Assimilation of visible channels: Experiments in convective-scale short-range NWP

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ECMWF / NWPSAF / JCSDA workshop on assimilating cloud and precipitation observations, 3 – 6 February 2020

Why assimilate visible channels?

➔ Added and complementary value to IR / WV channels:

- Visibility of low clouds
- Only cloud sensitive, sensitive to cloud water/ice

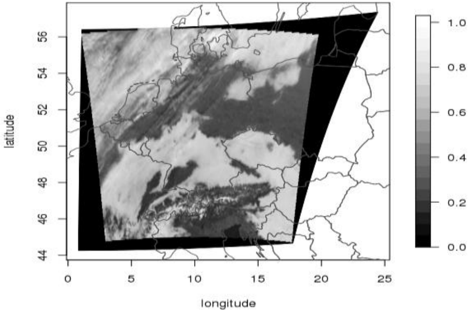
➔ Aim is to improve:

- Cloud analysis & forecast
- Convection - capture initial convective stage (CI)
- Representation of cloud related processes such as precipitation, radiation & boundary layer dynamics
- Application: short range forecasts, renewable energy

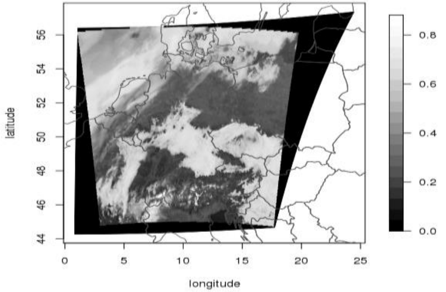
➔ In terms of categories in overview paper Geer at al., 2017, mainly

- Initializing cloud and precipitation
- Improved modelling of cloud and precipitation

Observations



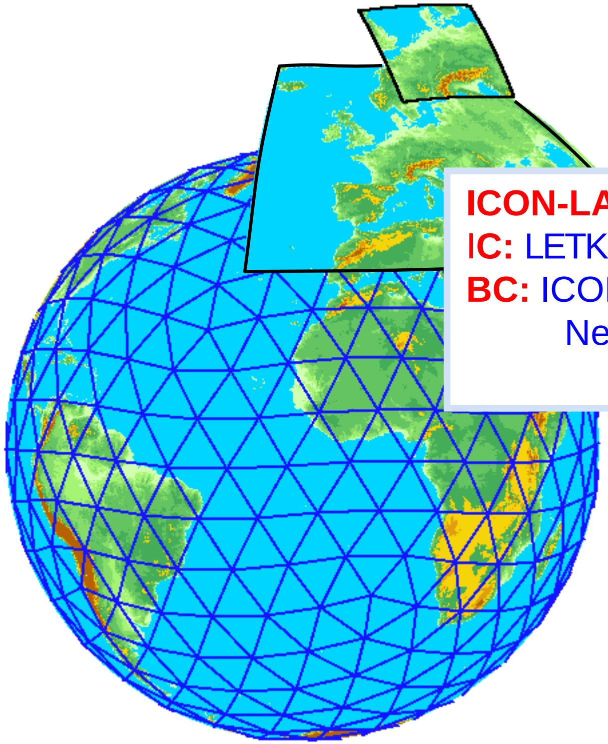
Model equivalents

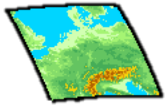


DWD COSMO Model @2.8 km

Context: Very short-range & convection-resolving NWP
SINFONY - project

Deutscher Wetterdienst
Wetter und Klima aus einer Hand





ICON-LAM-D2 ensemble @ 2 km
IC: LETKF ensemble DA
BC: ICON-EU nest ensemble
New forecasts: 3 hourly
range: + 48 h

SINFONY-RUC-ensemble:
ICON-LAM @ 2 km (+ 1 km)
IC: LETKF ensemble DA
+ 3D Radar, SEVIRI-VIS, Lightning
BC: ICON-EU nest ensemble
New forecasts: hourly
Range: + 12 h
combination with Nowcasting

ICON-EU nest ensemble &
deterministic @ 6.5 km

ICON global: ensemble (40 km) &
deterministic (13 km)

(Courtesy: U. Blahak)

SINFONY

Outline

- Observations and forward operator MFASIS
- Convective scale data assimilation system

- Results:
  - Case study
  - Single observation experiment
  - Numerical experiments with new ICON-LAM-D2

- Key challenges for VIS assimilation
- Summary & outlook

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Observations

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- **Visible imager** channels (**0.6 µm**)

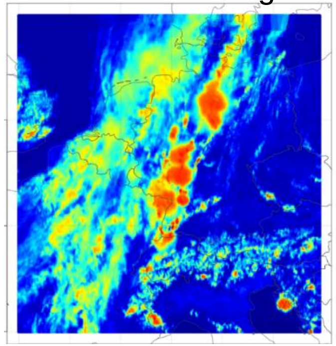
- Geostationary **SEVIRI** on MSG (0°/0°):
  - Temporal resolution: 15 minutes
  - Horizontal: 6 km x 3 km (over German ICON-LAM model domain)

  - **Reflectance** observations:
    - Percentage of reflected solar radiation by clouds and earth surface
    - Sensitive to cloud properties (optical thickness - number of particles, effective radii)

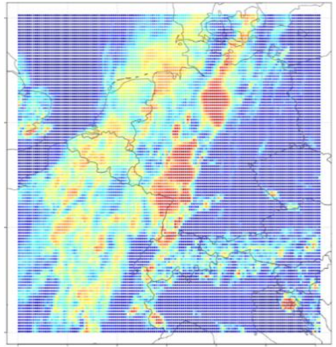
Pre-processing of observations

- Data are used as super-obbed reflectance values
  - Balancing conventional and remote sensing observations
  - Reduction of representativity errors, double penalty problems
  - Computation time of LETKF
  - Model FG values are super-obbed in the same way

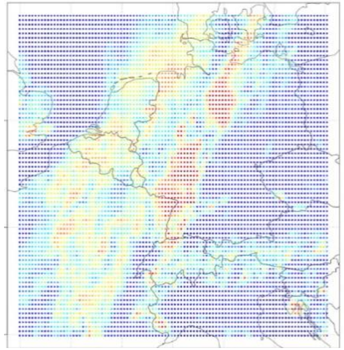
Volle Auflösung



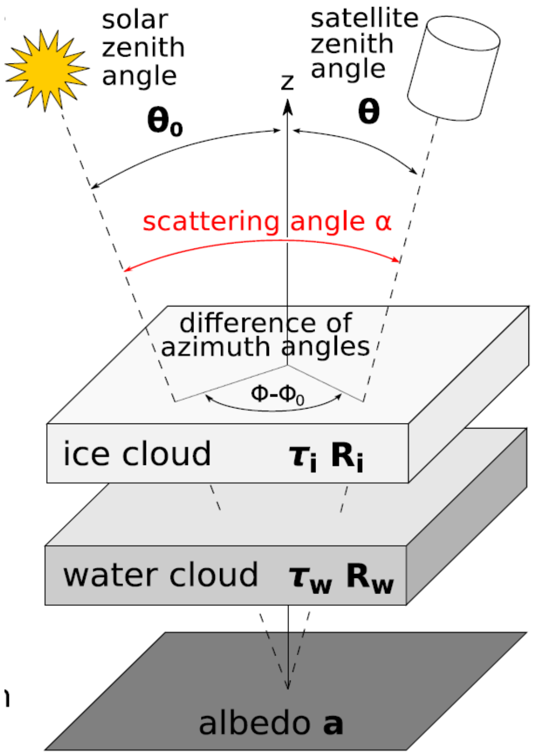
~12 km



~18 km



Forward operator MFASIS



- Very fast forward operator for VIS radiation (reflectance) in presence of clouds
- Uses a look-up table (LUT) approach
- Available in RTTOV (v12.2, v12.3)
- LUTs tuned on DISORT implementation: RTTOV-DOM

LUTs contain:

Fourier coefficients of reflectance

w.r.t. $\theta_0+\theta$ and $\theta_0-\theta$

for given conditions of

- scattering angle, optical cloud properties, albedo
- α , τ_w, τ_i, R_w, R_i , a

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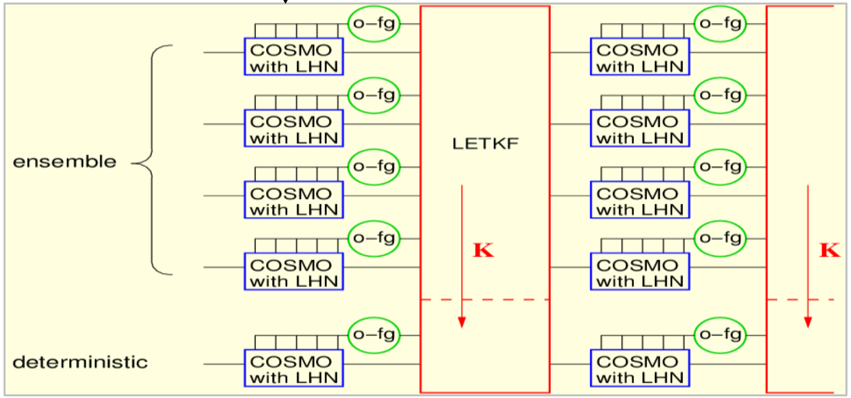
Ensemble data assimilation

- ➔ KENDA: 4D-LETKF (using model equivalents at observation time), 40 members
- ➔ State vector consists of
  - Temperature
  - Specific humidity
  - Pressure
  - Wind components (u, v)
  - Cloud water
  - Cloud ice

  } cloud variables

- ➔ Flow-dependent increments depend on covariances and inter-variable cross-covariances from ensemble
- ➔ Localization in observation space

H(x): RTTOV-MFASIS



LETKF implementation described in Schraff et. al, 2016

DA aspects to be considered

Assumptions in LETKF (and many other DA approaches) :

- Gaussianity of departures for the VIS reflectances
- No systematic biases
- Linearity of forward operator
- Localization of observation

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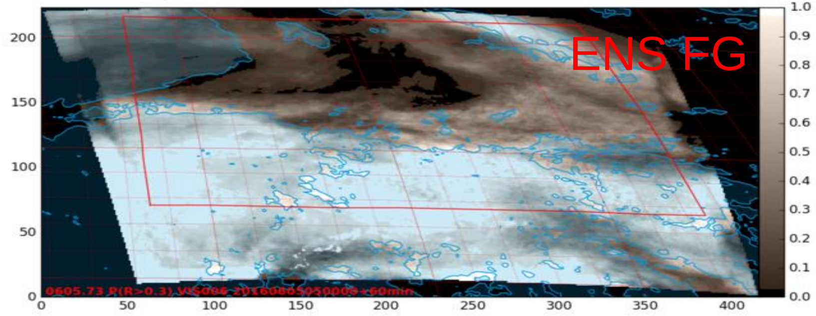
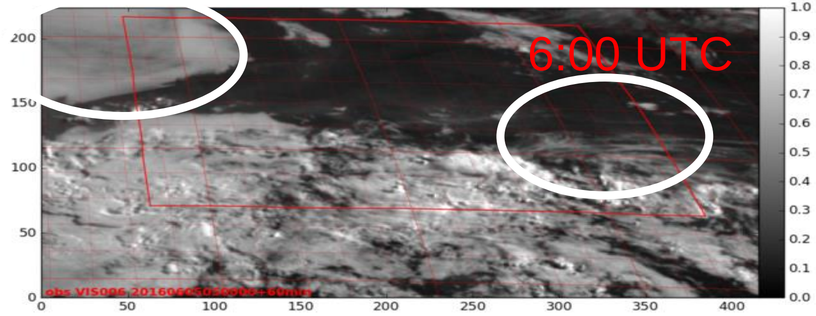
Case study I: First guess at 06 UTC

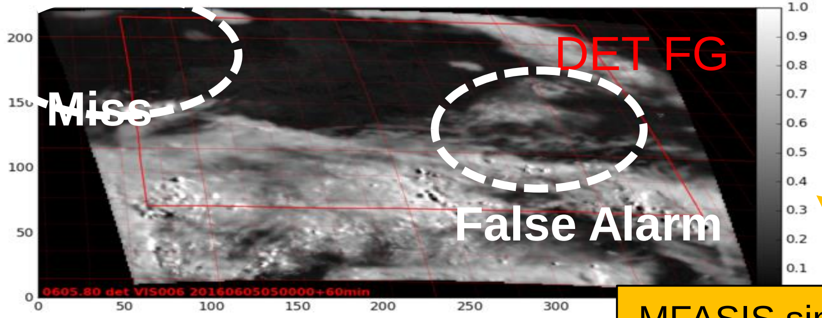
COSMO model

Proportion of clouds in ensemble





Observation



Deterministic run

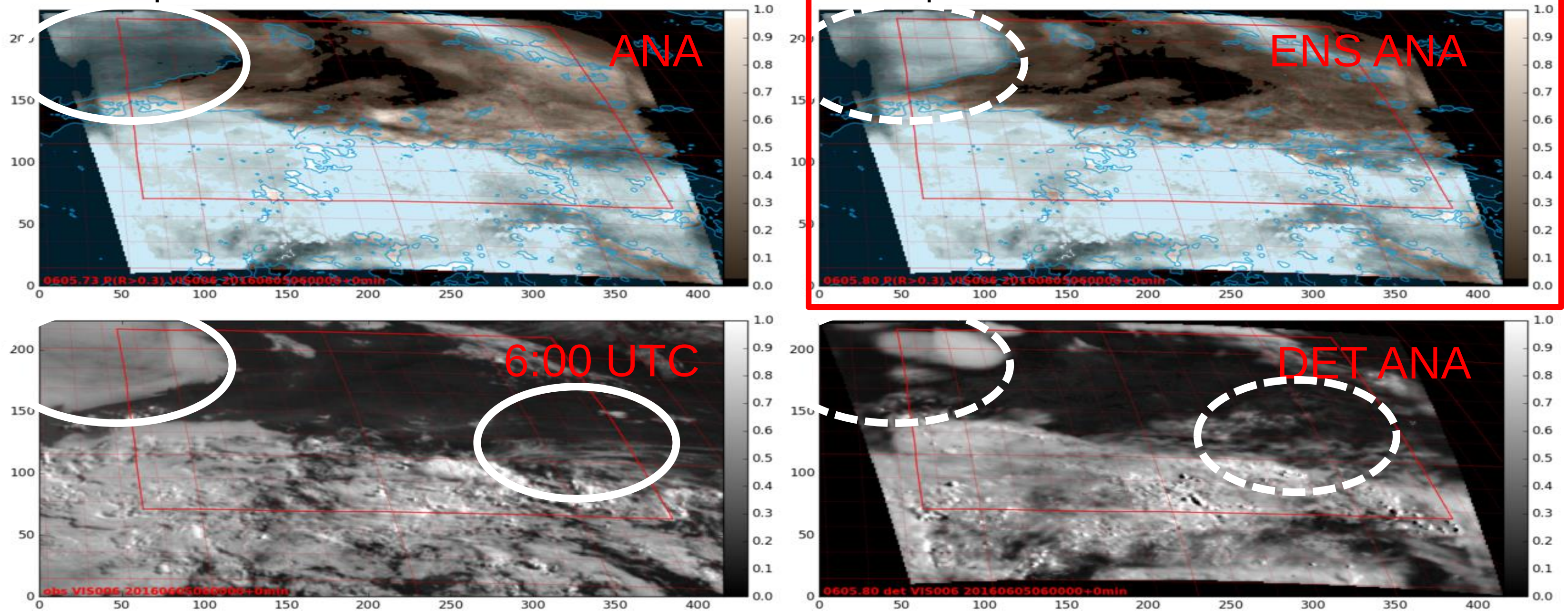
MFASIS simulation of model reflectance

Case study I: Analysis at 06 UTC

With SEVIRI

Proportion of clouds in ensemble

Proportion of clouds in ensemble



Observation

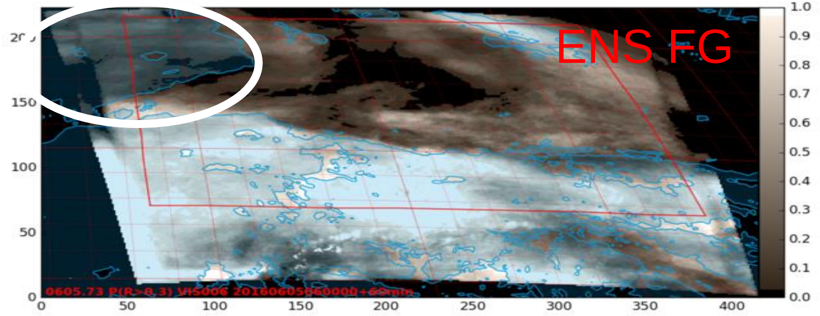
Deterministic run

Case study I: First Guess at 07 UTC

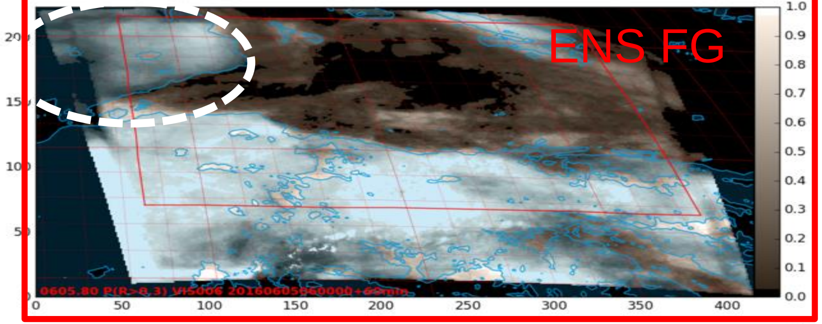
The improvement is kept in the 1h forecast

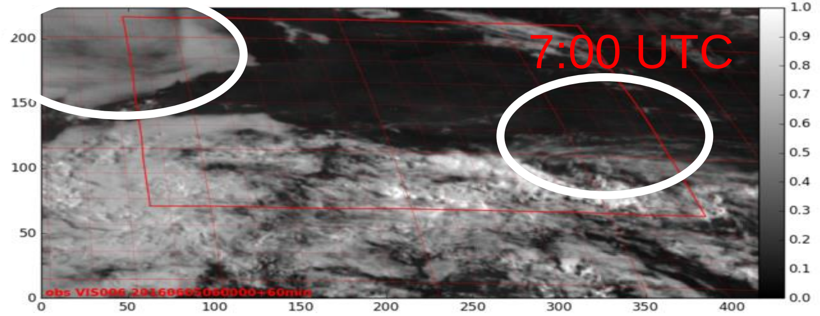
With SEVIRI

Proportion of clouds in ensemble

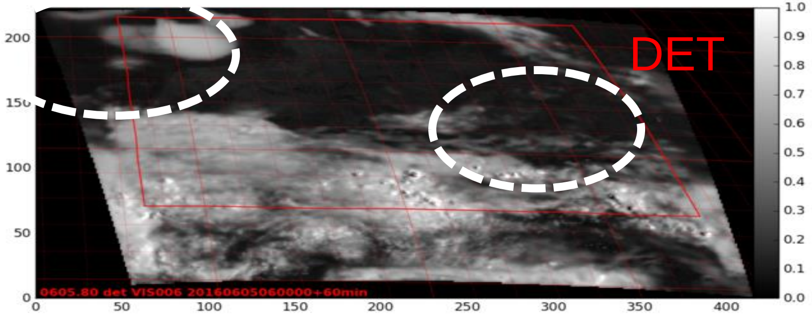


Proportion of clouds in ensemble





Observation

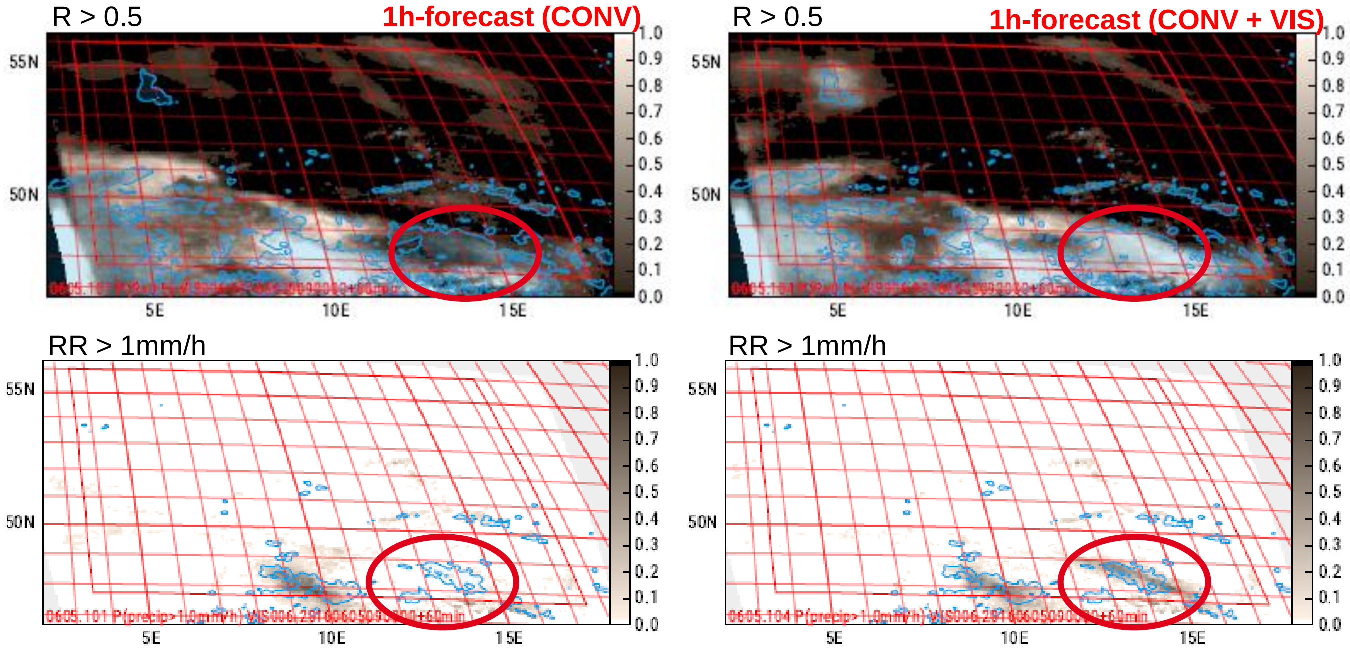


Deterministic run

Case study II: Clouds & precipitation

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

COSMO model: June, 5th 2016; 10 UTC



Shading:
percentage of cloudy ensemble members

Blue:
SEVIRI refl. > 0.5

Shading:
percentage of rainy ensemble members

Blue:
radar rain rate > 1 mm

(See also: Scheck et. al, 2019, submitted)

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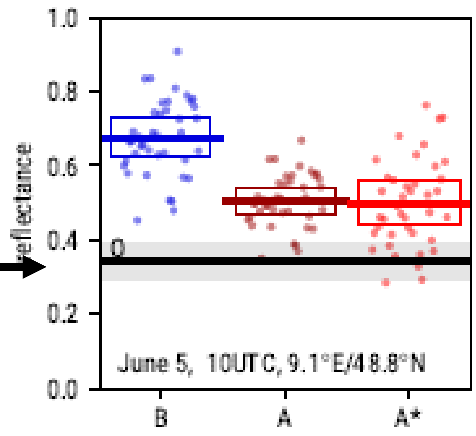
Single Observation Experiment I

- FG: Extended water cloud below thin ice cloud
  Reflectance: too high
- Analysis: Reduction of cloud water contents and reflectance
  Improved ensemble mean and distribution

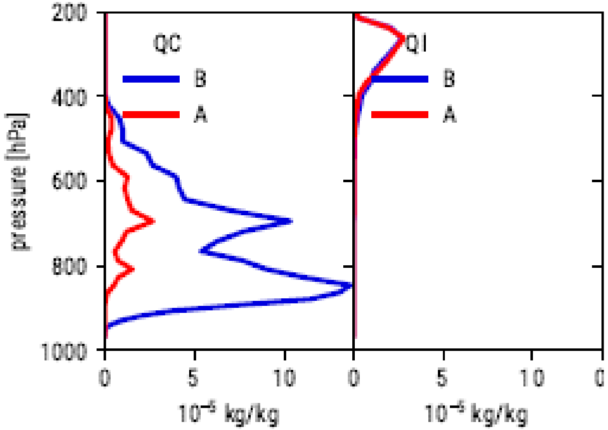
First Guess
Linear analysis
Non-linear analysis

Observation

Reflectance



Water Ice

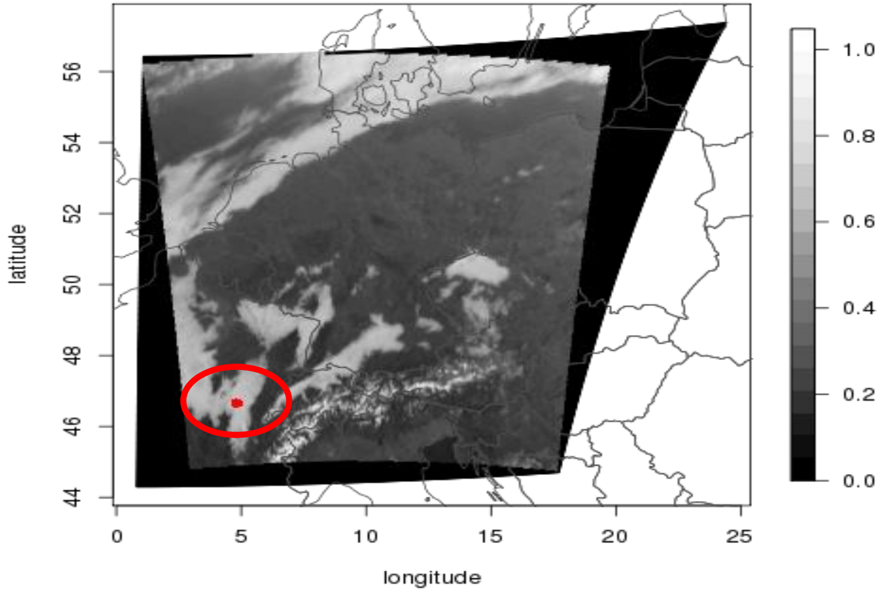


B First Guess
A Analysis

Aus Scheck et. al, 2019, submitted

Single Observation Experiment II

- Low stratus in Southern Germany/France
- 30 Dec 2016



Two Experiments testing localization

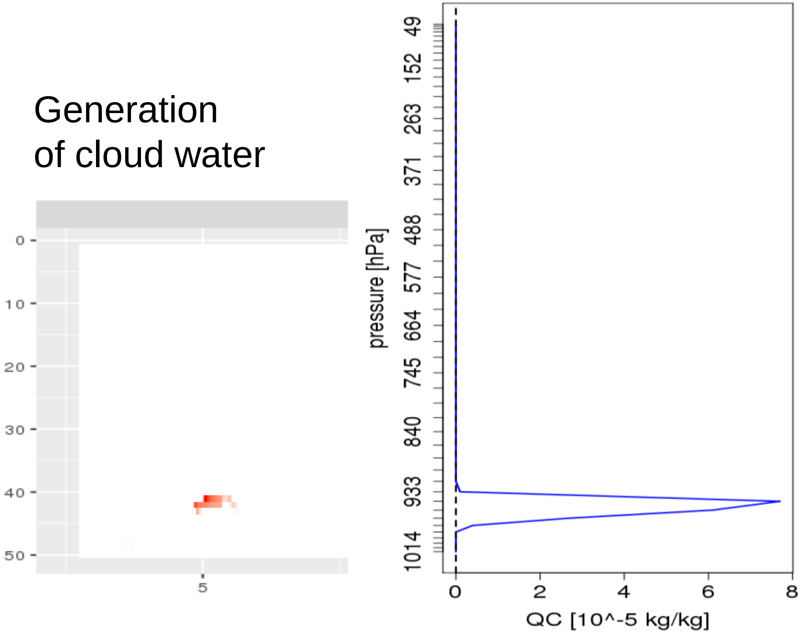
1. No vertical localization
2. Position at 950 hPa + narrow vertical localization

Analysis increments without vertical localization

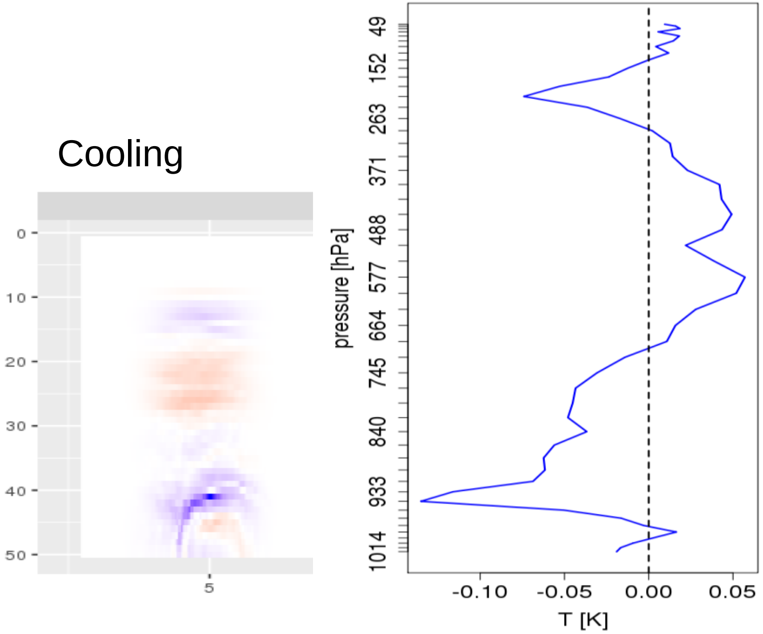
Assimilation of reflectance obs leads to physically consistent increments

- Cloud water
- Corresponding humidity and temperature increments (here cooling)

Generation of cloud water



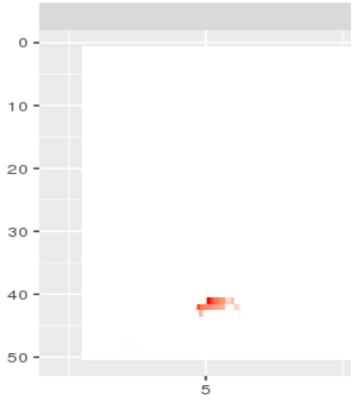
Cooling

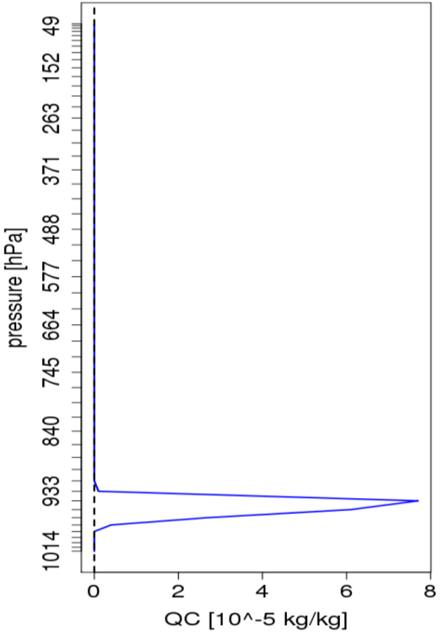


Analysis increments with vertical localization

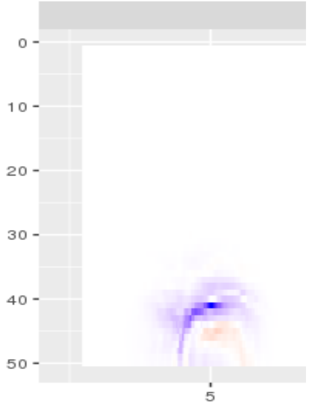
Vertical localization: Key challenge!

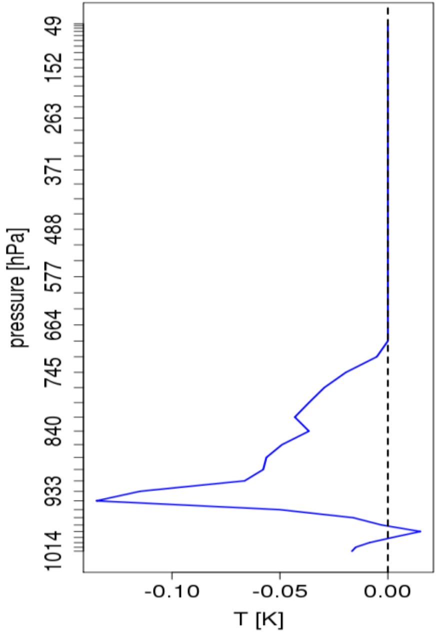
Generation of cloud water





Cooling





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Implementation stages

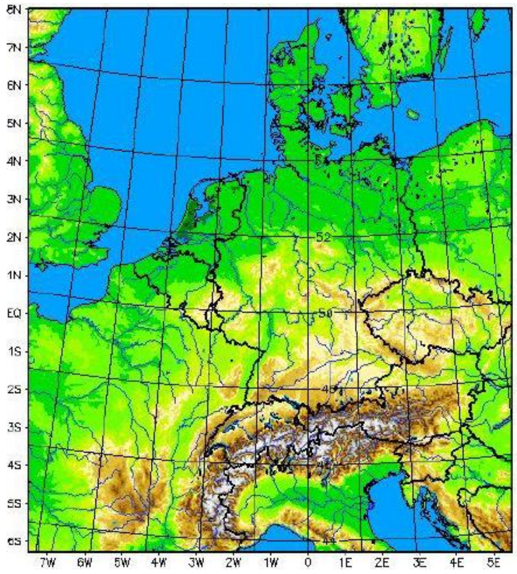
I. First developments and experiments in COSMO/KENDA
  - Convective and stratus situations
  - Single obs experiments
  - Tuning experiments
  - Longer experiments (~ 2-4 weeks)

See also
Scheck et al., 2019, submitted

II. Implementation of VIS assim in new ICON-LAM
  - Different model (dynamics and microphysics)
  - Initialisation: IAU
  - Longer experiments (since winter 2019)
  - At the same time:
    - Physics implementations ongoing,
      e.g. using the 2-moment scheme, ec-rad

Assimilation experiments with ICON-LAM-D2

- Study period: 1 – 14 June 2019
- VIS observations (setup as optimized in previous COSMO studies)
  - Superobbing (~ 12 km)
  - Hourly images
  - OBS error (reflectance): 0.2
  - No vertical localization (vloc=10; hloc=35km)
- Other data:
  - Conventional (RS, SYNOP, AIREP, MODE-S, wind profiler, BUOYS)
  - Radar rain rates (in this exp. via Latent Heat Nudging)
- Experiments:
  - ILAM_VIS_001: IAU (without update of cloud ice)
  - ILAM_VIS_002: IAU (with update of cloud ice)
  - ILAM_VIS_003: as 001 but super-obbing ~18 km
  - Reference: without VIS data



ICON – LAM
D2 domain @ 2.2 km

See also poster L. Bach

Verification focus

I. **Improvements in**

- ➔ Clouds (reflectance)
- ➔ Rain rates & 3D radar reflectivities

II. **Potentially improvements in**

- ➔ Surface screen variables
- ➔ Humidity fields

within SINFONY focus range:

+00 to +06 (+12) hours

III. **At least neutral verification versus**

- ➔ Conventional data in forecast range + 12h to +24 hours
  (to use same data setup also in standard short-range NWP)

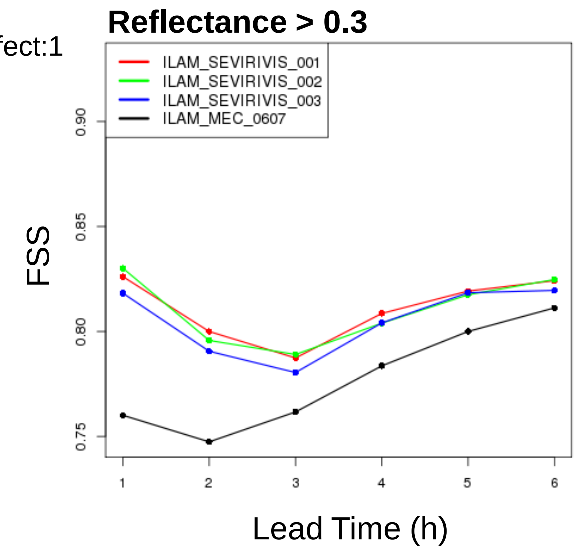
I) Reflectances: spatial verification

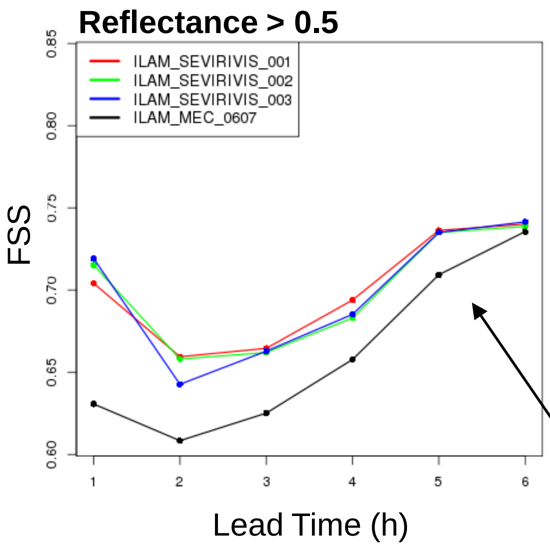
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Forecasts: starting at 12 UTC
Range: 6 hours
Average: 6 days

Score: Fractional Skill Score
Scale: 7 Pixels (~ 21 · 42 km^2)

Perfect:1





ILAM-VIS_001: IAU (without q_i); Iso=12km
ILAM-VIS_002: IAU (with q_i); Iso=12km
ILAM-VIS_003: IAU (without q_i); Iso=18km

Reference

Diurnal cycle effect

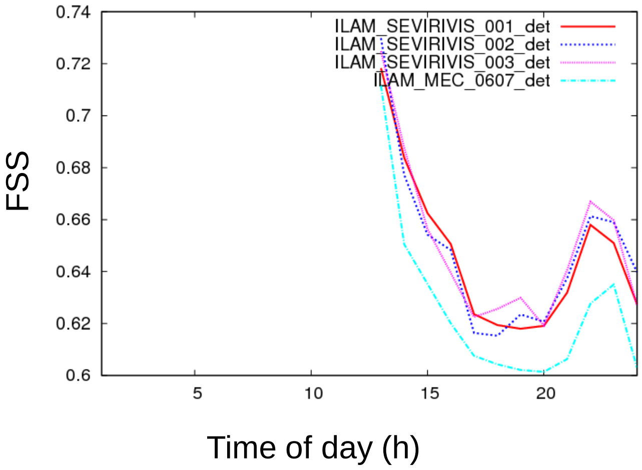
II) Rain rates: spatial verification with radar

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

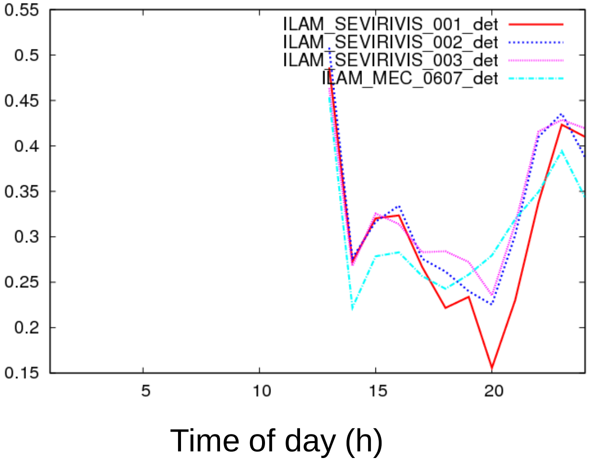
Forecasts: starting at 12 UTC
Range: 12 hours
Average: 7 days

Score: Fractional Skill Score
Scale: 11 Pixels (~ 33 · 66 km^2)

RR > 0.5mm/h



RR > 5mm/h



ILAM-VIS_001: IAU (without q_i); lso=12km
ILAM-VIS_002: IAU (with q_i); lso=12km
ILAM-VIS_003: IAU (without q_i); lso=18km

Referenz

III) Surface variables

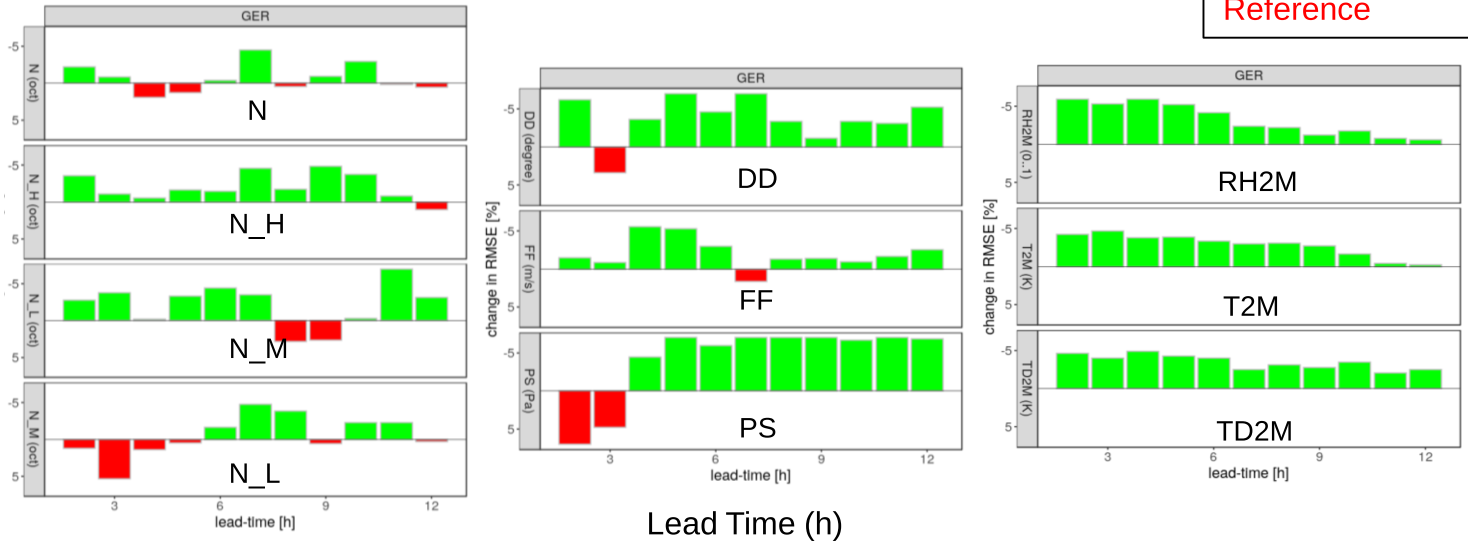
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Forecasts: starting at 12 UTC, 18 UTC
Range: 12 hours
Average: **14 days**

Verification versus SYNOP stations

ILAM-VIS_001: IAU (without q_i)
Reference

Relative change in RMSE [%]



Lead Time (h)

IV) Upper air fields: RS verification

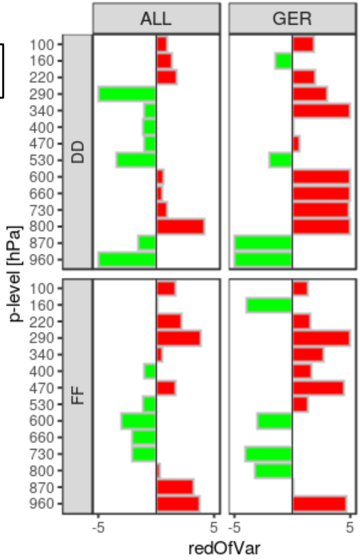
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

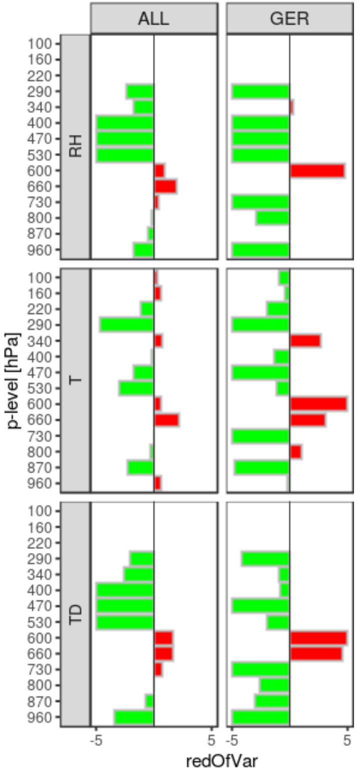
Forecasts: starting at 12 UTC, 18 UTC
Range: 12 hours
Average: **14 days**

ILAM-VIS_001: IAU (without q_i)
Reference

Wind speed

Wind direction





RH

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- Evaluation of 6h, 12h forecasts
- Improvements in humdity, T
- Mixed result / degradation in winds
- Note:
  - degradation visible also in 1h forecasts → spin-up / noise issues

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Key Challenges

(I) Volume of assimilated satellite observations

- Balancing high-resolution satellite data with conventional data
- Fit of analysis vs. induced forecast spin-up / error-growth

Solution: Tuning experiments regarding

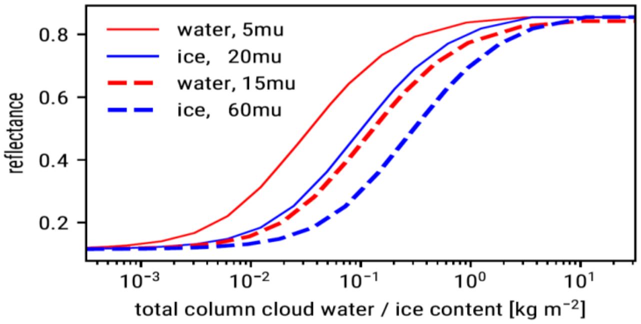
- Observation superobbing scale
- Horizontal localization radius
- Observation error
- Number of used ‚images' per assimilation window

Key Challenges II

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

(II) EnKF assumes linearity and Gaussianity

- Relationship between cloud particles and reflectance is non-linear
- First guess-departures can be non-Gaussian



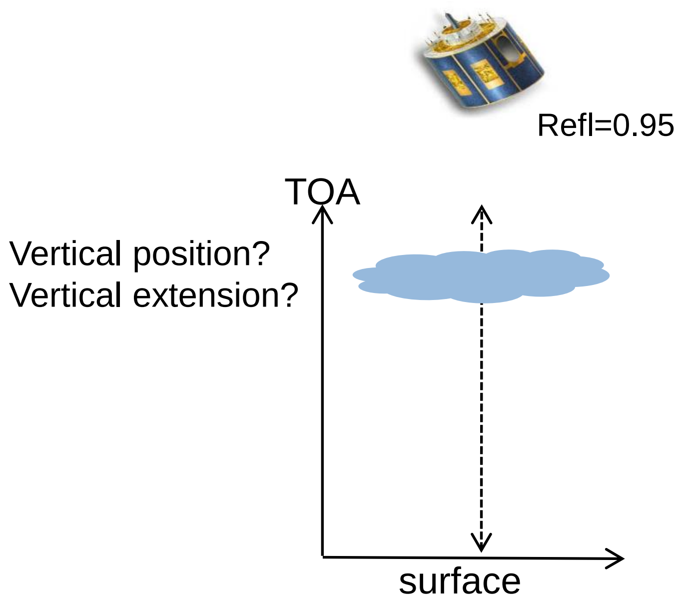
Possible solution: Application of particle filters

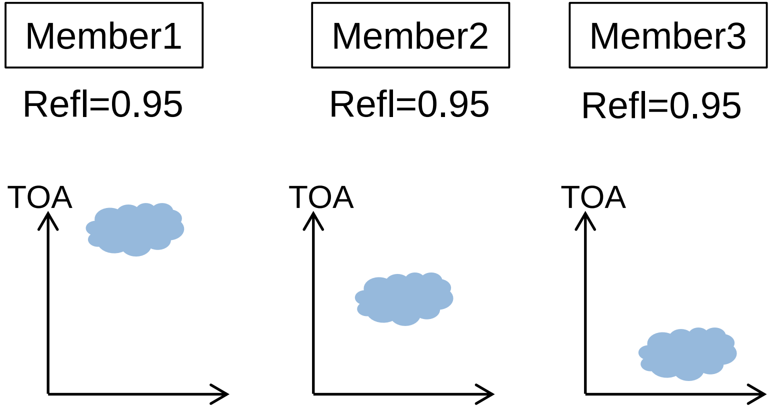
- Particle filter DA in development & testing at DWD (→ see talk by R. Potthast, Session 4)
- May raise efficiency of all-sky assimilation in the future

Key Challenges III

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

(III) Unknown vertical position & extension of observed cloud





First approach:
- no vertical localization
- forward operator is applied to all vertical levels

→ All members obtain equal weight in the analysis

Key Challenges III

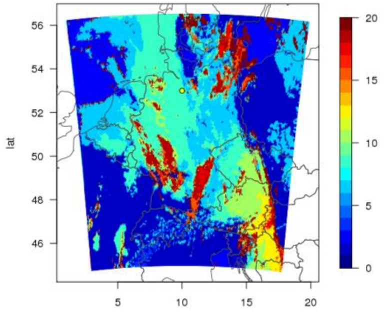
(III) Unknown vertical position & extension of observed cloud

Solutions we are working on

(A) Vertical localization using cloud type information

- of VIS observations
- of forward operator H(x)

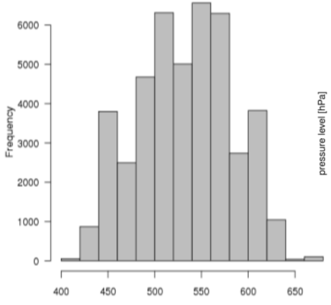
NWCSAF cloud type

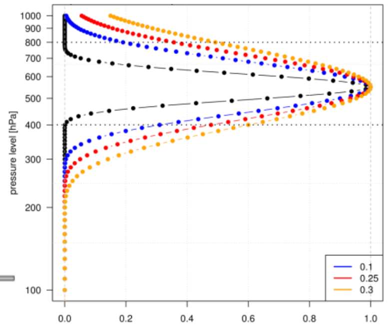


Specify Gaspari-Cohn

Localization of forward operator

NWCSAF Cloud Top Pressure (medium clouds)





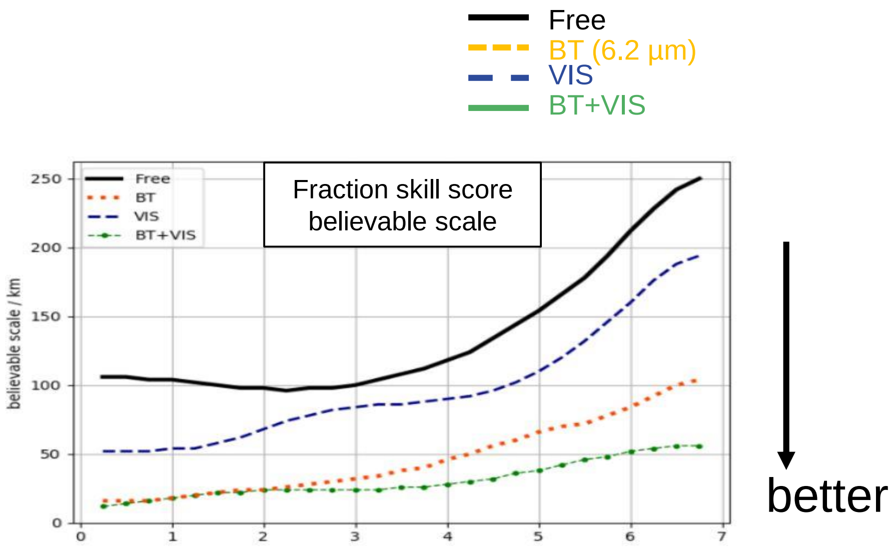
Key Challenges III

(III) Unknown vertical position & extension of observed cloud

Solutions we are working on

(B) Combination with other IR channels

OSSE experiment for case study
- *combination of IR + VIS*
- *positive results for FSS (rain rate > 1 mm/hh)*



From Schröttle, Weissmann, Scheck, Hutt: "Assimilating visible and thermal radiances in idealized simulations of deep convection", in preparation.

Key Challenges IV :

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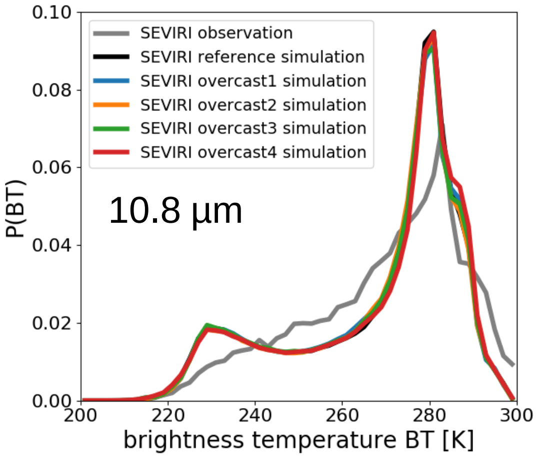
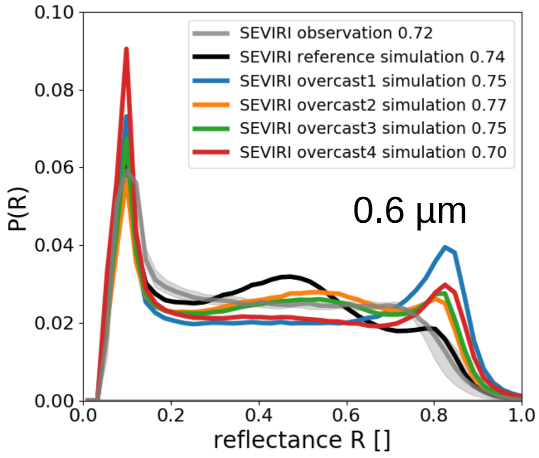
Wetter und Klima aus einer Hand

(IV) Consistency of model physics and forward operator

- Tests using various model physics setups (sub-grid scale cloud parameterizations)
- Evaluation using SEVIRI IR and VIS

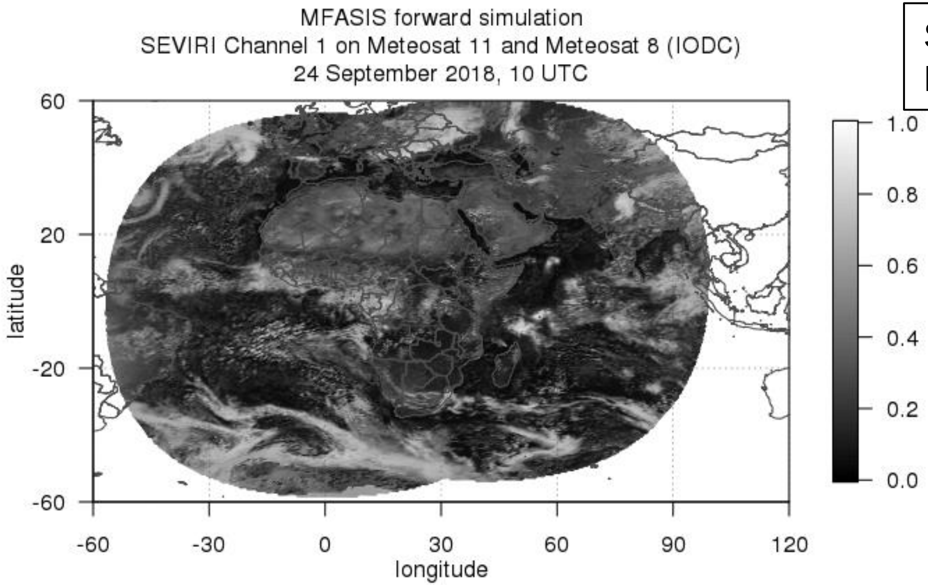




Courtesy:
S. Geiss

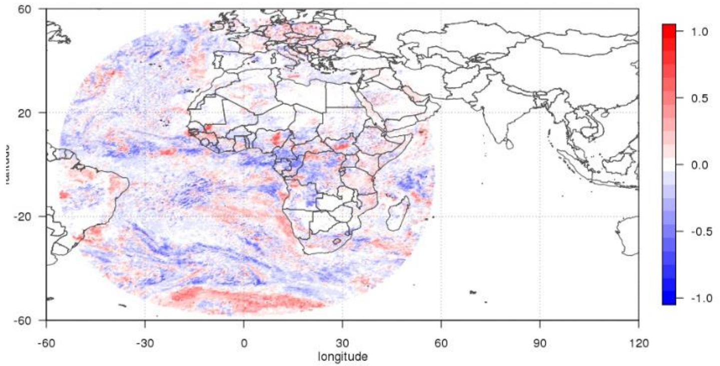
- IR 10.8 µm is nearly blind to these changes in subgrid clouds
- VIS 0.6 µm is sensitive
- ❑ Using full spectral range (also VIS) improves model physics developments - and assimilation
- ❑ Adding further channels will enhance benefit (e.g. 1.6 µm)

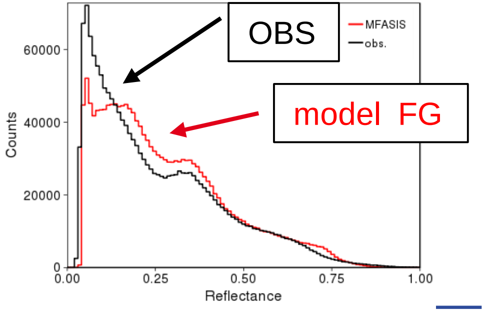
Extension to global ICON model



Simulated SEVIRI 0.6 µm
ICON model FG

OBS – FG





Evaluation and improvement of

- MFASIS over full range of cloud situations
- Model physics

...... and ultimately assimilation

See also poster Ch. Stumpf

Summary and outlook

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

- ➔ Use of VIS reflectances : cloud ice and cloud water information, low clouds
- ➔ Promising impact for very short range forecasts (clouds, screen level variables, precipitation) in LETKF setup

- ➔ State vector contains cloud water and cloud ice
- ➔ Key challenges to obtain a more efficient data assimilation are being adressed

Outlook

- ➔ Towards operationalisation in ICON-LAM-D2 for seamless forecasting system SINFONY
- ➔ Work ongoing for:
  - Vertical localization using additional cloud products
  - Combination with WV / IR channels (all-sky) to reduce ambiguities
  - Model physics: e.g. use of 2-Moment-scheme to better represent cloud micro-physics

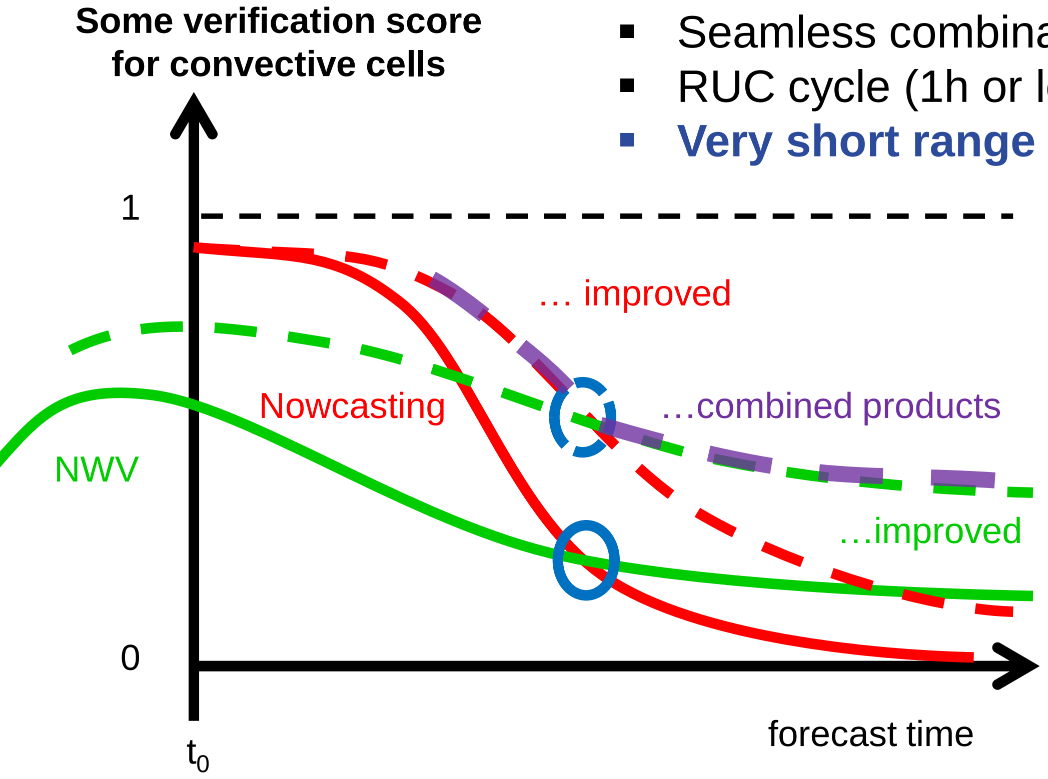
Thank you !

Questions ?

Context: Main idea of SINFONY

Aims:

- Seamless combination of NWP with obs-based nowcasting
- RUC cycle (1h or less) with very short cut-offs (~10 min.)
- **Very short range forecasting range: 1- 6 (12) h**



e.g. Radar reflectivities
(NWP output of 5 min.
simulated volume scans)

(Courtesy: U. Blahak)