Tuning radiation for ICON-LAM with two-moment microphysics

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Outline

I. A new module to calculate the effective radius

II. Coupling the effective radius to radiation

III. Results and tuning with the two-moment scheme coupled to radiation

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Effective radius in the model

- The effective radius determines the optical properties of clouds.

$$\tau = f\left(q_x, r_{eff}^x\right) \approx \int \frac{q_x}{r_{eff}^x}\,\mathrm{dz}$$

- The effective radius relates the hydrometeor extinction coefficient to the mean volume. To calculate the effective radius you need knowledge/assumptions about the particle size distribution (particle number density, but also shape and broadening) and particle geometry.

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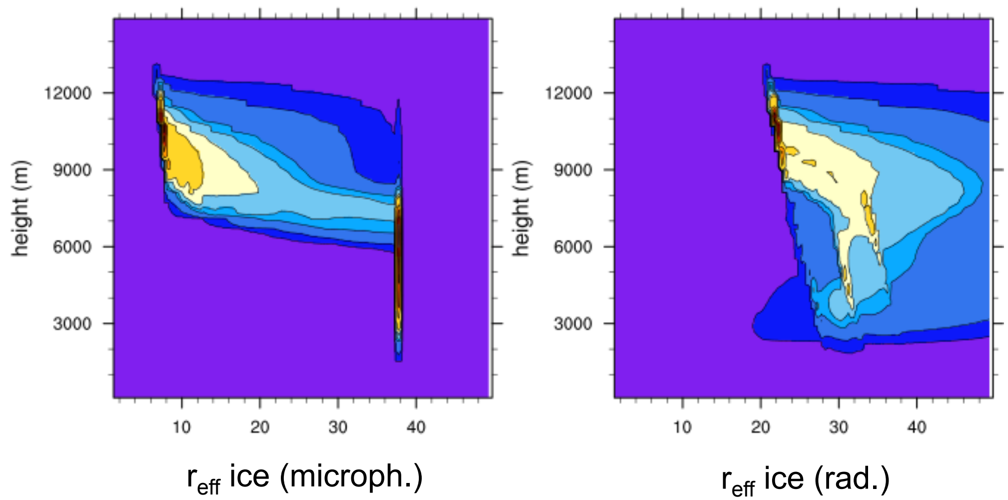
- Current parameterizations for effective radius in radiation (RRTM and EcRad) are not fully consistent with microphysics.



How many effective radius do we have?

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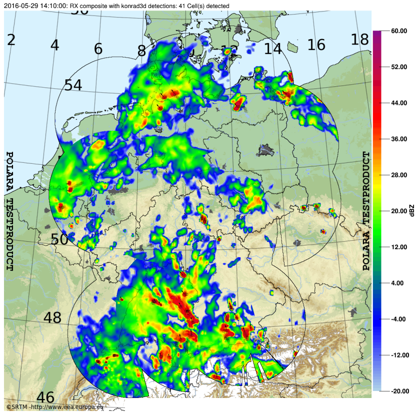
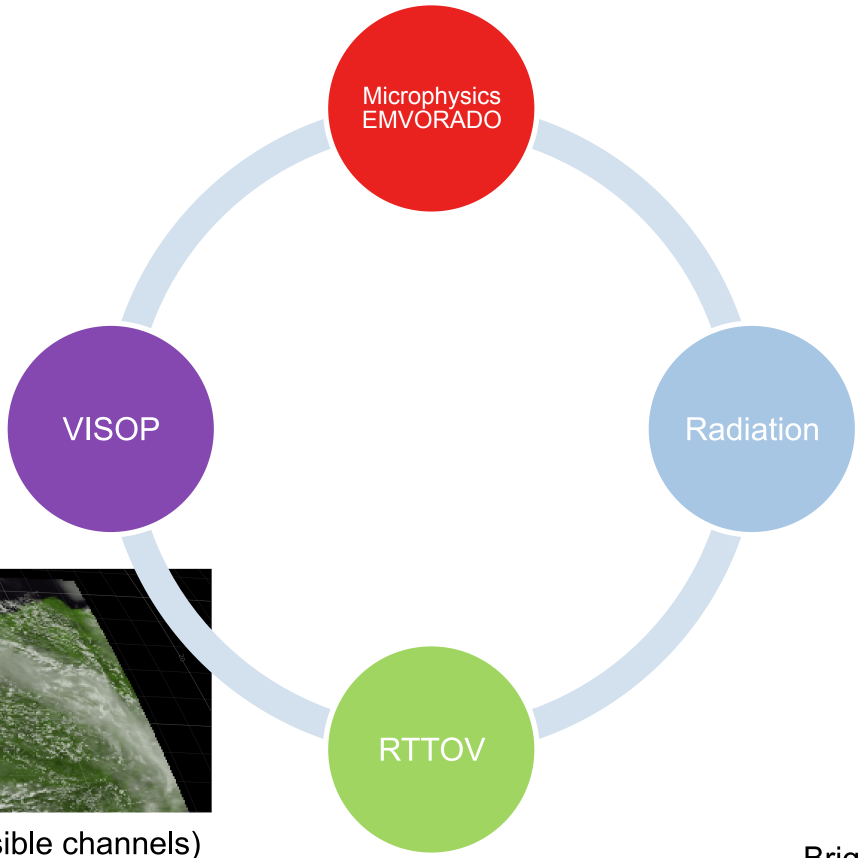
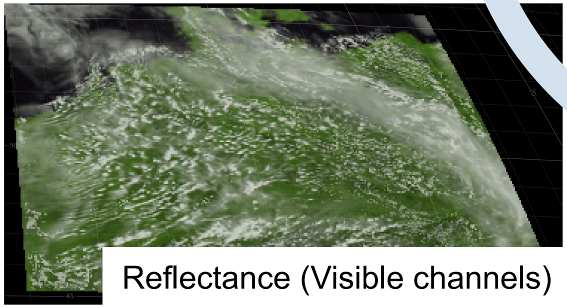
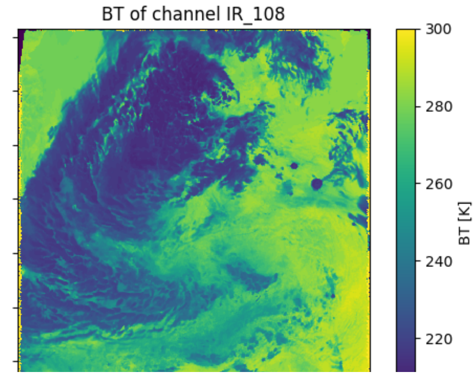


Radar Reflectivity




Reflectance (Visible channels)



Brightness Temperature (IR channels)

→ Besides, current research in the DWD (IconArt, PermaStorm, two-moment scheme) aims to better predict the droplet size distribution and therefore the effective radius. How to transfer this knowledge?

How many effective radius do we have?

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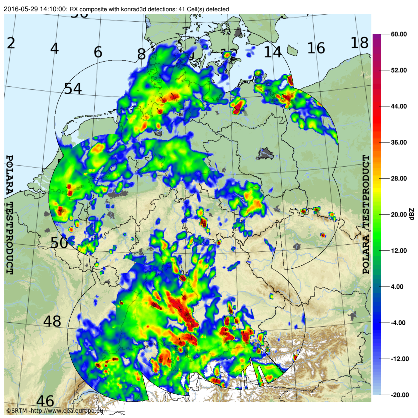
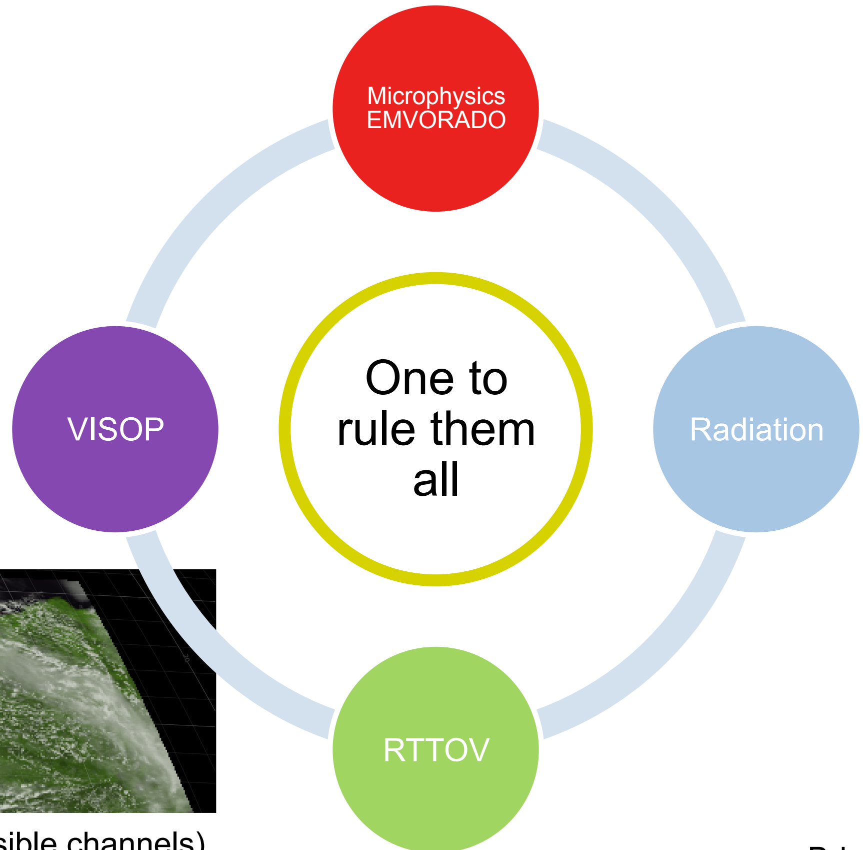
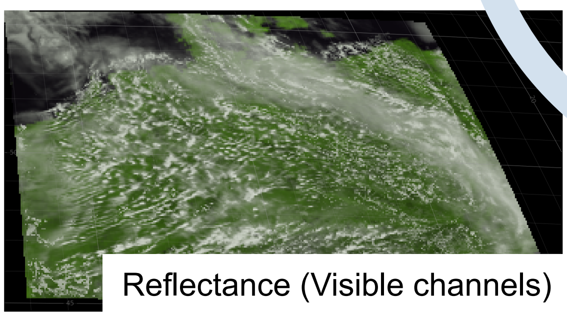
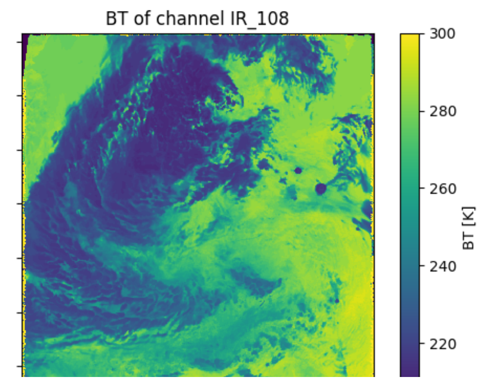


Radar Reflectivity





Reflectance (Visible channels)



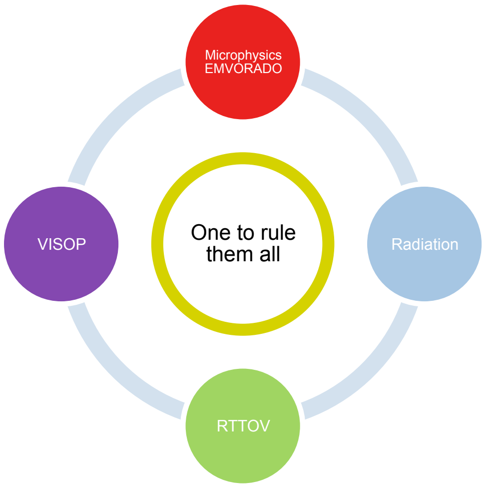
Brightness Temperature (IR channels)

➔ Besides, current research in the DWD (IconArt, PermaStorm, two-moment scheme) aims to better predict the droplet size distribution and therefore the effective radius. How to transfer this knowledge?

New effective radius module in ICON

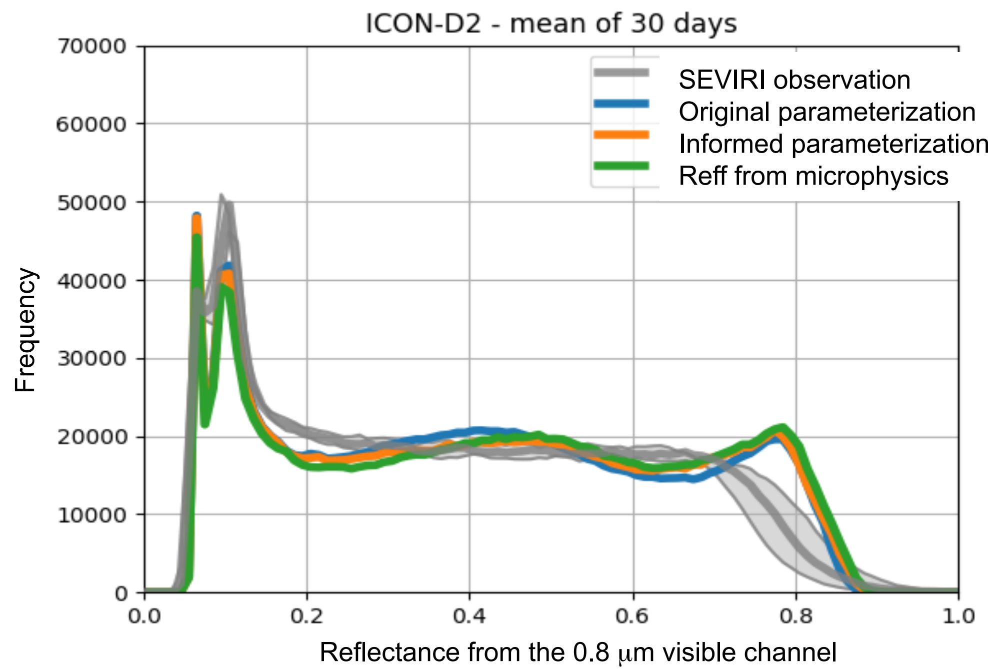
- New module that computes the effective radius of all hydrometeors. Already on incon-nwp/dev !
- The formulation is equivalent to the one of Simon (KIT), but with a more efficient and flexible implementation. Calculations are done in the microphysics module.
- WMO accepted an application to include different effective radius in grib codes.
- New namelist parameter:

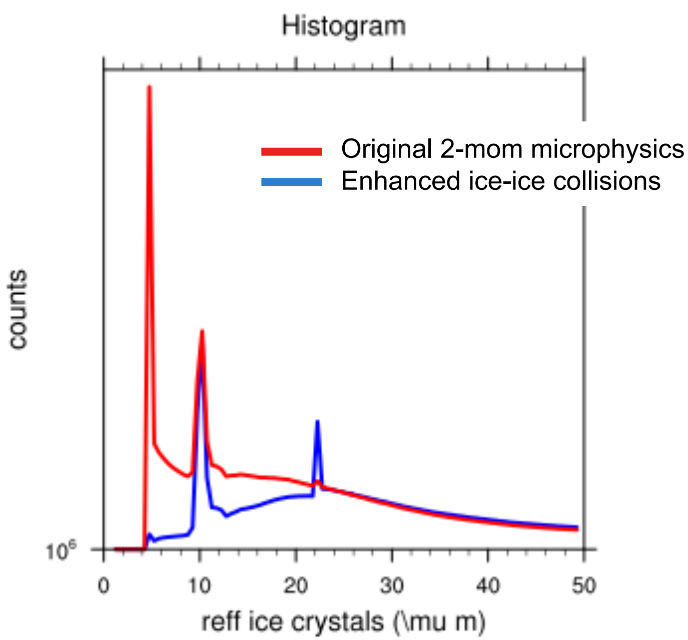
```
icalc_reff =

0     ! No calculation of effective radius
1     ! Operational LAM one-moment microphysics
….
4     ! Standard two-moment microphysics.
…
100   ! Consistent with chosen model microphysics
101   ! RTTM parameterization for ice and water
```



Using the effective radius module

- ➔ The output (grib, netcdf) can be used by offline operators like VISOP or RTTOV. This reduces the uncertainty of the effective radius parameterization. Online operators in other development branches.





- ➔ It can be also used to investigate cloud microphysics.

Outline

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Radiation-r_{eff} coupling

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➔ We provide the effective radius calculated from its own module to the radiation schemes implemented in ICON (RRTM and EcRaD).

➔ The direct interpolation of the effective radius to the radiation grid does not make much sense. Instead, we interpolate the mass fraction q and the approximate extinction coefficient:

$$r_{eff} = \mathrm{interp}(q) \,/\, \mathrm{interp}(q/r_{eff})$$

➔ Results produce almost identical results for RRTM. The small differences are explained by the different interpolations.

➔ This is a simple coupling. We have not yet changed the functions to calculate optical properties of clouds.

Redefining ice/liquid

- Radiation codes consider a single water and ice hydrometeor category.

- But, what is ice? The partition of the frozen phase between ice, graupel, snow and hail depends on the assumptions of the microphysical scheme. This should not be reflected in radiation. Currently snow is almost neglected:

$$q_i^{rad} = \max(q_i, 0.1(q_i+q_s)) + q_i^{sgs}(RH)$$

- Calculating the effective radius for all components allows for defining a frozen and a liquid phase:

$$\frac{q_c+q_r}{r_{liq}} = \frac{q_c}{r_c} + \frac{q_r}{r_r}$$

$$\frac{\sum_{fr} q_x}{r_{fr}} = \sum_{fr} \frac{q_x}{r_x}$$

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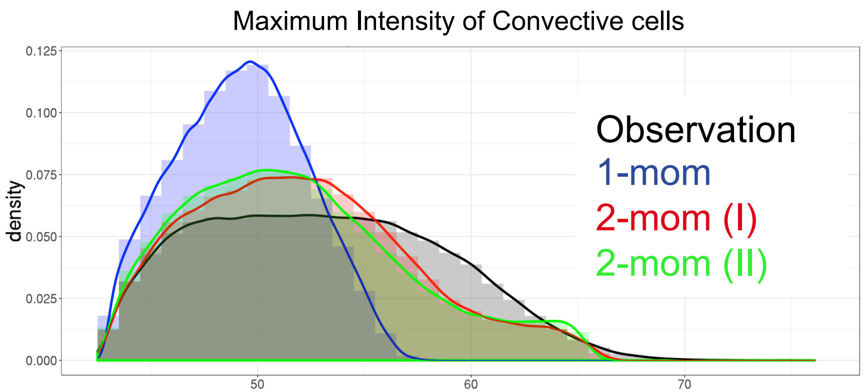
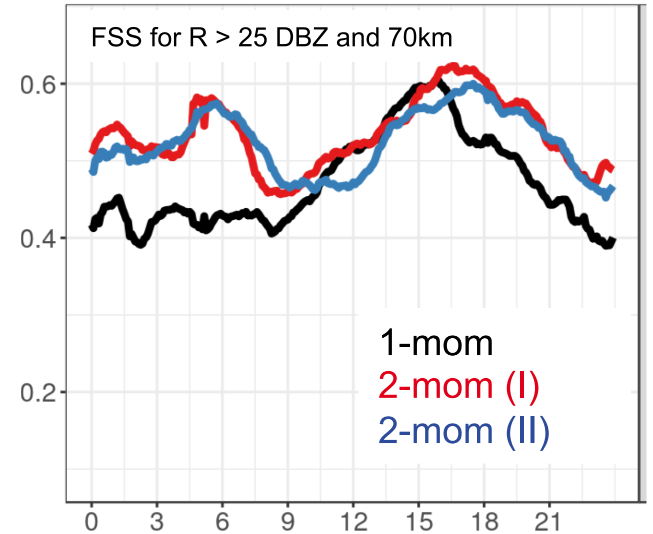
- The Sinfony project aims for improving short-range forecast of convective cells through a combination of Nowcasting and NWP. For this, we need realistic convective cells in the model. This can be achieved with a rapid (1h) assimilation of radar reflectivity and visible satellite channels.

- The two-moment microphysical scheme (Seifert and Beheng 2006) provides a significantly better representation of convective cells and has therefore the potential to improve the Sinfony predictions:





Coupled radiation

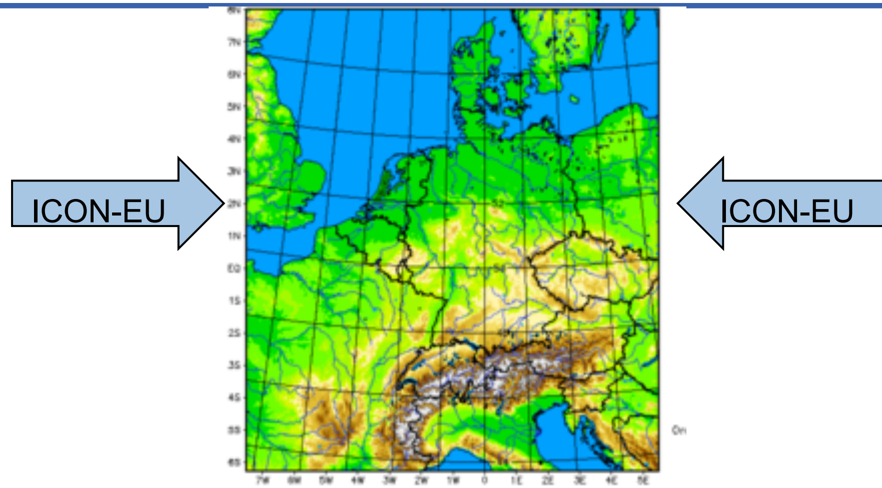
- The two-moment scheme has a prognostic equation for the cloud-number concentration. This information is not used to predict optical properties of clouds (radiation and forward operators), in the standard configuration.

- By coupling the effective radius to radiation and forward operators, the full information provided by the two-moment scheme can be used.

- This allows us for a more consistent tuning of microphysics, because changes in the number concentration have a direct effect on observations and radiation.

- This coupled configuration can more easily profit from advances in ICON-Art/ Perma-Storm.

Hindcast experiments



D2 Domain (2.1 km)

- ➔ We investigate long ICON D2 simulations (1 month) <u>without data assimilation</u> (no spinup or interaction with data assimilation).
- ➔ The boundary conditions arises from ICON-D2 reanalysis, thus forcing the system to be close to the observed weather condition.
- ➔ Investigate averaged properties (like histograms) in order to find a model climatology.

Coupled simulation are much colder

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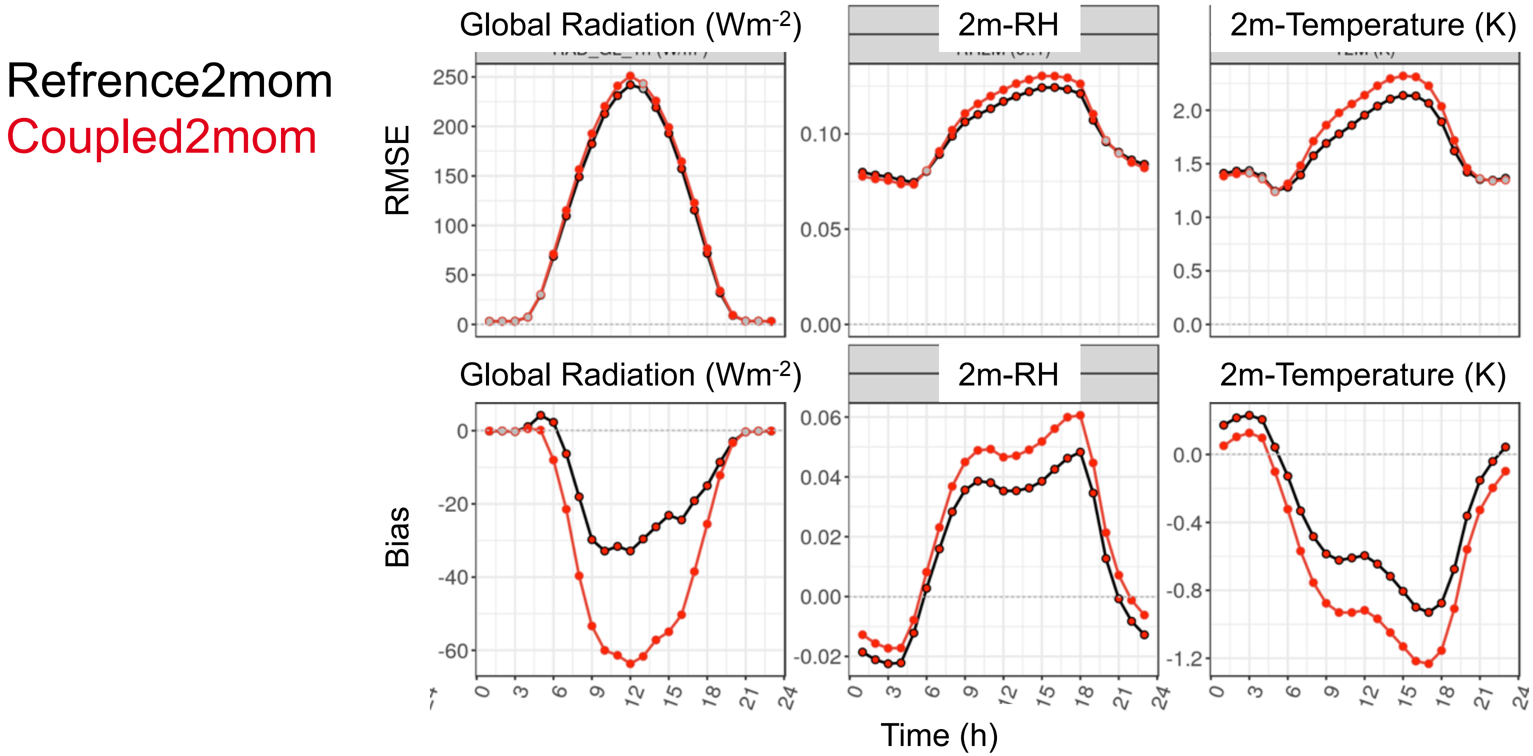

➔ The radiation bias increases to 60 W (80 W difference with the one-moment scheme) and 1.2 K cold bias at the surface.

➔ Not completely surprising as the model was never tuned for radiation: we need to retune the model.

Satellite statistics

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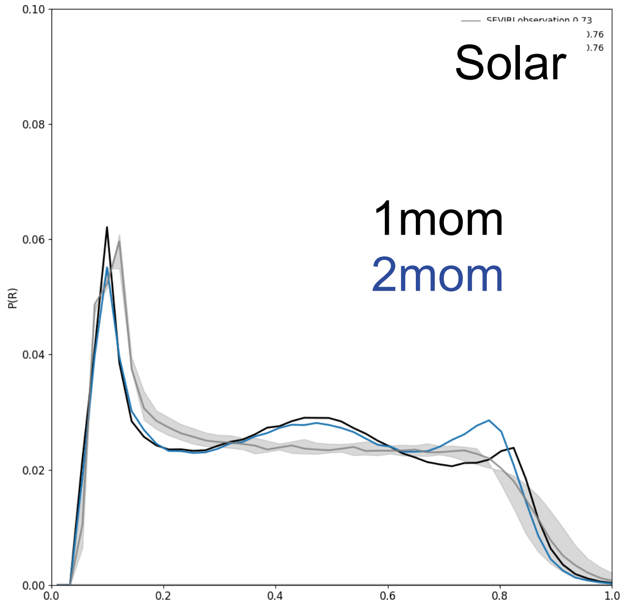
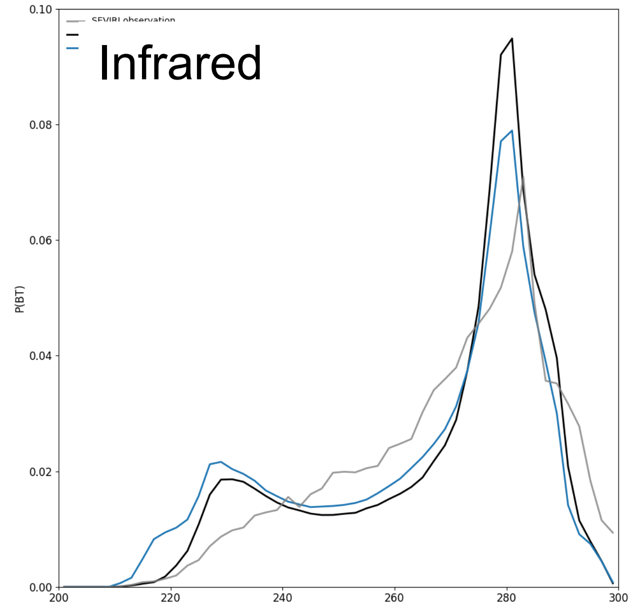
➔ Satellite observations suggests that the two-moment scheme produces too many clouds, specially high clouds.



Reflectance from the 0.8 μm channel



Brightness Temperature (K) from the 10.8 μm channel

Tuning ICON

Two levels of tuning:

- Changing model parameters that are uncertain in the model and are typically used to tune radiation:
  1. Sub-grid liquid clouds (asymmetry factor).
  2. Sub-grid ice clouds (new parameterization for q_i=0)
  3. Aerosol number concentration (in future it could come from ART)
  4. Optical properties of subgrid clouds (effective radius)
  5. Shallow convection
  6. Horizontal-inhomogeneity factor (the infamous 0.5 factor in COSMO, now in ICON 0.8)

- Tuning the microphysical processes.

Two levels of tuning:

- Changing model parameters that are uncertain in the model and are typically used to tune radiation:
  1. Sub-grid liquid clouds => Up to 75 W, but worst RMSE for better bias.
  2. Sub-grid ice clouds => 20 W and better high clouds.
  3. Aerosol number concentration => 30 W but worst solar hist. for better bias.
  4. Optical properties of subgrid clouds => max. 10 W. Not relevant.
  5. Shallow convection ??
  6. Horizontal-inhomogeneity factor => 20W, only changes radiation.

- Tuning the microphysical processes.

Tuned two-moment scheme

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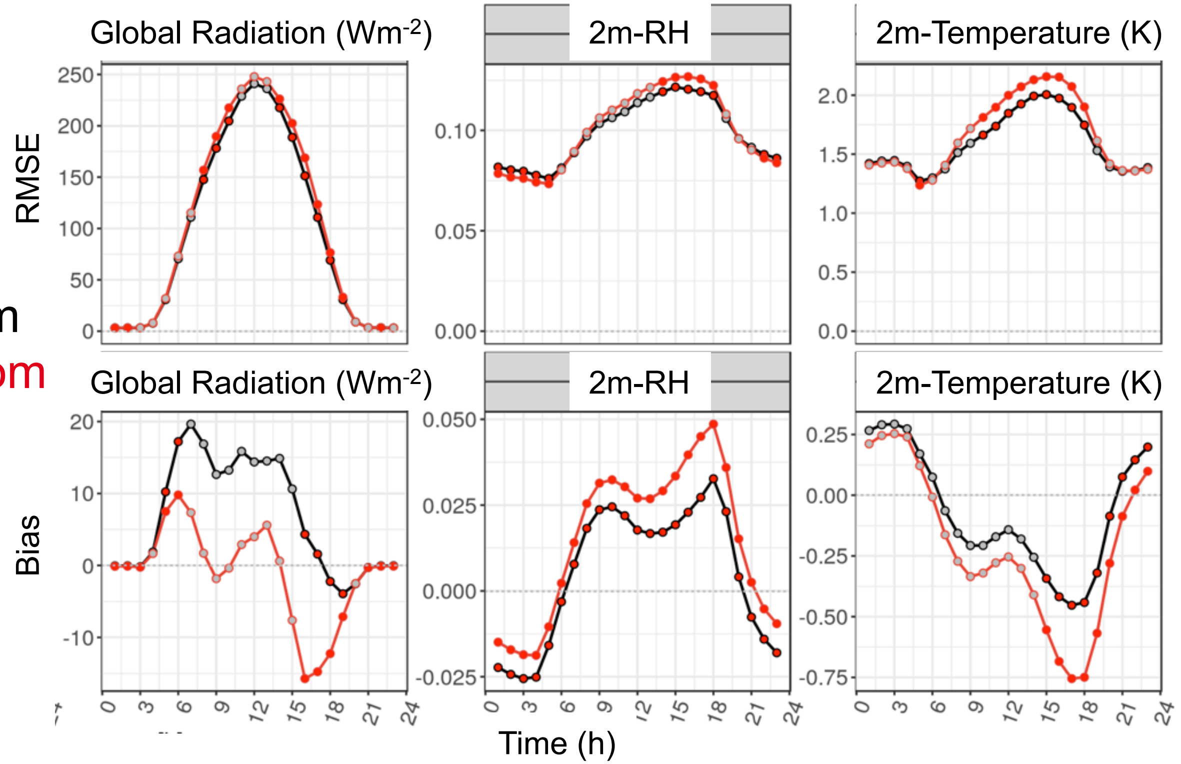
Operational 1mom
Coup. Tuned 2mom



- ➔ The tuned configuration (less CCN, inhomo. 0.6, sgsice =0, sgswater =3.0) has a good radiation balance, although not very good clouds from satellite.
- ➔ When compared with the operational system it does have a worst rmse for radiation, temperature and relative humidity
- ➔ BACY experiments with data assimilation also showed a worst performance.

ICON Sensitivity

Two levels of tuning:

➔ Changing model parameters that are uncertain in the model and are typically used to tune radiation:

① Subgrid liquid clouds => Up to 75 W, but worst RMSE for better bias.

② Subgrid ice clouds => 20 W and better high clouds.

③ Aerosol number concentration => 30 W but worst solar hist. for better bias.

④ Optical properties of subgrid clouds => max. 10 W. Not relevant.

⑤ Shallow convection ??

⑥ Horizontal-inhomogeneity factor => 20W, only changes radiation.

➔ Tuning the microphysical processes.

Enhanced Ice-ice conversion

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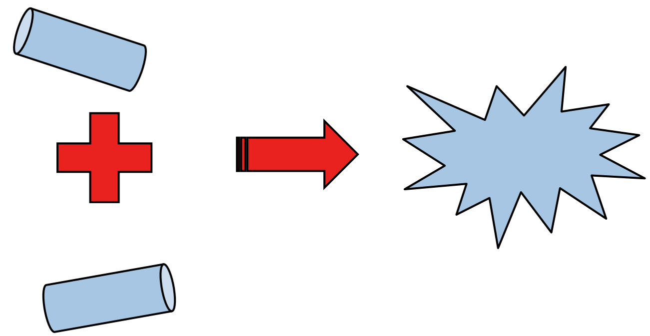
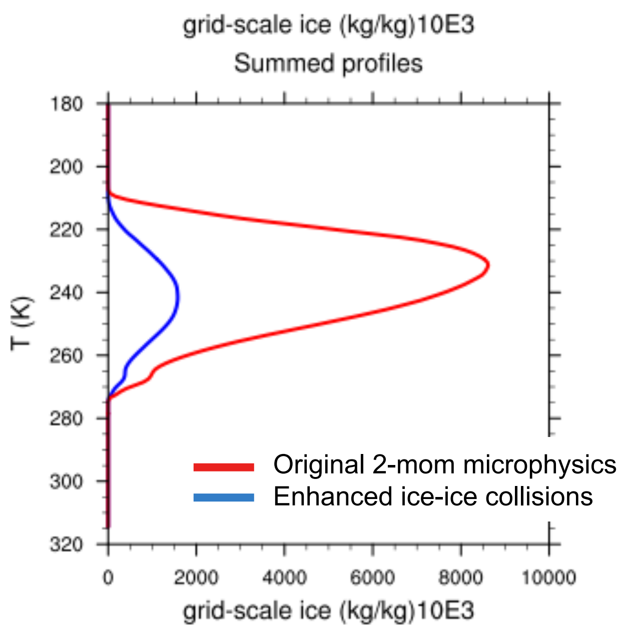
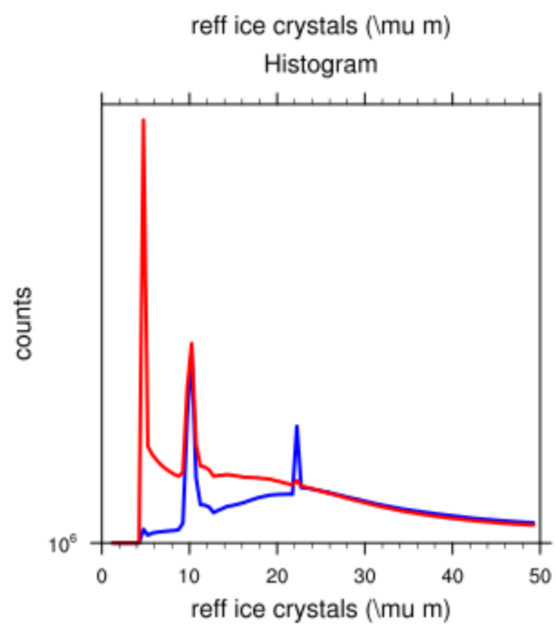
➔ Idea: remove some ice clouds by speeding up the ice-ice to snow collision process.







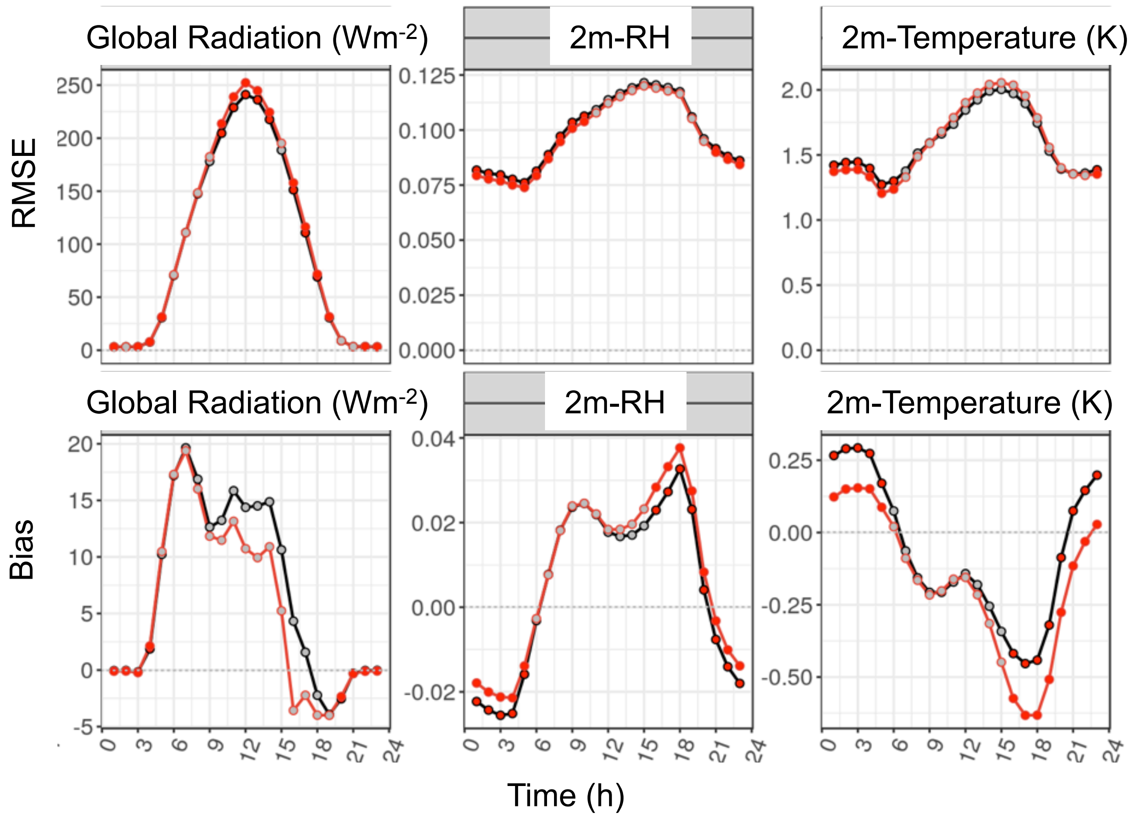
Second try reducing incoming radiation

Two levels of tuning:

- ➔ Changing model parameters that are uncertain in the model and are typically used to tune radiation:
  1. Subgrid liquid clouds => A = 3.0 (from 3.5).
  2. Subgrid ice clouds => same.
  3. Aerosol number concentration => SK8 (continental scenario).
  4. Optical properties of subgrid clouds => same.
  5. Shallow convection => same.
  6. Horizontal-inhomogeneity factor => 0.6 (from 0.8).
- ➔ Tuning the microphysical processes:=> enhanced ice-ice conversion

Tuned with enhanced ice-ice conversion

1-mom
2-mom



➔ Scores and biases are comparable in both schemes.

➔ BACY experiments (with assimilation) over a different period show similar scores.

Tuned with enhanced ice-ice conversion

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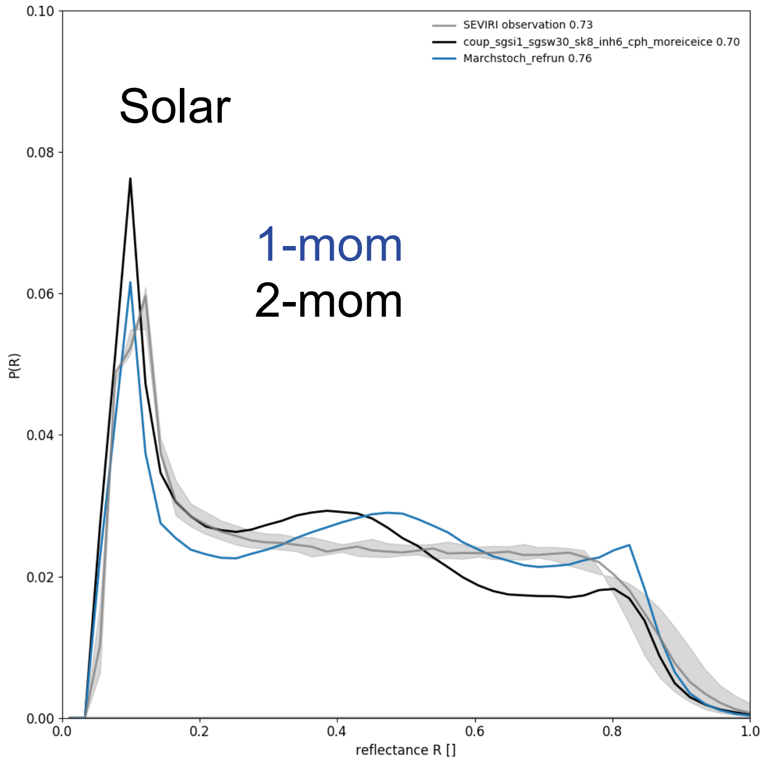
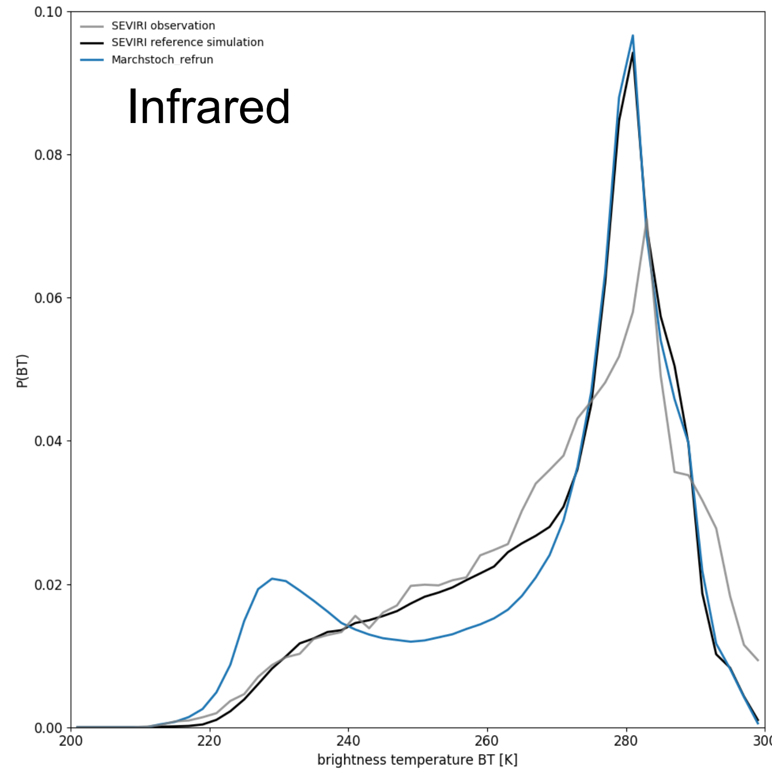


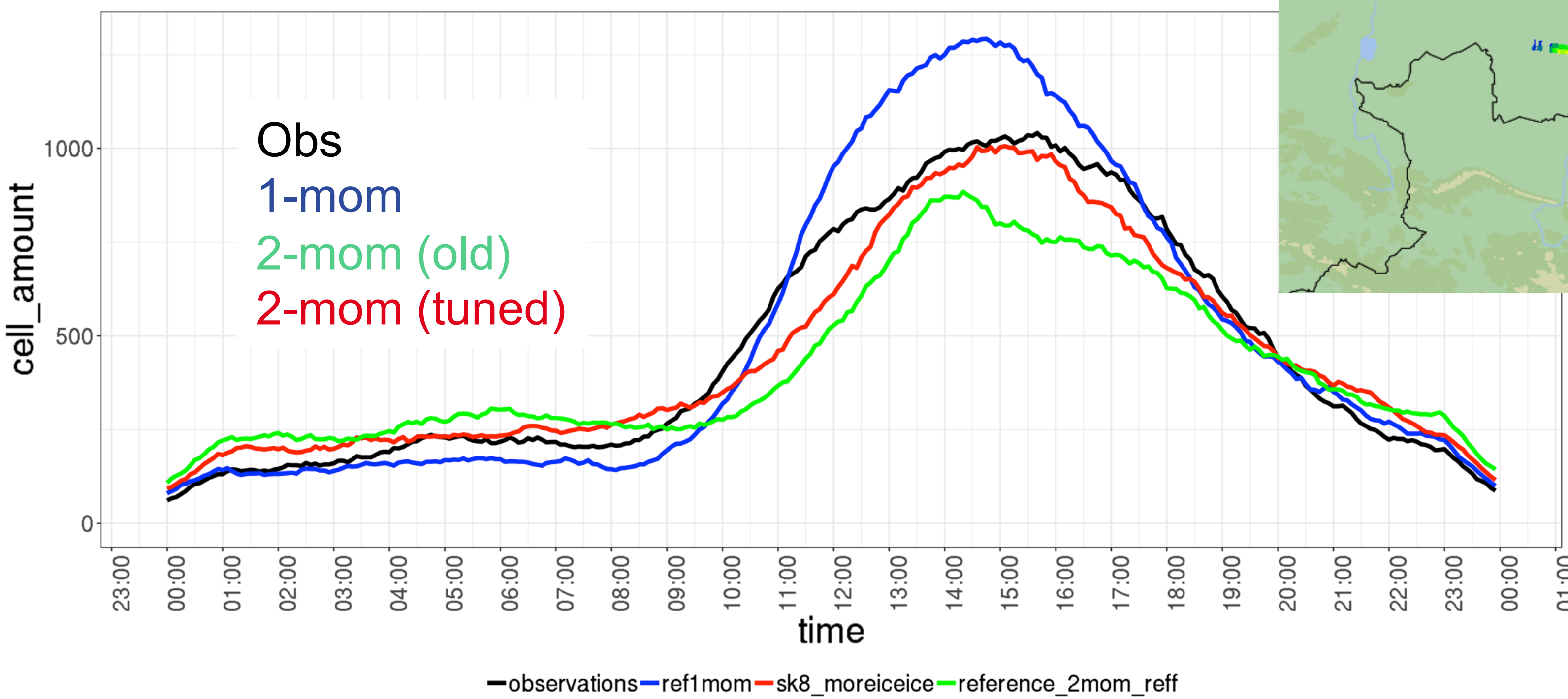


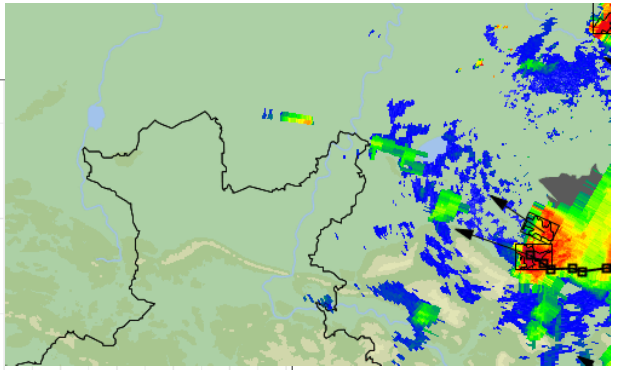
- ➔ The infrared histogram looks great, the cirrus parameterization (subgrid cloud parameterization) is doing a nice job!
- ➔ The solar histogram is not that good. It suggests we need more clouds but the model is already too cold.
- ➔ However, less frequent low-rate precipitation in two-moment scheme.

Number of long-lived cells (t> 60 min)

➔ More realistic diurnal cycle, but still slightly delayed.

Number of cells per each time step



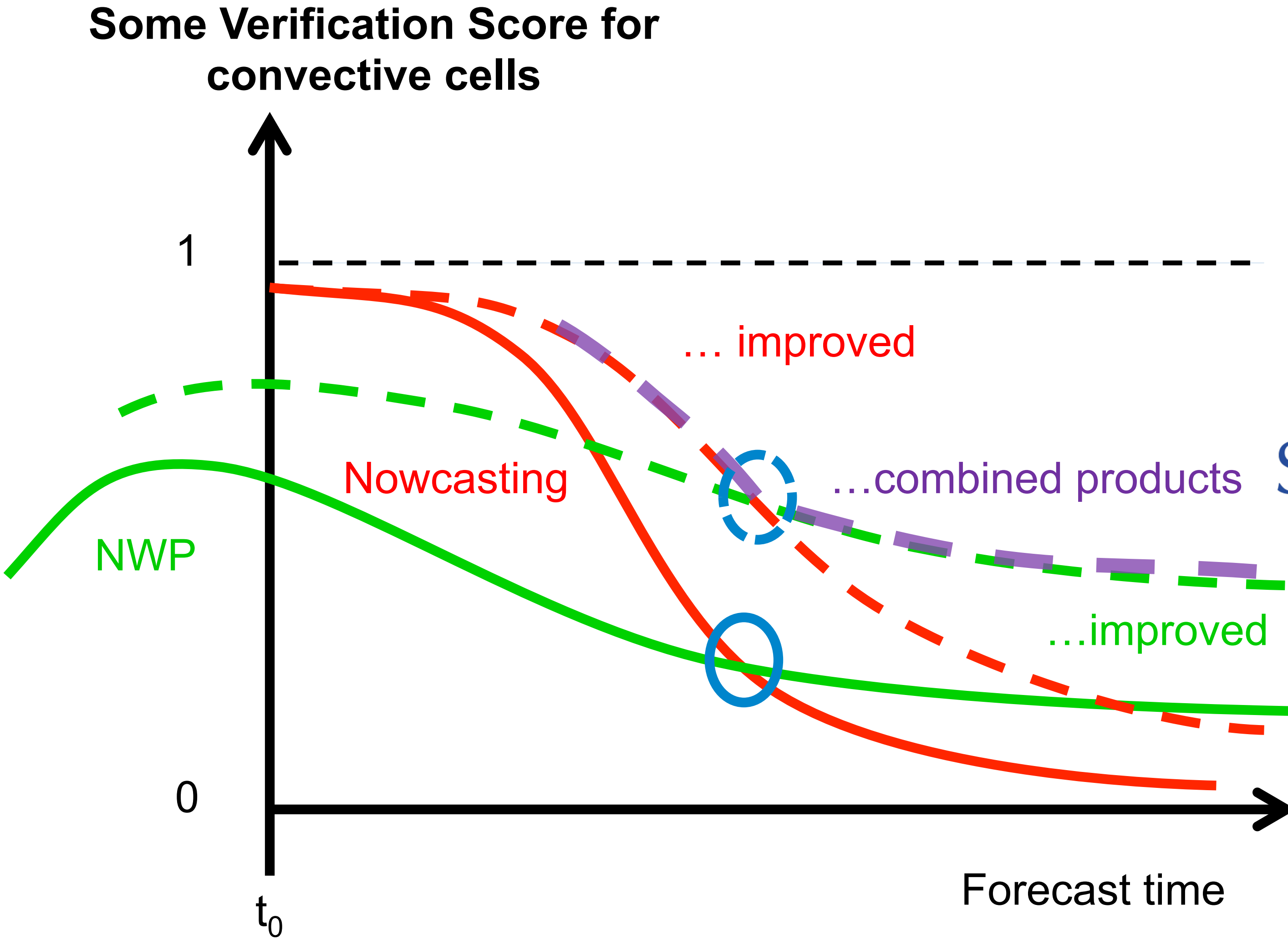


Conclusions/outlook

- We have presented:
  ① A new module for the calculation of the effective radius consistent with microphysics.
  ② A simple coupling to radiation through the effective radius.
  ③ Tuned model with modified two-moment microphysics produces same/ better scores than operational except for precipitation.
- Outlook:
  ① Technical work: NEC, push radiation coupling to the dev branch.
  ② Tune the model again for the cp/cv bug plus EcRad (now 1K warmer).
  ③ Look at precipitation again.
  ④ Include stochastic shallow convection.

Thank you very much!

SINFONY Idea



Two-moment microphysics

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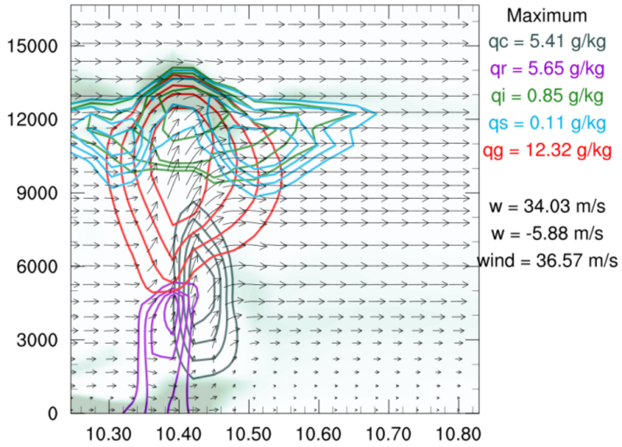
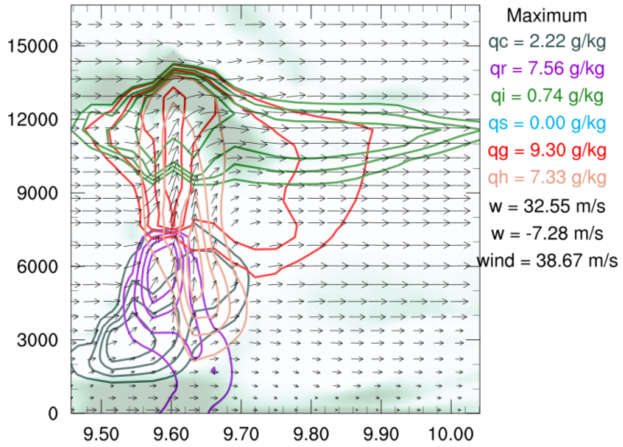
- **Research question:** does the two-moments microphysical scheme provides a better representation of clouds and convection?

- We test the 2-moment-scheme of Seifert and Beheng (2006) with additional hail class by Blahak (2008) and Noppel et al. (2010)
  - Additional prognostic number concentrations, more realistic particle sizes
  - Additional hail class allowing for large hail particles
  - But computationally more expensive, and not yet tuned!

COSMO 1MOM



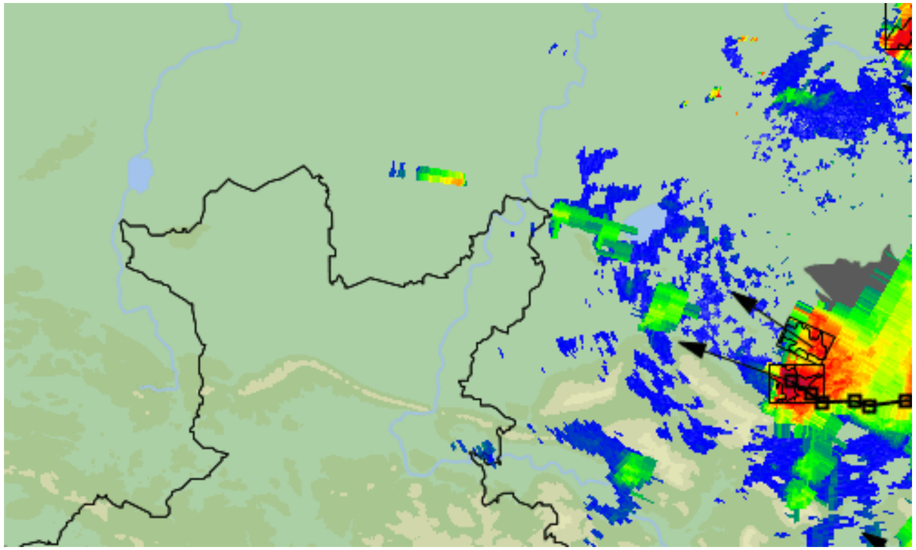
COSMO 2MOM



Cell detection with Nowcasting

➔ KONRAD is a system for detection, tracking and forecast of convective cells (thunderstorms) based on weather radar measurements (Nowcasting).

➔ As a successor of the existing KONRAD system, DWD is currently developing KONRAD3D. KONRAD3D exploits radar data from different heights (three-dimensional approach) and uses an adaptive threshold for the detection of convective cores.

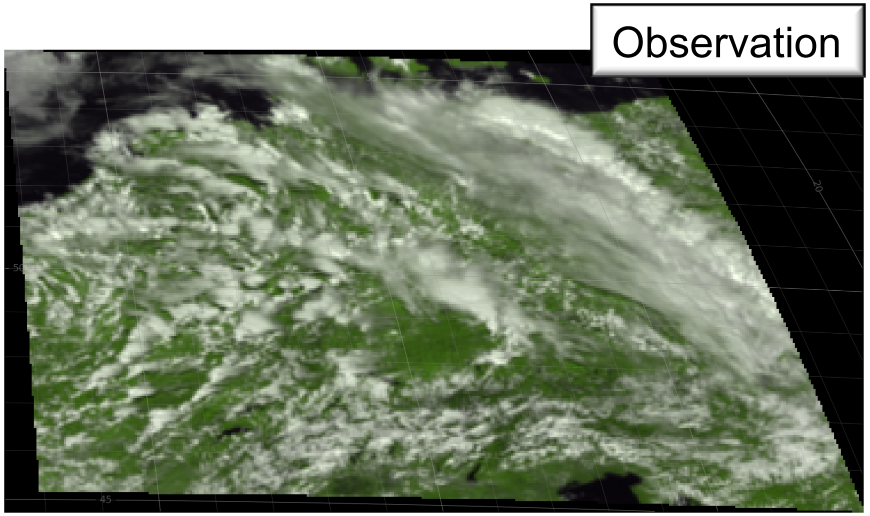


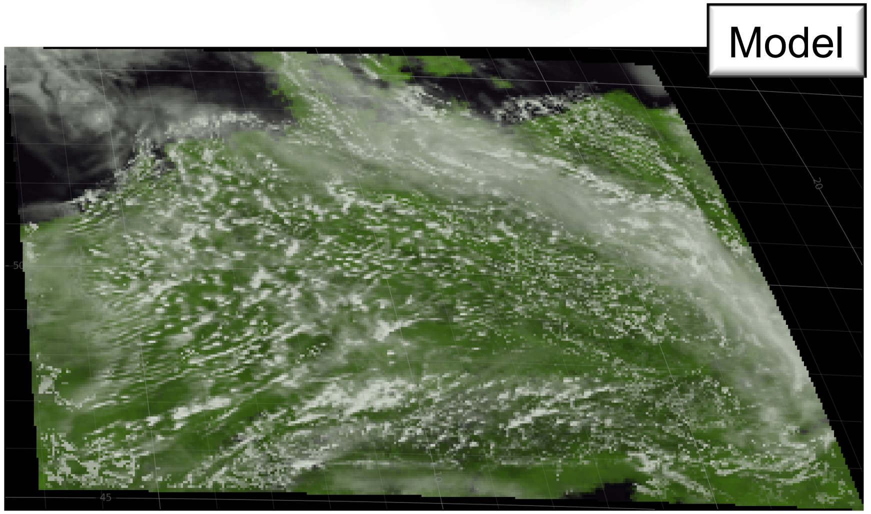
KONRAD3D

SMG-SEVIRI Visible Channels

- Forward-operator: **MFASIS** (Method for FAst Satellite Image Simulation) is a fast look-up table based RT-method (Scheck et al., 2016).

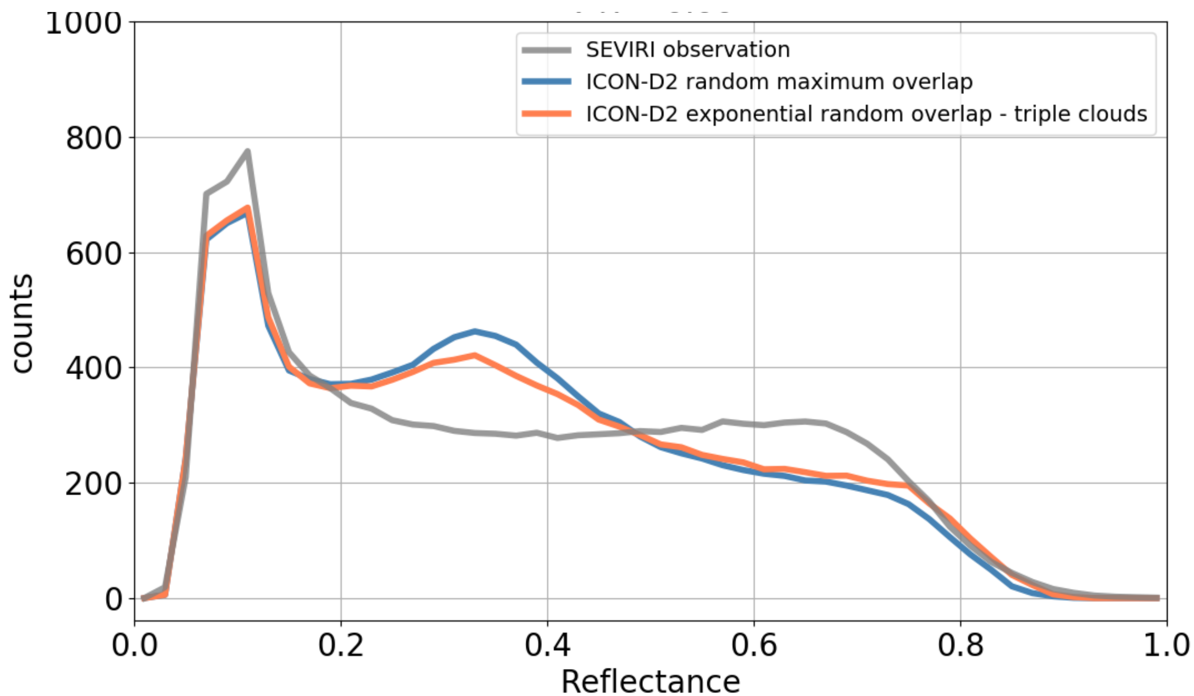
- We investigate two channels in the visible spectrum (one scan per hour).





SMG-SEVIRI Visible Histograms

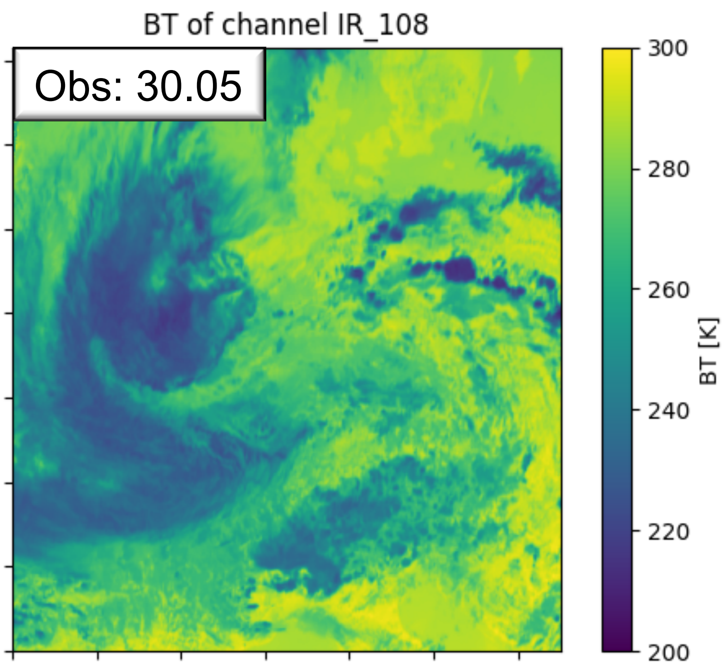
- One month only reflectances at 12.00 .
- There is still some uncertainty in the forward operator, due to uncertainties in cloud overlap, the variability of hydrometeors and effective radius. Here we show different variations.
- The Visible signal is related to cloud fraction and cloud thickness: it seems that the model produces too many thin clouds, but it lacks thicker ones.

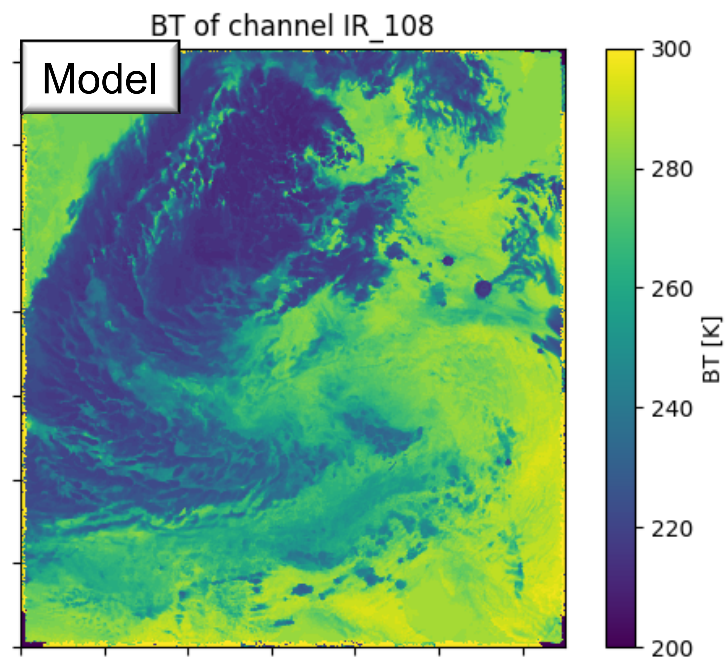


SMG-SEVIRI IR Channels

- Forward-operator: **RTOV v10** (Radiative Transfer for TOVS) is a very fast radiative transfer model for passive visible, infrared and microwave downward-viewing satellite radiometers, spectrometers and interferometers (Saunders, R. et al. 2018).

- We investigate four channels in the infrared spectrum (one scan per hour).





Observational Systems

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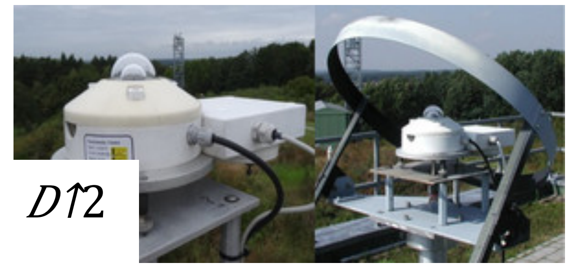
Radar (3D Scans)



Surface Radiation (Direct and Diffusive)

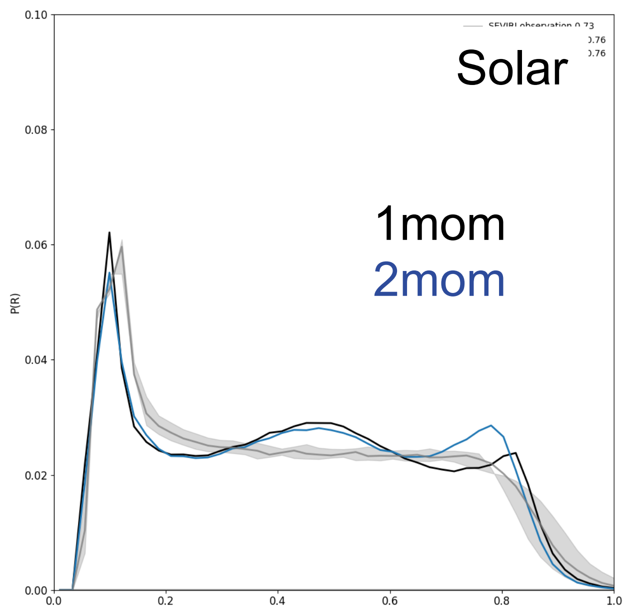
Rain Gauges

D↑2

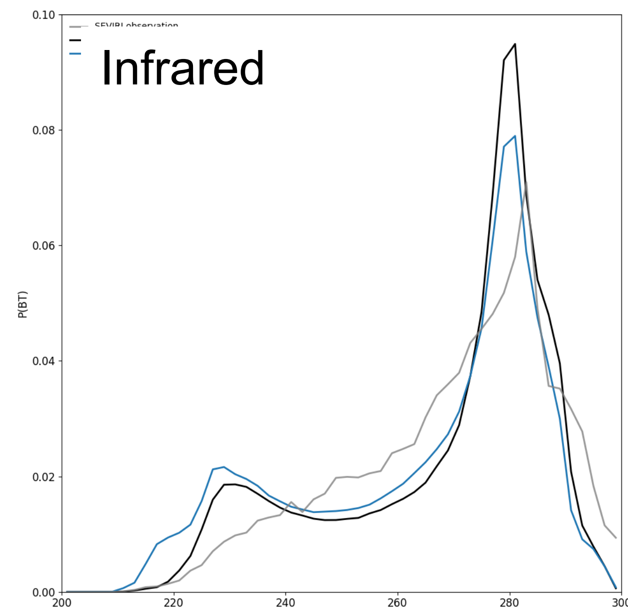
MSG-SEVIRI (Visible channel)

Coupled radiation (also operators)

- ➔ We also aim to obtain a better representation of clouds with the two-moment scheme: improved radiation and assimilation of all-sky satellite observations.
- ➔ By coupling the effective radius to radiation and forward operators, all information provided by the two-moment scheme can be used.
- ➔ However, tuning is necessary. We tune with 2-m observations but also with histograms from cloud-related satellite observations.

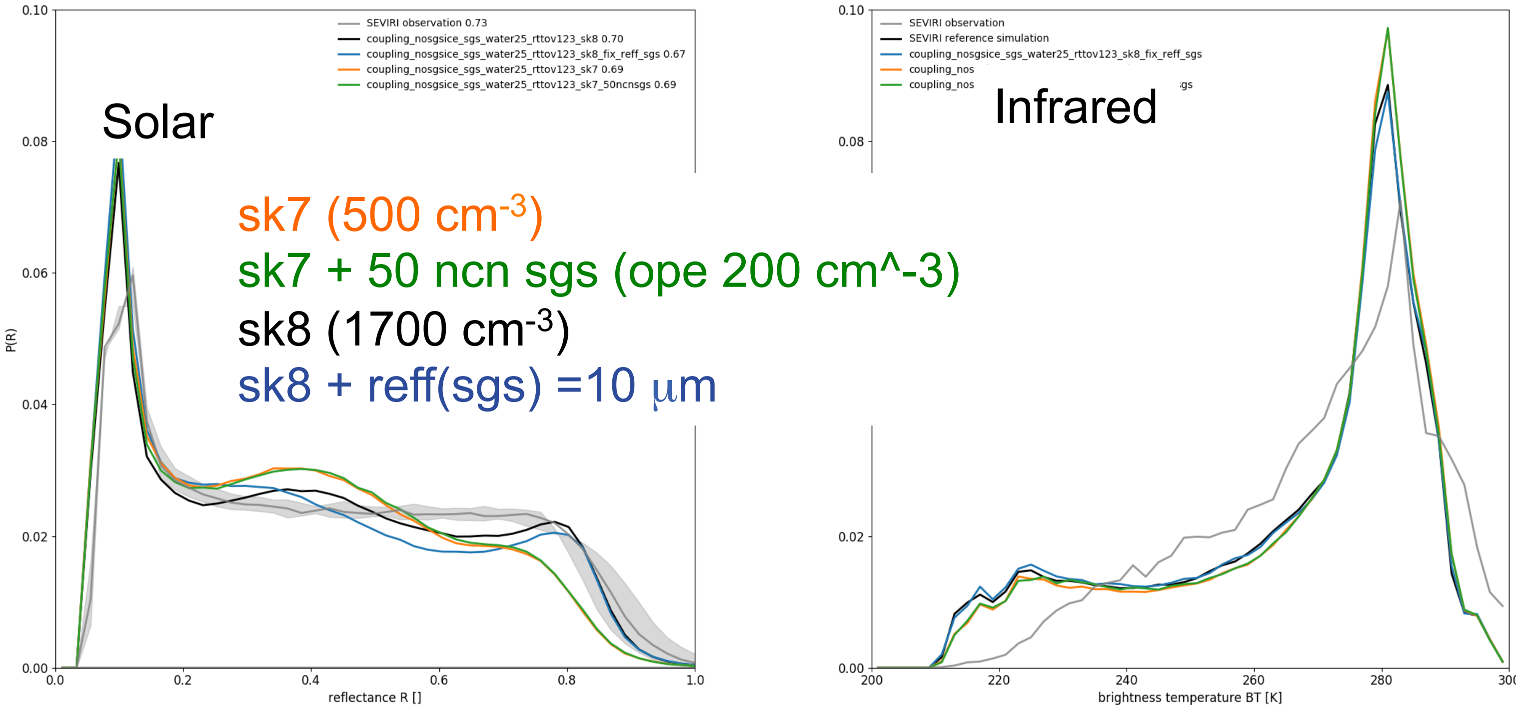


Reflectance from the 0.8 µm channel



Brightness Temperature (K) from the 10.8 µm channel

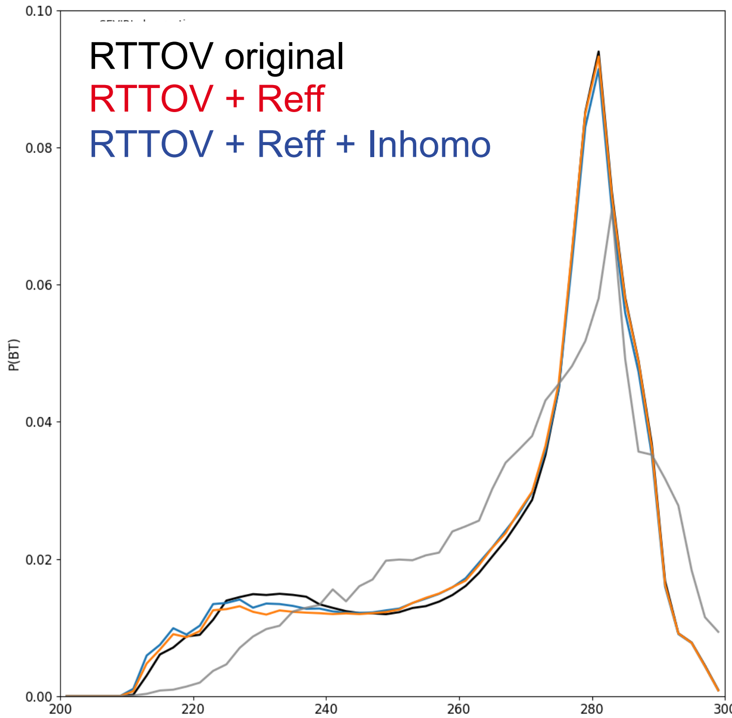
Sub-grid-optical properties(MFASIS)



- ➔ Changing the number concentration did not have any considerable effect.
- ➔ Fixing the effective radius to a large value (10 μm) did decrease the histogram almost everywhere.
- ➔ Almost no differences in infrared histograms.

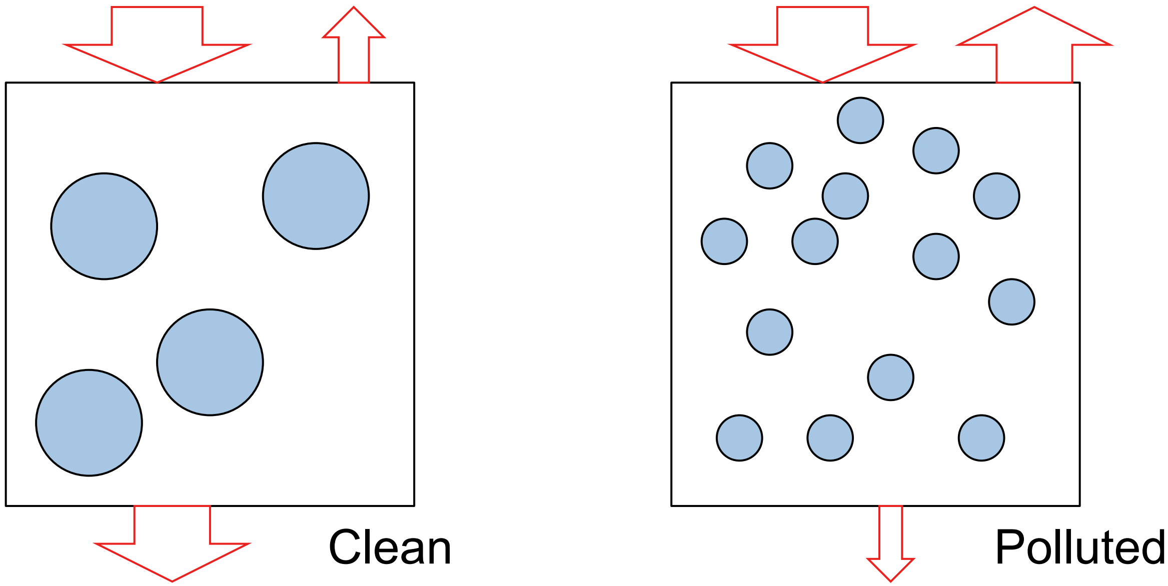
Coupled radiation (also operators)

- ➔ We also aim to obtain a better representation of clouds with the two-moment scheme: improved radiation and assimilation of all-sky satellite observations.
- ➔ By coupling the effective radius to radiation and forward operators, all information provided by the two-moment scheme can be used.



Brightness Temperature (K) from the 10.8 μm channel

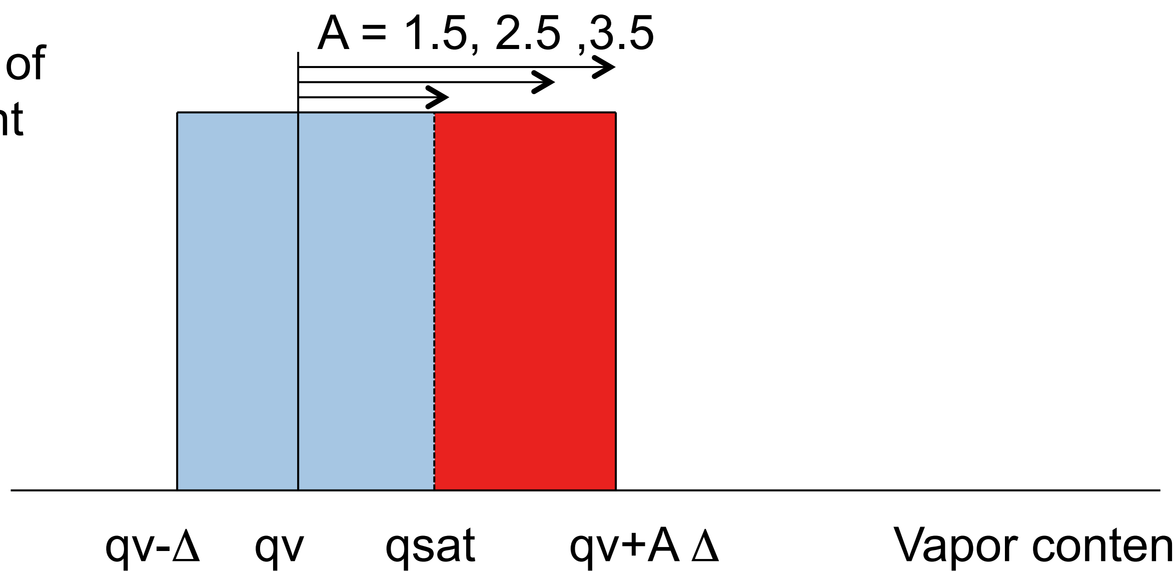
CCN scenario



➔ We have compared Segel-Khain in two scenarios, continental (N = 1700 cm^{-3}) and intermediate (N = 500 cm^{-3}) and the Hande parameterization (fit to case study in Spring).

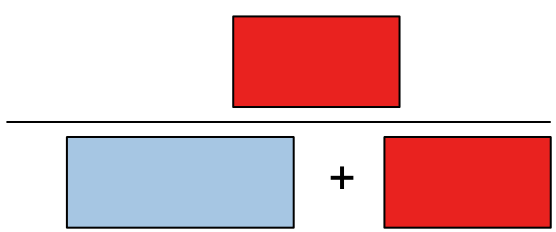
Sub-grid Clouds

Assumed distribution of sub-grid vapor content

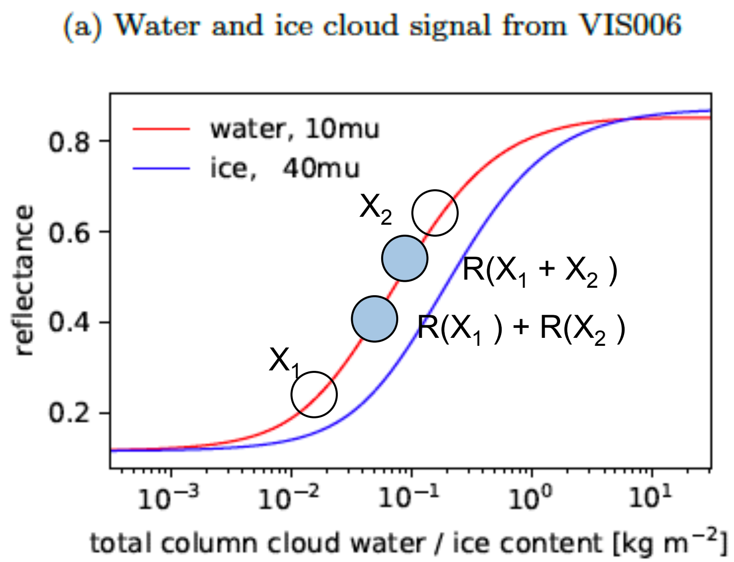


qv	: grid-scale water content
Δ	: variance of water vapor. It is proportional to turbulence variance qvar.
A	: asymmetry factor. ICON assumes more sub-grid liquid clouds (A=3.5)

Cloud cover ~



Horizontal Inhomogeneity factor



- ➔ The radiative transfer function is highly non linear. The linearization overestimates the effects of clouds on radiation.
- ➔ In the radiation routine the LWP/IWP is multiplied by 0.77/0.80 due to inhomogeneities in the hydrometeor concentrations. This factor is 0.5 in COSMO, and difficult to estimate in ECCRAD.