



Comparison of linear estimate for analysis model equivalents from LETKF and actual model equivalents obtained by applying nonlinear operator to analysis (incl. inflation, saturation adjustment):
Significant differences for individual (super-)observations (blue), less impact on ensemble mean (red).

Reduces effectiveness of LETKF for large increments
→ avoid long assimilation intervals, assume larger observation errors? Outer-loop-like strategies?