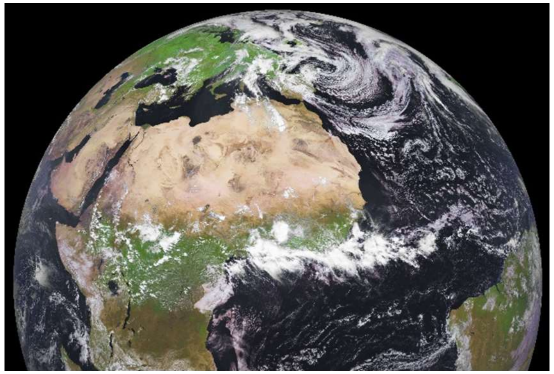
Deutscher Wetterdienst
Wetter und Klima aus einer Hand

All-sky DA of visible channels of SEVIRI in ICON-D2-KENDA

COSMO General Meeting, KENDAScope Session

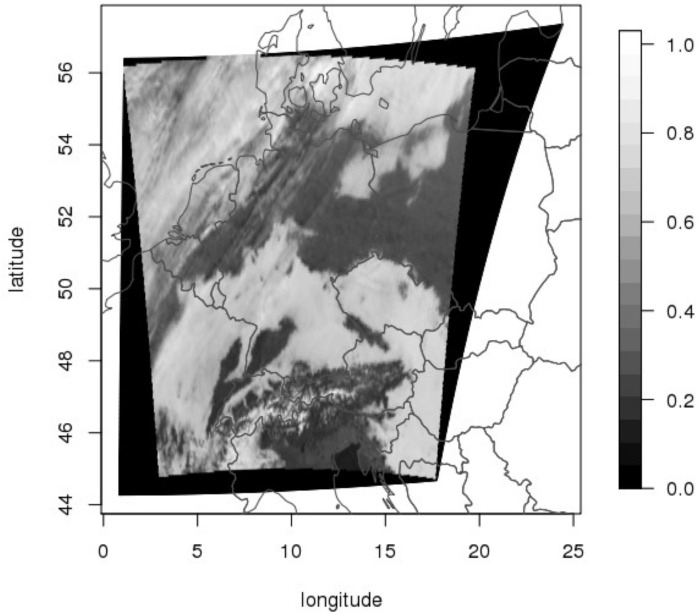
Liselotte Bach & Thomas Deppisch



with C. Stumpf, L. Scheck
R. Faulwetter, M. Bender
A. Schomburg
C. Köpken-Watts, C. Schraff
A. de Lozar

Observations

- Imager channel in the visible spectral range (0.6 µm)
- SEVIRI instrument on geostationary MSG (0°/0°)
  - Horizontal resolution: 6 km x 3 km (Central Europe)



What is reflectance?

- Percentage of infalling solar radiation that is reflected by clouds and the earth‘s surface

Important characteristics

- Availability limited to day time
- Also sensitive to snow (alps!), volcanic ash, Saharan dust

All-sky data assimilation

Clouds reside in meteorologically interesting regions

- ➔ Tropical cyclones, fronts, convection, low stratus
- ➔ Clouds cover roughly 67 % of the earth‘s surface

Traditional all-sky satellite data assimilation

- ➔ Gain of vast amounts of temperature- and humidity-sensitive satellite data

But what is our goal?

- ➔ Assimilate visible channels directly sensitive to
  - ➔ Cloud water mass
  - ➔ Cloud optical properties
  - ➔ Cloud positions

  - ➔ Water vapour
  - ➔ Surface albedo

Why visible satellite data?

How does VIS differ from IR?

➔ Sensitive to cloud properties (VIS) rather than to temperature-humidity mixture (IR)

➔ Sees *also* boundary layer clouds (convective initiation, low stratus)

➔ Sensitive to a much larger range of LWP / IWP than IR

➔ Except for very small LWP / IWP (thin cirrus)

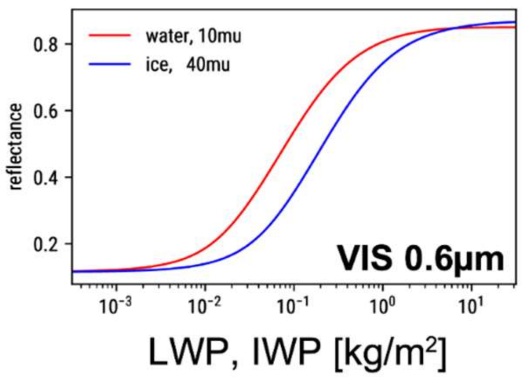
1. Warnings high impact weather
2. Solar power forecasting
3. Flight meteorology (visibility)

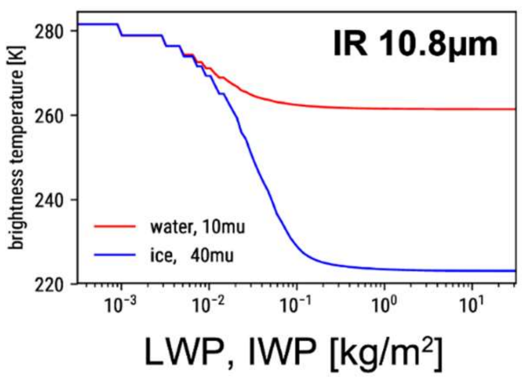
Which forecast impact can we expect?

➔ Cloud positions ~ precipitation

➔ Cloud optical depth ~ solar radiation

➔ Processes related to solar radiation, e.g. surface fluxes





Data assimilation methodology

Simulation of visible satellite pictures

RTTOV-MFASIS forward operator

- ➔ Fast & accurate radiative transfer method MFASIS (Scheck, 2016)
- ➔ DA in operations conceivable for the first time
- ➔ Look-Up Table Approach; vertical integrals instead of vertical distribution
- ➔ Treatment of cloud variables: avoid interpolation (nearest neighbor)
- ➔ Ongoing developments: NIR-channel, aerosol, neural networks

Micro- and macro-physical assumptions

Cloud properties based on parameterization of effective radii (Reff):

- Deff-scheme: Martin 1994 (cloud water)
- Baum-scheme: Mc Farquhar 2003 (cloud ice)
- Or use of Reff from ICON

Cloud overlap: maximum random overlap, no horizontal inhomogeneity

Model variables

Temperature
Pressure
Specific humidity
Cloud ice
Cloud water
Density
Cloud cover

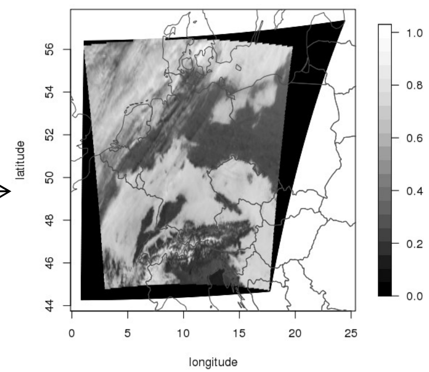
Compute

Dimensions

Look Up Table

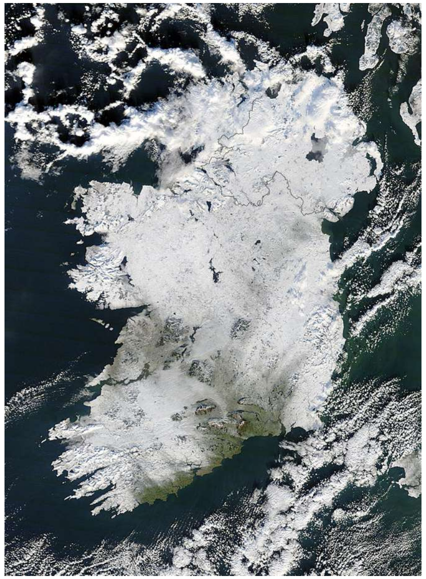
Integrated optical thickness
Effective particle radius
Albedo (BRDF)
Sun zenith angle
Satellite zenith angle
Scattering angle

Simulated satellite picture

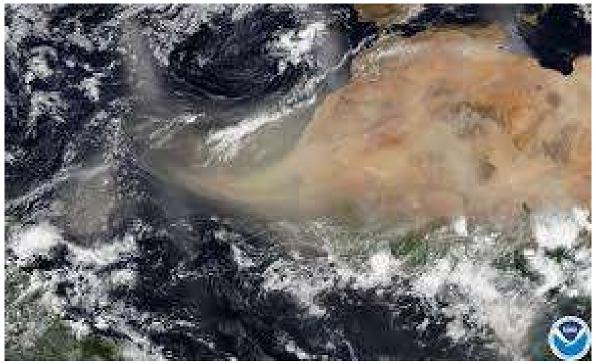


Quality control

Parameter	Reason for rejection
Sun zenith angle (> 75°)	Missing 3D-effects in MFASIS Night
Model orography > 1100 m Cloud mask = „SNOW“	Misinterpretation of snow as clouds
Obs > 1.5	Missing 3D-effects in MFASIS
Saharan dust / volcanic ash Cloud mask = „DUST“	Misinterpretation as clouds
MFASIS operator flags	Magnitude of effective radius



Mixture of snow and clouds



Saharan dust outbreak

NWC-SAF cloud mask

Use flags for snow, aerosol, volcanic ash as part of satellite preprocessing QC (satpp)

Full satellite picture to observations

Data reduction (superobbing) to

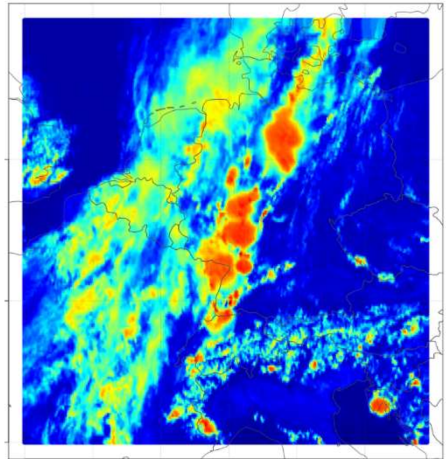
➔ Balance remote sensing data and conventional observations

➔ Reduce representativity error and double penalty problems

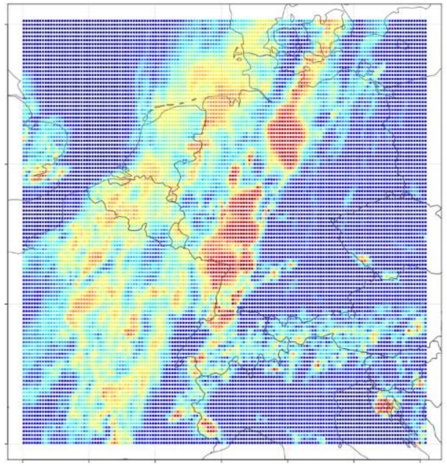
➔ Account for assumption of spatially uncorrelated observation error

➔ Applied to both y and H(x) after nearest neighbor interpolation of model columns to satellite grid

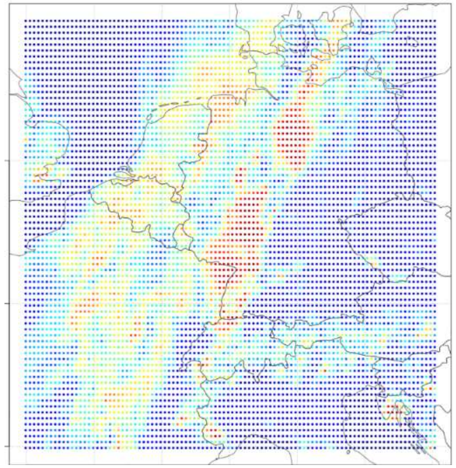
Full resolution



~12 km



~18 km



Vertical localization

Problem

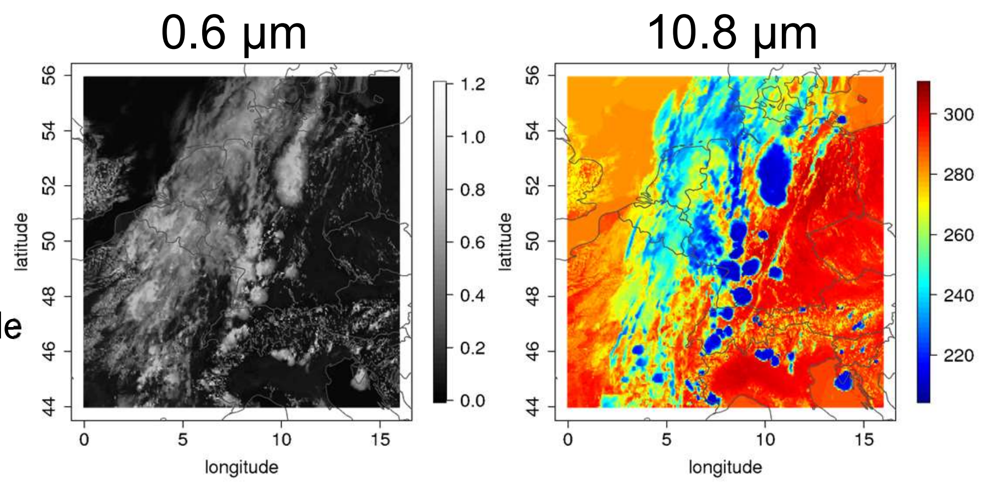
- ➔ Reflectance represents vertical integral over model column
- ➔ No height information, no information about vertical extent of clouds
- ➔ Attempts with vertical localization based on cloud products (cloud type, NWC-SAF)

How do we deal with that?

- ➔ Currently no vertical localization of vertical intervariable correlations
- ➔ Future: visible + infrared channels

Does it work?

- ➔ Mainly directly cloud-dependent processes are improved
- ➔ By tendency little impact through intervariable correlations (e.g. rho(T,REFL))



What can be possible predictors of obs error?

- ➔ Nonlinearity
- ➔ Sun zenith angle
- ➔ First guess departure ~ displacement error

Inflate obs error depending on first guess departure

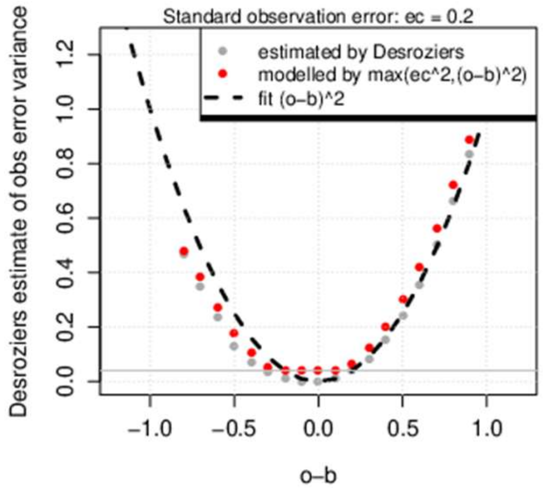
➔ $\sigma_o^2 = \max(e_c^2, (o-b)^2)$

Account for spread

➔ $\sigma_o^2 = \max(e_c^2, (o-b)^2 - \sigma_b^2)$

$$Var(o-b) = Var(o) + Var(b) - 2 * Cov(o,b)$$

Desroziers estimation stratified by first guess departure



$$\sigma_o = \frac{1}{N}\sum_{i=1}^{N}(o_i - a_i)(o_i - b_i)$$

Calibration of observed satellite pictures

Pure observation bias

➔ SEVIRI visible channels ~ 8-10% too dark compared to the moon, MODIS satellite data (EUMETSAT)

How do we fix that problem?

➔ Calibrate satelite observations by fixed factor of 1.08

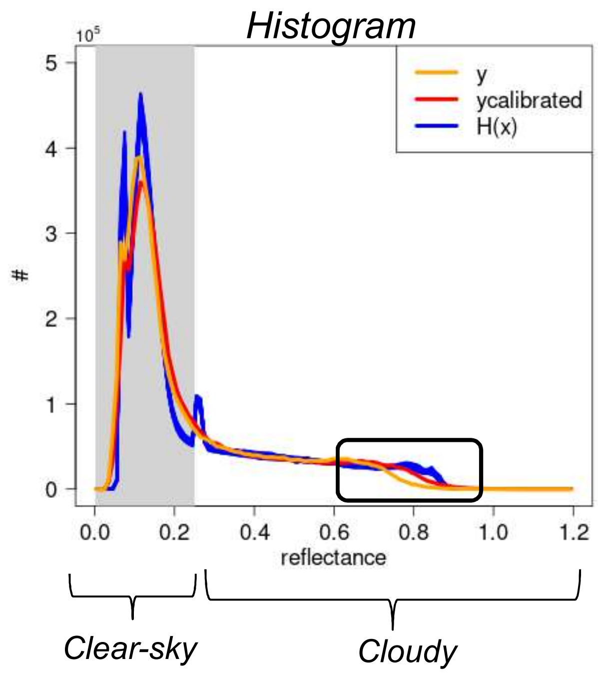
➔ Better agreement of histograms

What about remaining bias of first guess departures?

➔ Conditional bias in cloudy part of the histogram leads to detrimental forecast impact

➔ New histogram-based bias correction to stabilize impact

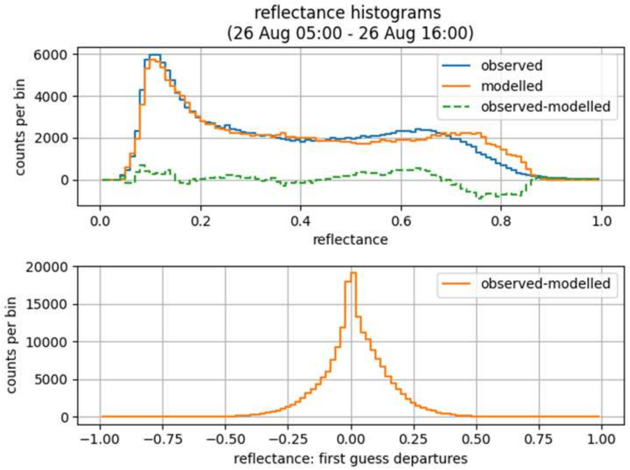
Observation
Calibrated observation
Model equivalent



How to do bias correction?

What is our goal?

➔ Apply locally conservative corrections to every pixel of the simulated satellite picture such that histogram error vs. observed reflectances is reduced



Methodology

➔ Correction function: polynomial in reflectance weighted by sun zenith angle

$$f(r,\theta) = \sum_{ij} c_{ij} T_i(r) U_j(\theta)$$

➔ Estimate coefficients c bei minimizing the following cost function

$$J[c^a] = \alpha \left\| c^a - c^b \right\|^2_{B_1^{-1}} + \beta \left\| c^a - c^0 \right\|^2_{B_2^{-1}} + \left\| hist(fg) - hist(obs \right\|^2_{R^{-1}} \ (Kalman\ Update)$$

Prior   Relaxation

Issues

➔ How adaptive should the bias correction be?

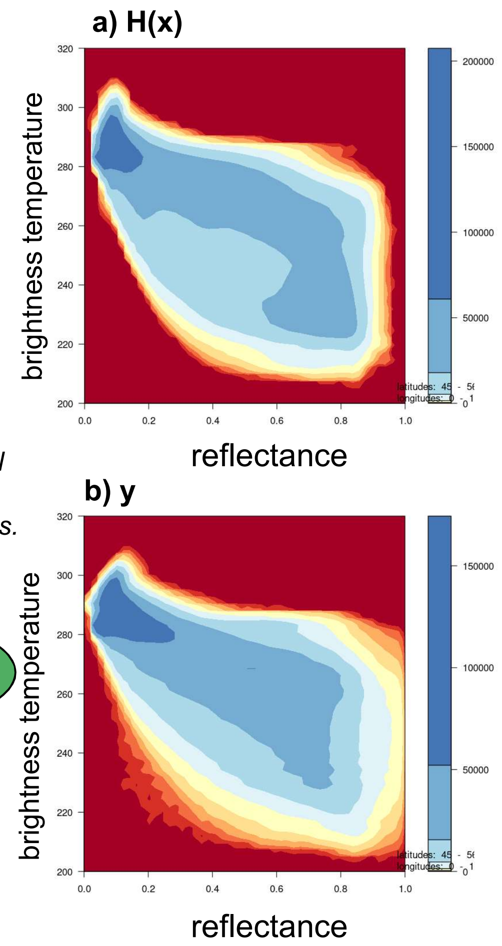
➔ How strongly does reflectance histogram bias vary depending on diurnal cycle / weather regime?

What else can we do concerning bias?

1. Statistical bias correction in data assimilation
   ➔ Bias of first guess departures

2. Tune ICON model vs. satellite observations
   ➔ Better frequency distributions
   ➔ Reduced compensating error

Figure shows joint frequency distributions of reflectance (0.6 µm) and the infrared window channel (10.8 µm) for a) simulated, b) observed satellite pictures.

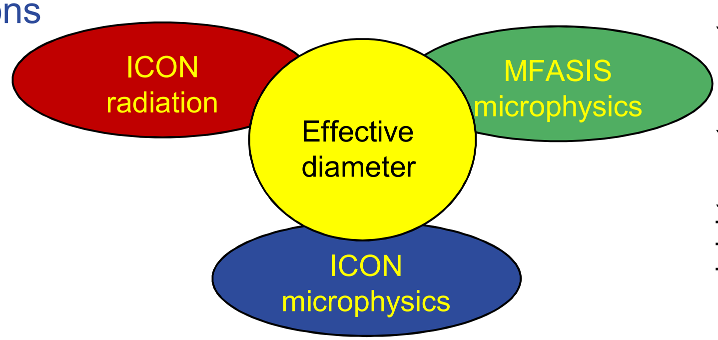


Inconsistent microphysical assumptions

➔ Horizontal heterogeneity

➔ Vertical cloud overlap

➔ Effective diameters



How do we deal with that?

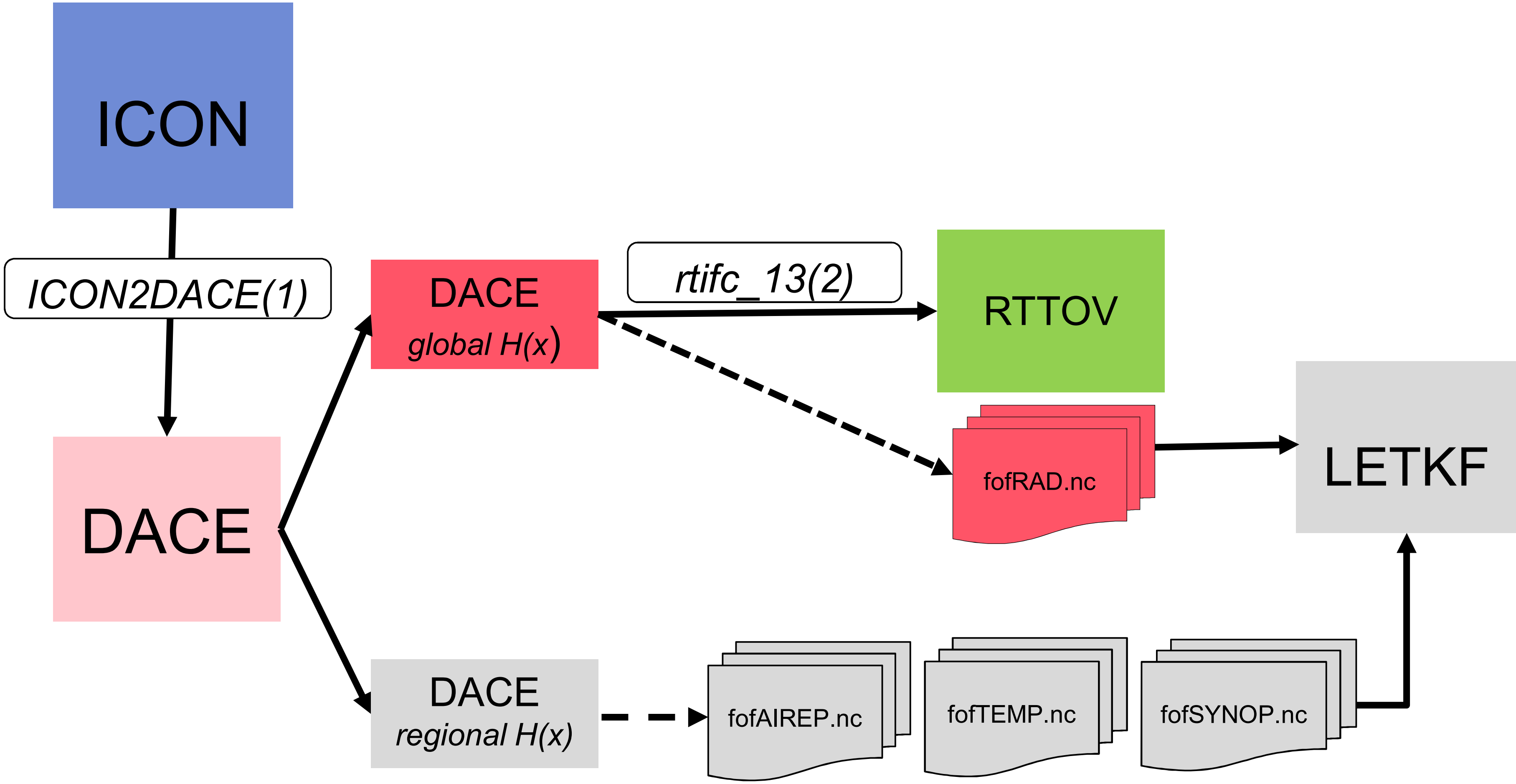
➔ Effective diameter parameterized (1MOM) / forecasted (2MOM) by ICON microphysics

➔ Used in ICON microphysics, ICON radiation, MFASIS forward operator

NWP framework

Program structure

1. *Interface from ICON to DACE that calls forward operators during model run*
2. *Interface from dace to rttov*



Impact experiments with ICON-D2

Experiments

General Settings

- ICON-D2, cpcv-bugfix, 1MOM
- *Offline interface to RTTOV-MFASIS*
- *2.August 2020 – 26.August 2020*
- *DA of 0.6 µm (LB)*
- *DA of water vapour channels (AS)*

Observations

- 1 satellite picture / hour [@60min]
- Conv. obs AIREP, TEMP, SYNOP, MODES
- Latent Heat Nudging
- 3D radar reflectivities + radial winds
- Calibration of observations 1.08

DA settings

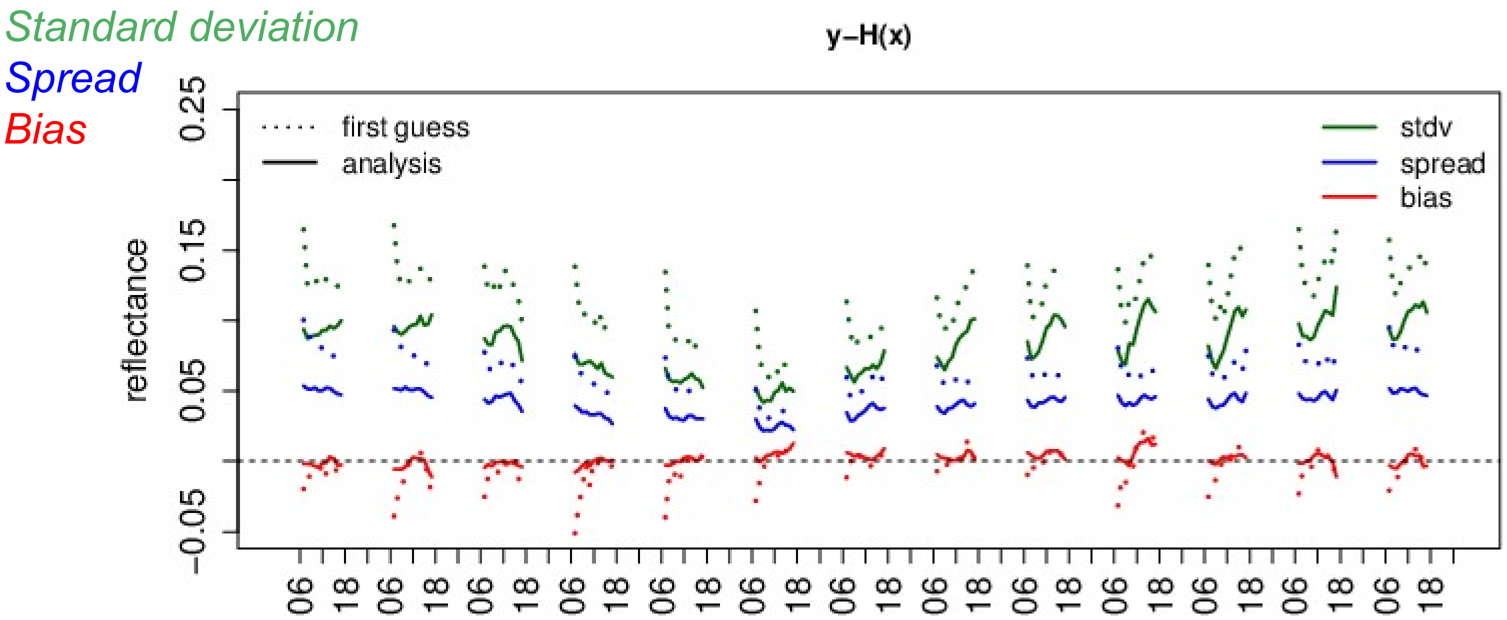
- 12 km superobbing scale
- 35 km horizontal localization
- Observation error 0.2
- No vertical localization
- No bias correction

Observations are rejected if

- Sun zenith angle > 75° (3D-effects)
- Model orography > 1100 m (snow)
- Obs > 1.5 (missing 3D-effects)
- Boundary of domain
- *Saharan dust, snow, nonlinearities*

Results in DA cycle

Reflectance statistics in DA cycle

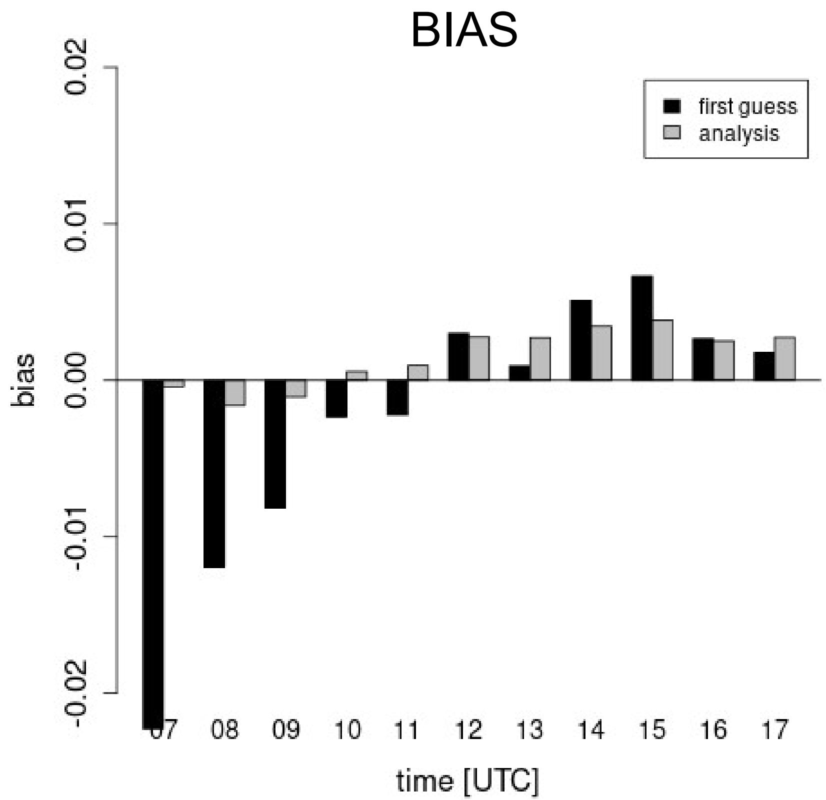


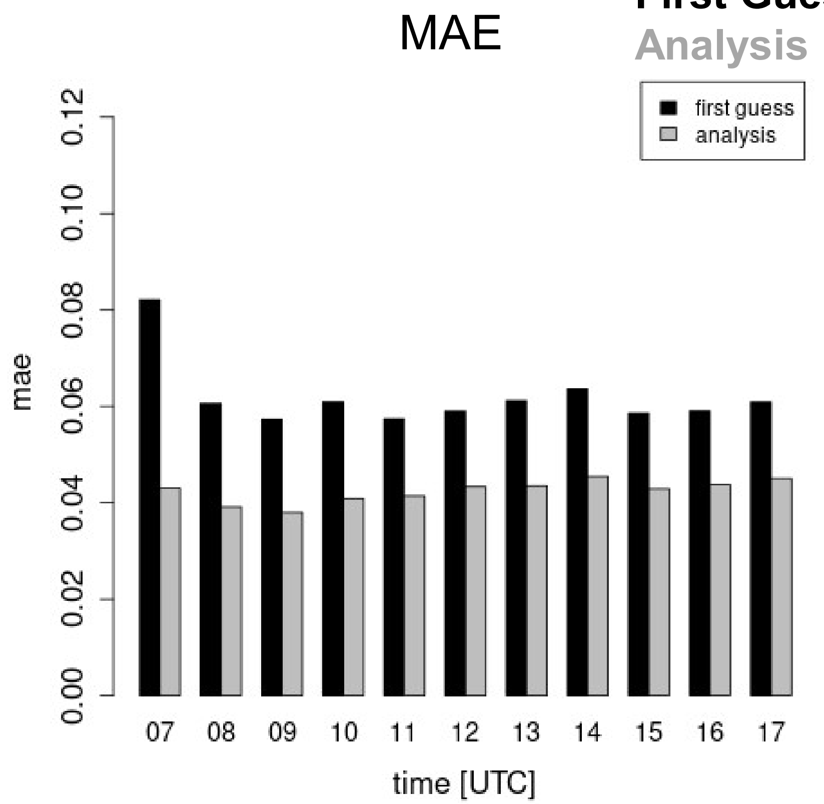
On superobbing scale

DA allows to better understand model error

Error reduction in reflectance in DA cycle

First Guess
Analysis



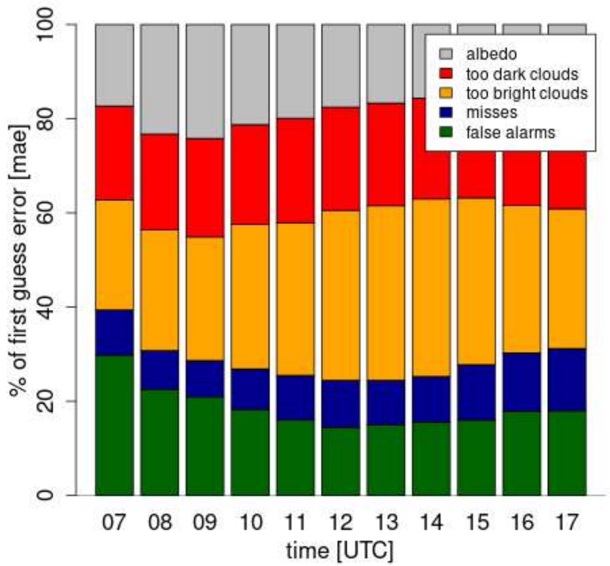


<u>Threshold : REFL=0.25</u>
REFL < 0.25 : Clear-sky
REFI > 0.25 : Cloudy

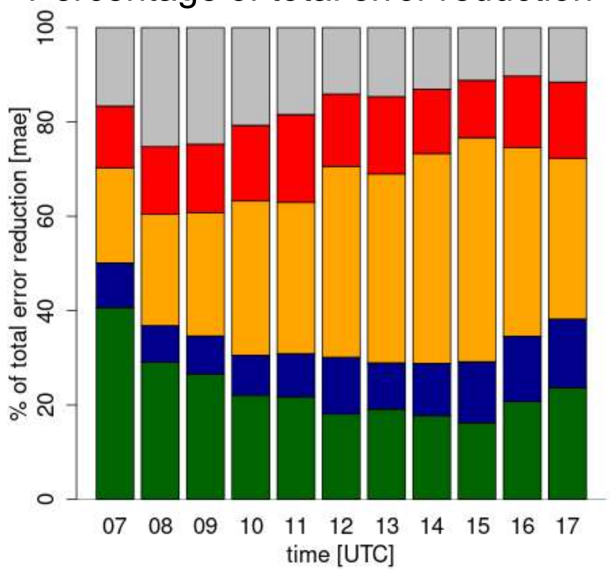
DA allows to better understand model error

Error reduction in reflectance categories

Percentage of first guess error



Percentage of total error reduction



Clear sky error
Cloud too dark
Cloud too bright
Cloud is missing
Cloud is false alarm

Ambigious reasons for errors

Clear Sky	: Erroneous BRDF-climatology, missing aerosol in LUT, water vapour erroneous
Too dark	: Missing 3D effects, too little water mass, wrong water phase (ice), too big particles, too few particles
Too bright	: Too much water mass, too small particles, wrong water phase (water), too many particles
Cloud is missing	: Cloud position error, model cloud is missing, threshold error
False alarm cloud	: Cloud position error, cloud number overestimation, threshold error

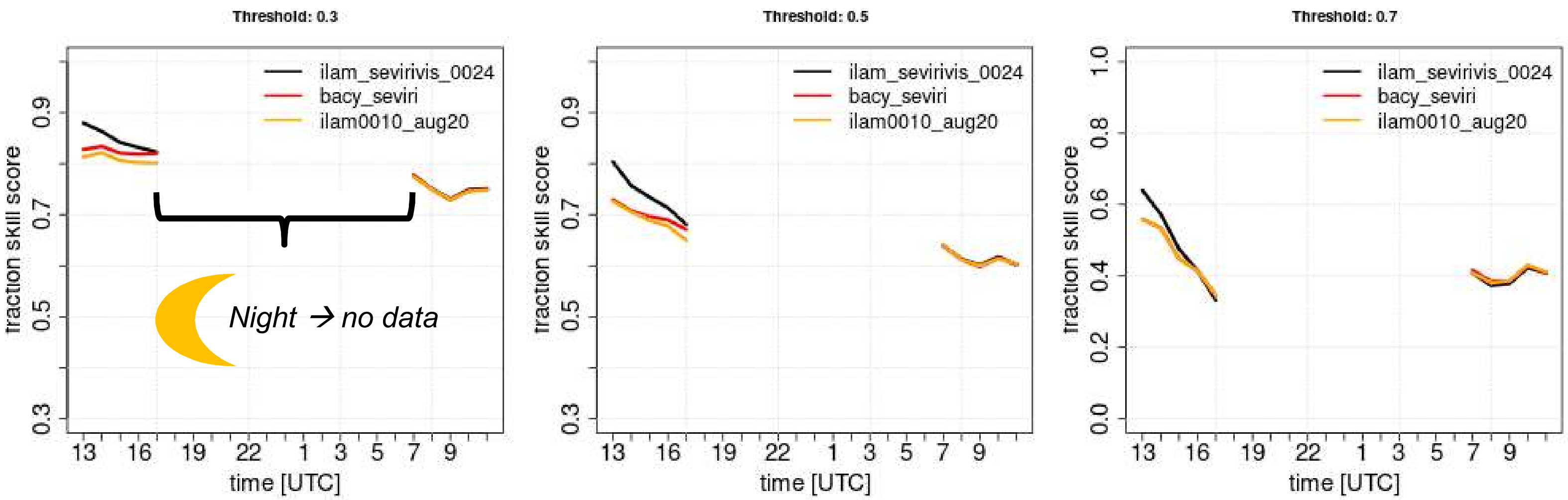
Forecast impact

CONV + RADAR + SEVIRI-VIS
CONV + RADAR + SEVIRI-WV
CONV + RADAR

Reflectance (Fraction skill score)

FSS, 7 satellite pixels
Initialized at 12 UTC
24 days

REFL > 0.3 | REFL > 0.5 | REFL > 0.7



Perfect: 1

REFL > 0.3 : all clouds
REFL > 0.5 : optically medium thick and thick clouds
REFL < 0.7 : optically thick clouds

CONV + RADAR + SEVIRI-VIS
CONV + RADAR + SEVIRI-WV
CONV + RADAR

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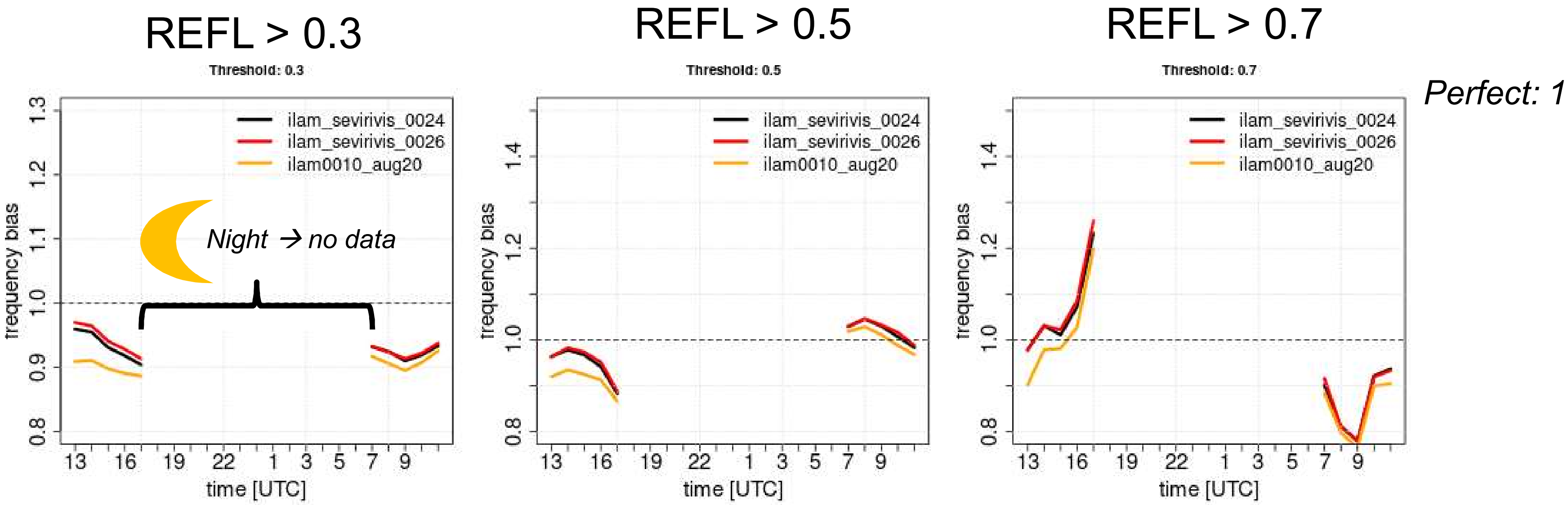
Reflectance (Frequency bias)

FBI
Initialized at 12 UTC
24 days

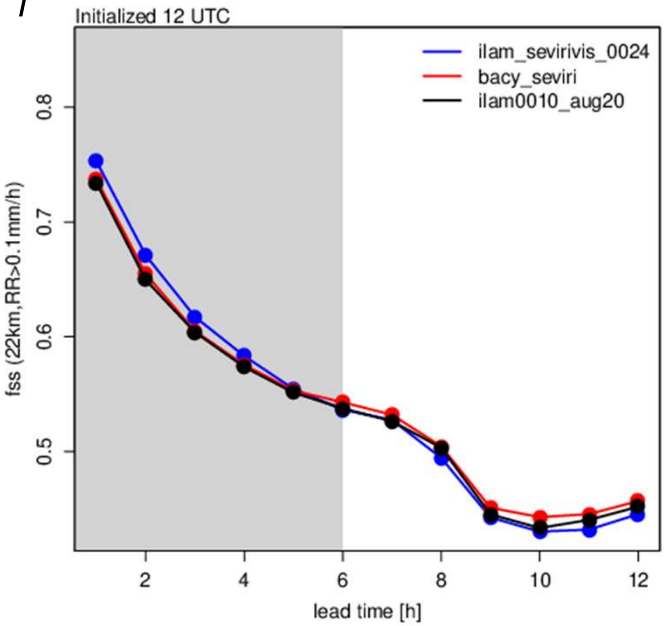


REFL > 0.3 : all clouds
REFL > 0.5 : optically medium thick and thick clouds
REFL < 0.7 : optically thick clouds

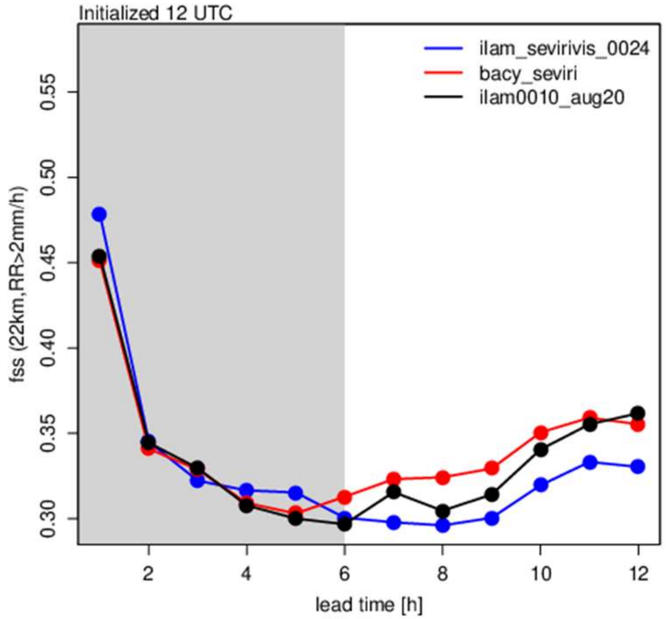
Precipitation

Perfect: 1

RR > 0.1 mm/h



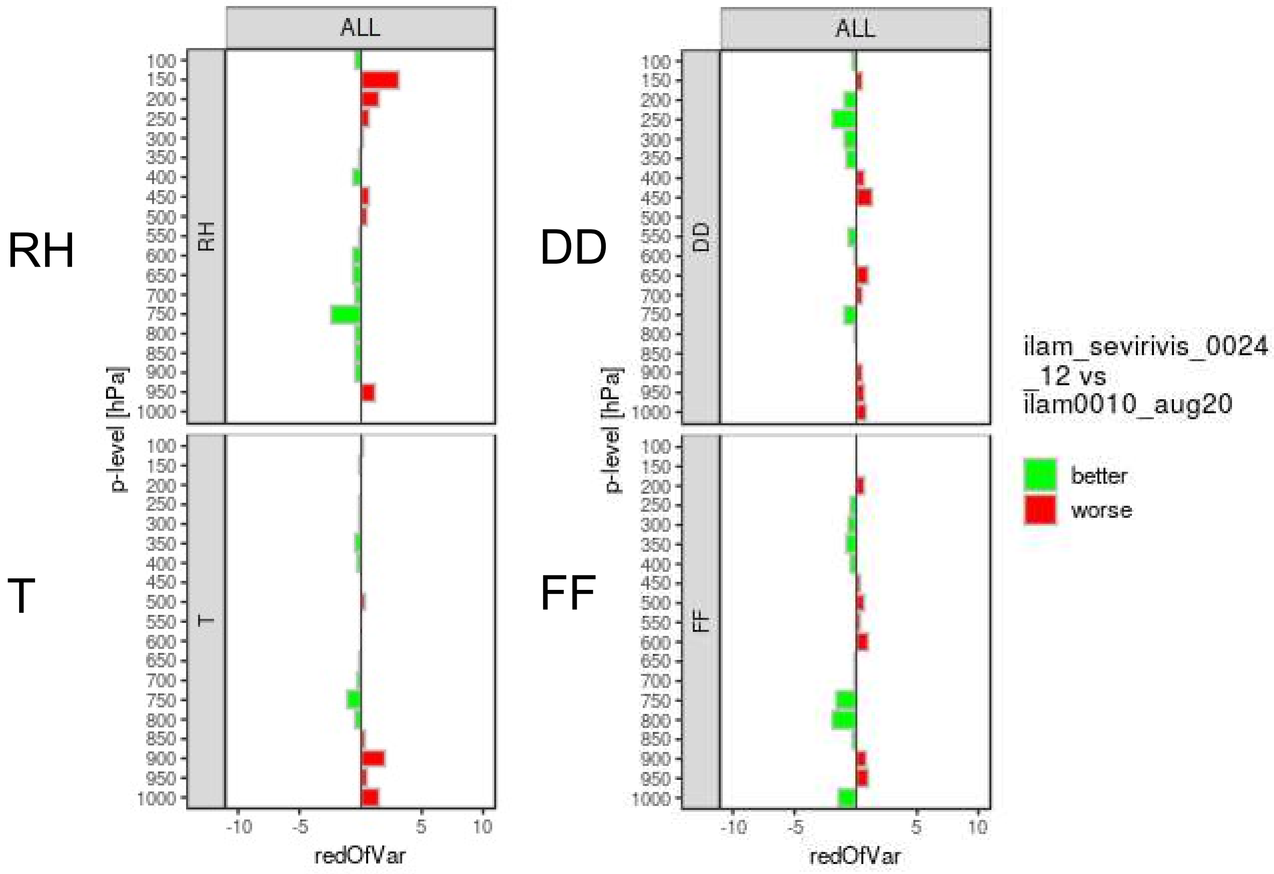
RR > 2 mm/h



Verified vs. radar precipitation rate

Upper Air Verification

CONV + RADAR + SEVIRI-VIS better
CONV + RADAR better



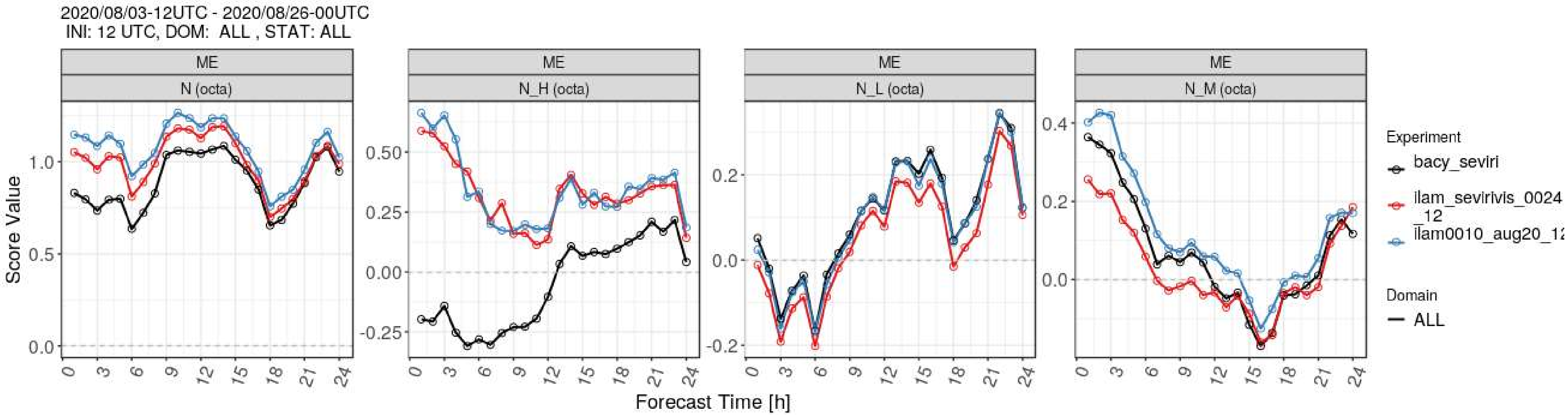
Verified vs. radiosondes

Initialized 12 UTC
24 days

CONV + RADAR + SEVIRI-WV
CONV + RADAR + SEVIRI-VIS
CONV + RADAR

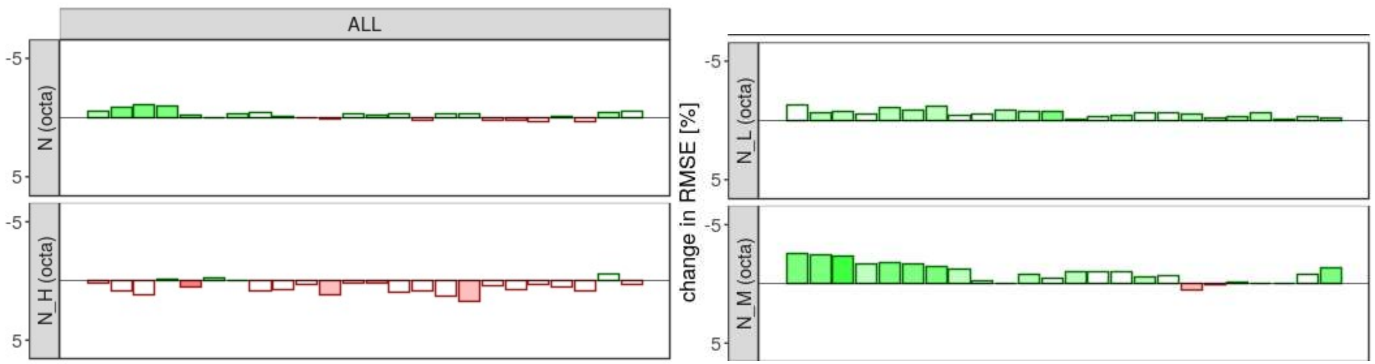
Cloud cover

- ✓ Improvement of cloud cover bias over whole forecast horizon (24h)
- ✓ Error reduction in RMSE



Total

High clouds



Low clouds

Medium clouds

CONV + RADAR + SEVIRI-VIS better

Verified vs. SYNOP observations

Initialized 12 UTC
24 days

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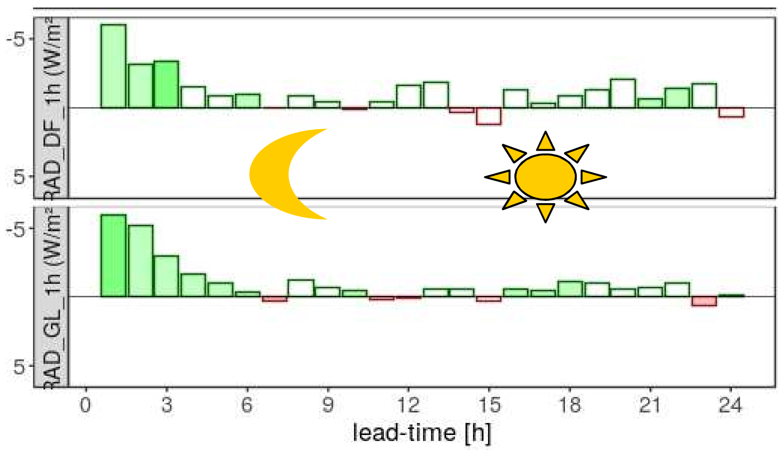
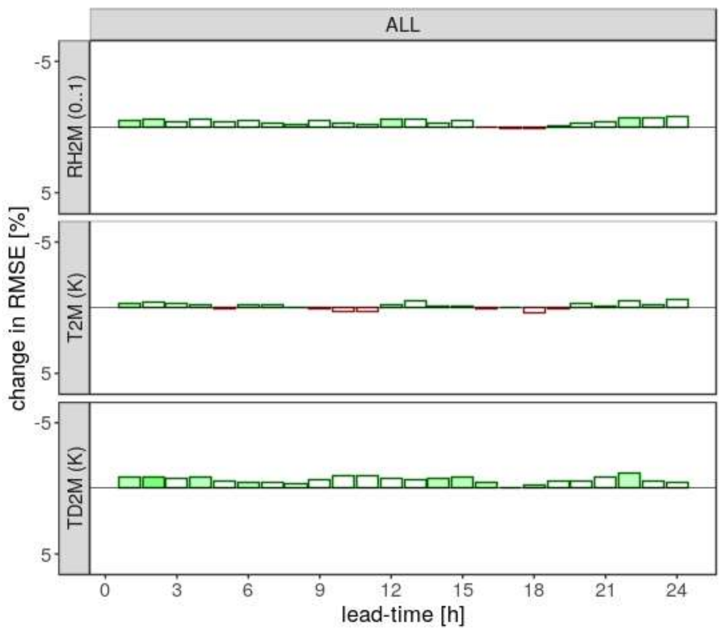
Short-wave radiation and surface variables

- ✓ Improvement of radiation through improved cloud cover / cloud optical depth
- ✓ Through better radiation better screen-level temperature and humidity

Diffuse radiation

Global radiation





RH2M

T2M

TD2M

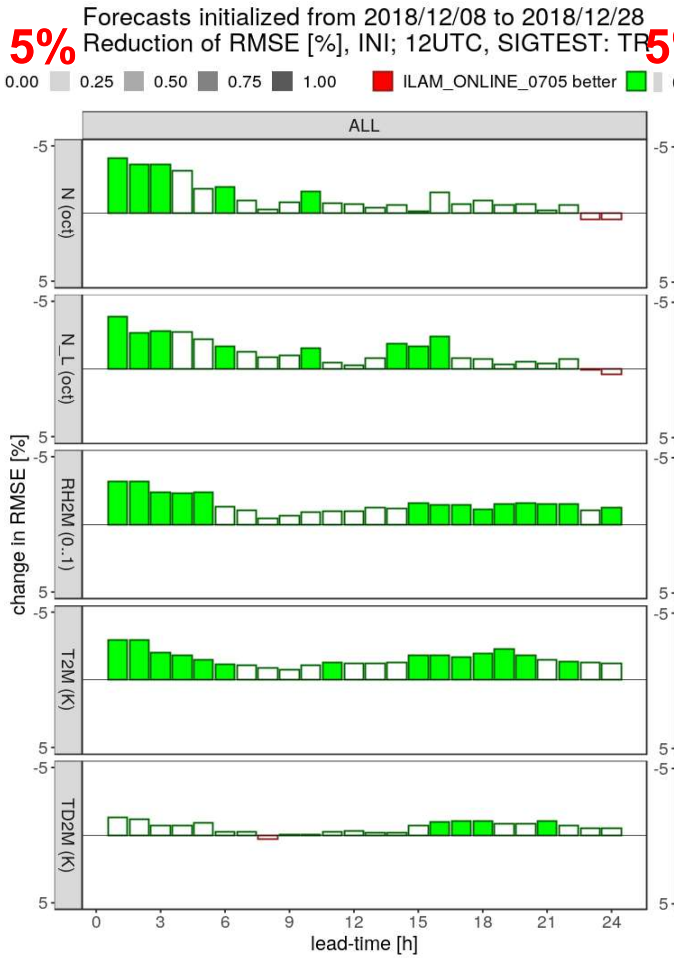
CONV + RADAR + SEVIRI better

CONV + RADAR better

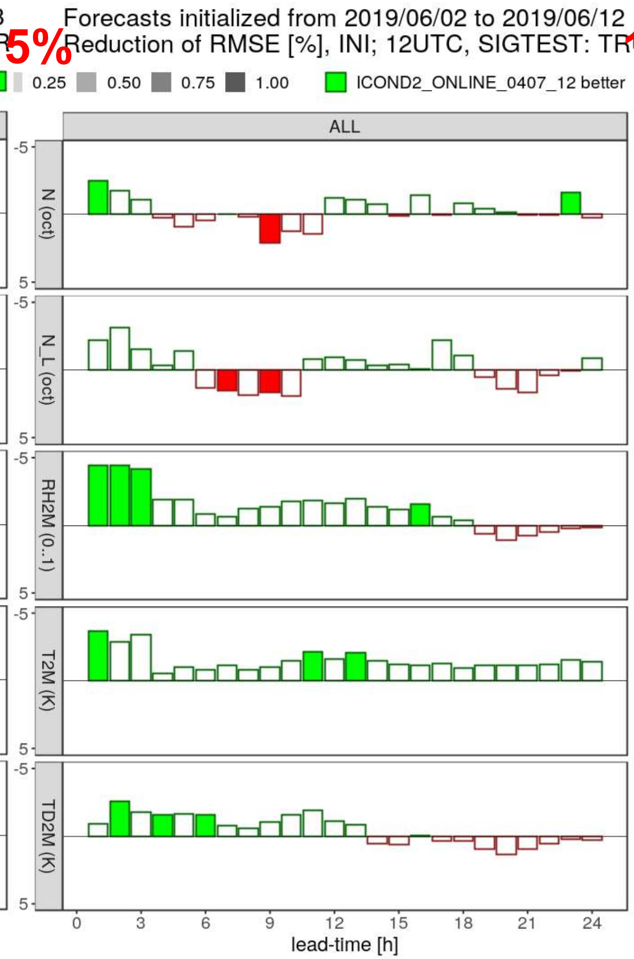
The impact is very dependent on the model version

Initialization 12 UTC

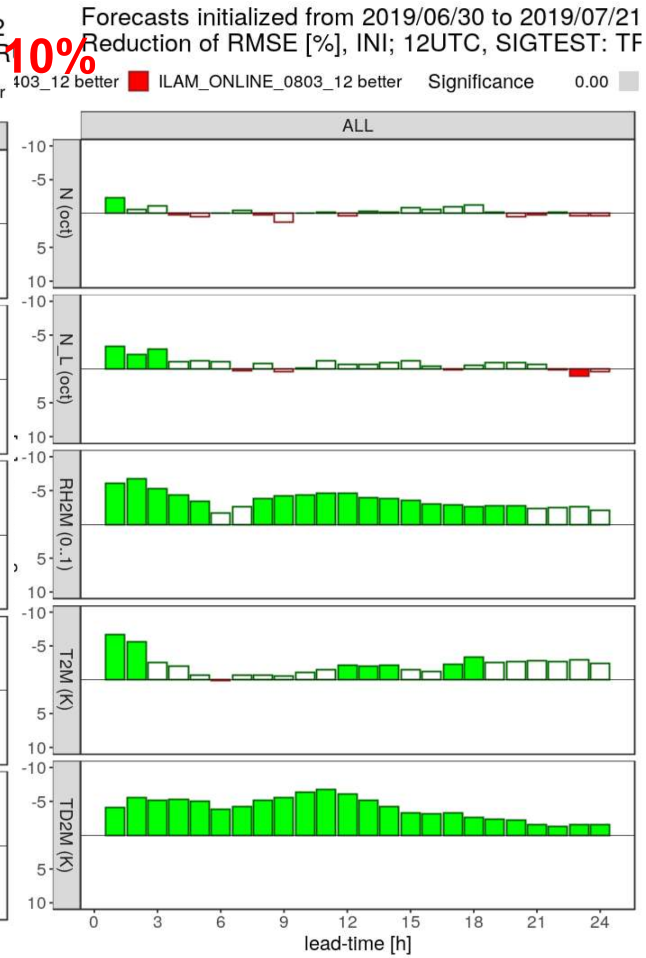
Dec 2018



June 2019



July 2019



Conclusion

- ➔ SEVIRI-VIS shows to have impact on reflectance, precipitation, global radiation and surface variables
- ➔ Results are highly different between different model versions

- ➔ New experiments run with technically mature 4D-LETKF, i.e. RTTOV is called during ICON run
- ➔ Parallel-operations in SINFONY-RUC and ICON-D2 are pursued in the near future
- ➔ Preparations for data bank arrival times, satellite preprocessing (satpp), NUMEX finished

Final requirements

- ➔ Understanding differences in simulated satellite pictures (ICON, VISOP, offline interface)
- ➔ Final model tuning for 2-Moment-Scheme
- ➔ Working bias correction (for ICON-D2) and alert system
- ➔ Experiments