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Clouds and Aerosols Improvements in ICON Radiation Scheme - CAIIR Priority Project

Harel Muskatel (IMS)

24th COSMO General Meeting, September 14, 2022

Clouds and Aerosols Improvements in ICON Radiation Scheme - CAIIR Priority Project

Project duration: March 2020 - September 2023

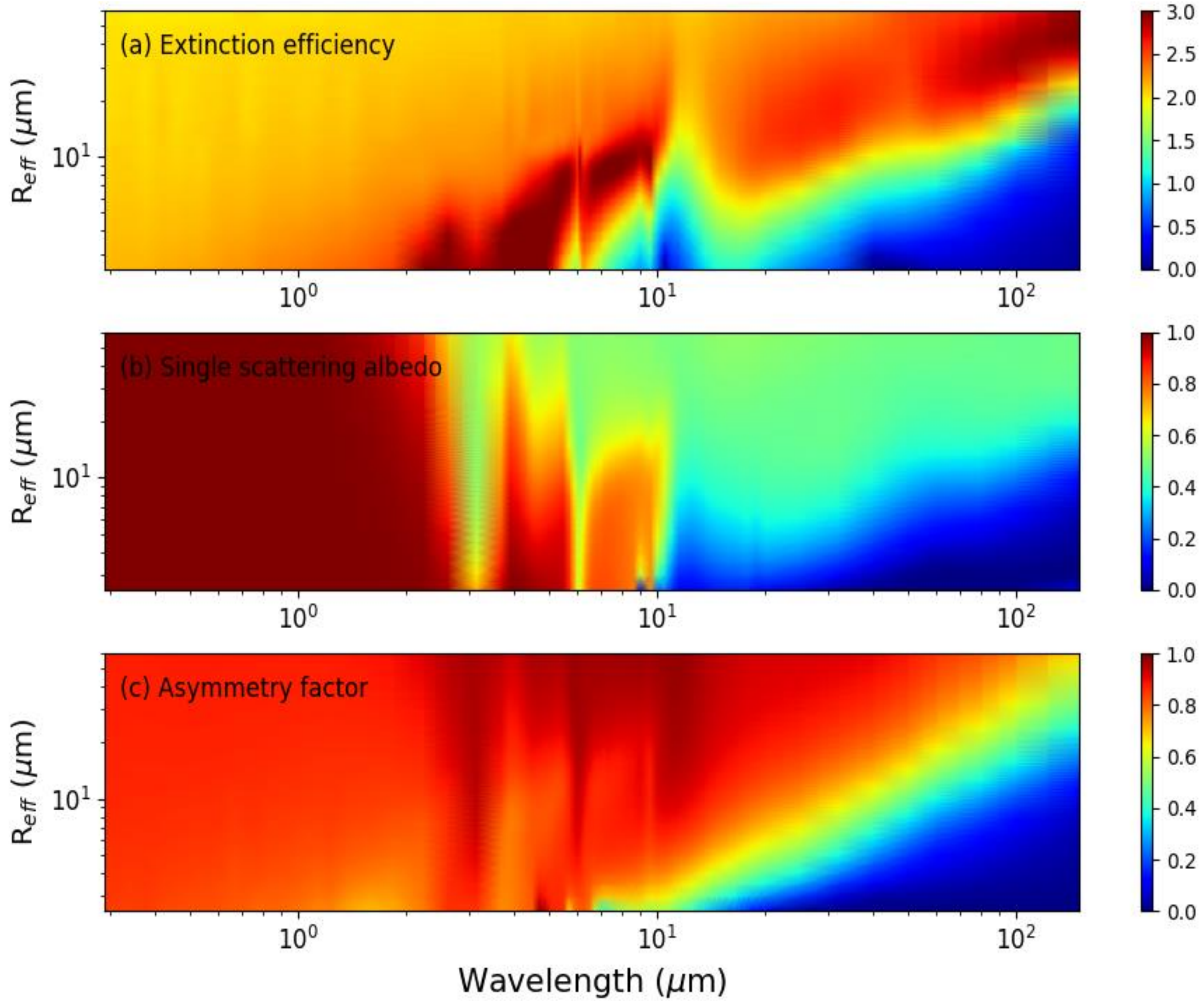
Participants:

- Harel Muskatel (IMS)
- Pavel Khain (IMS)
- Alon Shtivelman (IMS)
- Yoav Levi (IMS)
- Daniel Rieger (DWD)
- Ulrich Blahak (DWD)

- Alexey Poliukhov (RHM)
- Julia Khlestova (RHM)
- Gdaly Rivin (RHM)
- Natalia Chubarova (RHM)
- Marina Shatunova (RHM)

- Cloud optics
- Aerosols inputs: CAMS forecast, CAMS climatology, 2D advection scheme
- Microphysics – new cloud nucleation schemes
- Spectral Bin Microphysics

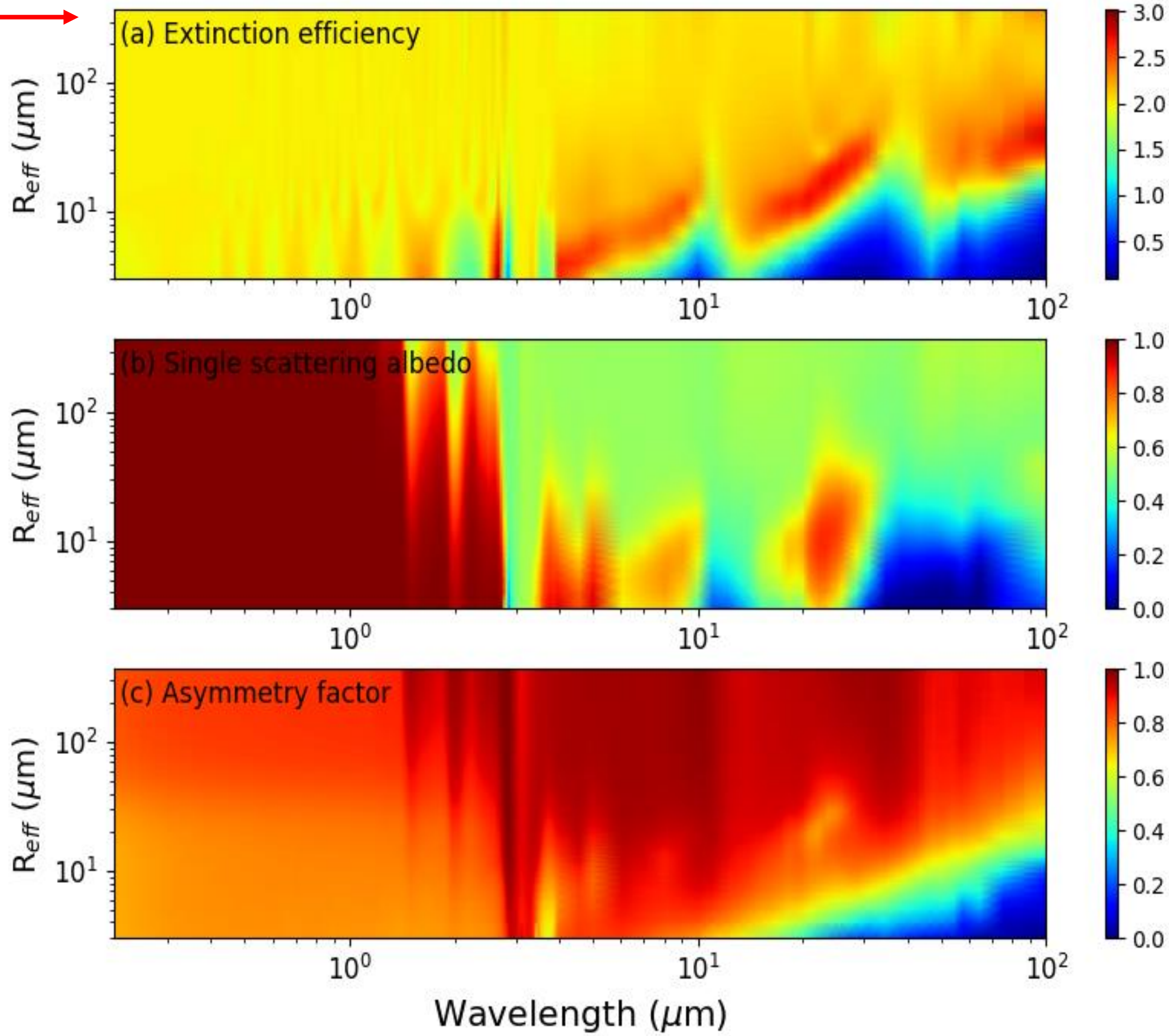
New droplets optical properties for ecRAD



Muskatel, Blahak, Khain, Levi & Fu; *Atmosphere* 2021, *12*, 89.

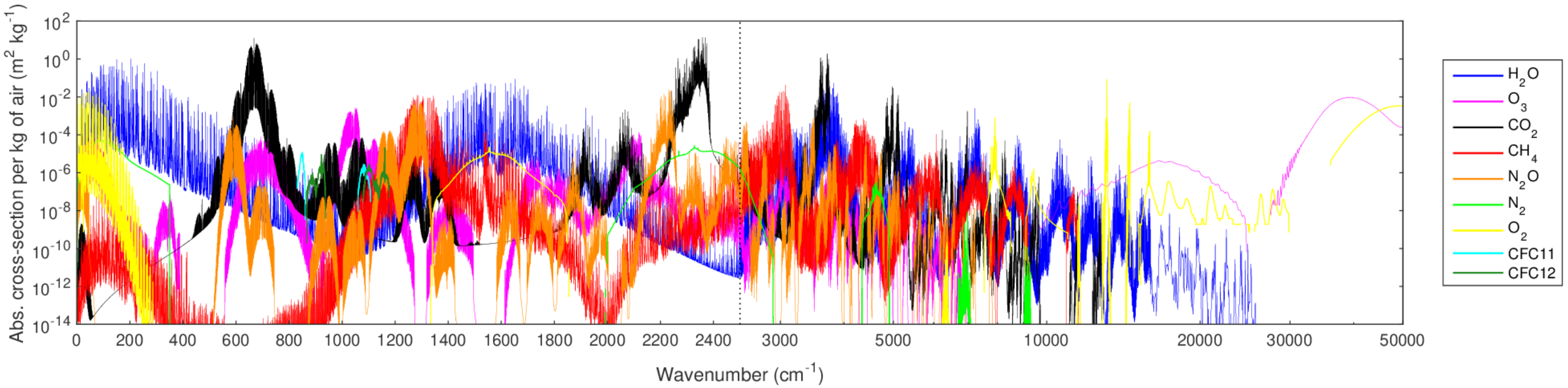
New ice optical properties for ecRAD

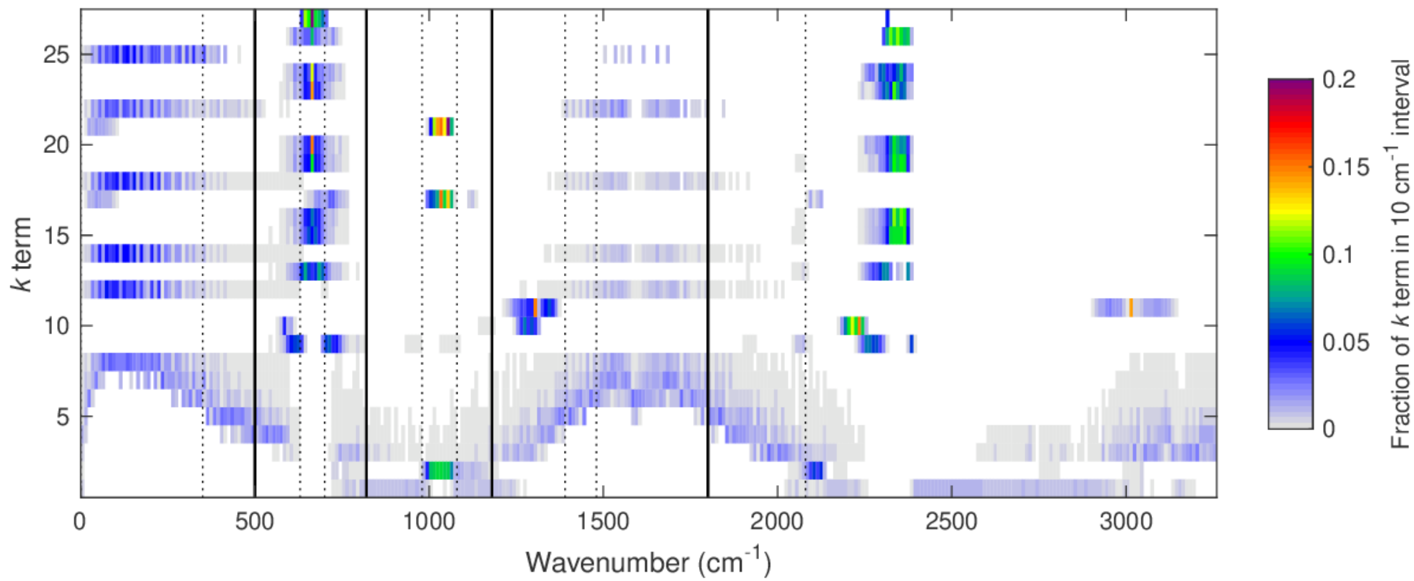
Extended size



Our new parametrization is now implemented in IFS. ICON is next…

ECCKD



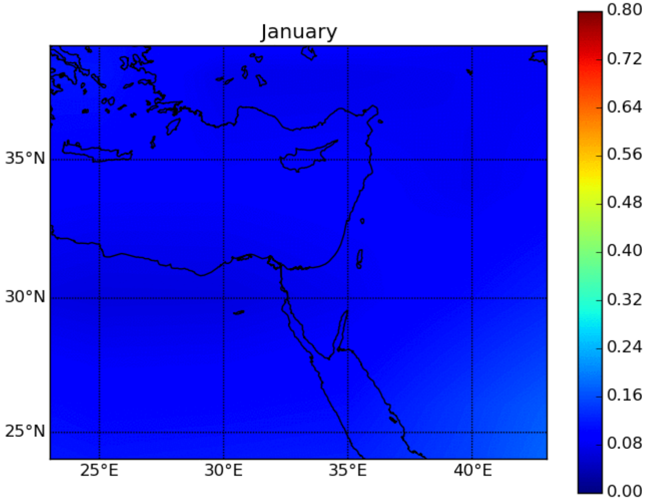


https://confluence.ecmwf.int/display/CKDMIP/

Aerosols Inputs in ICON Radiation scheme

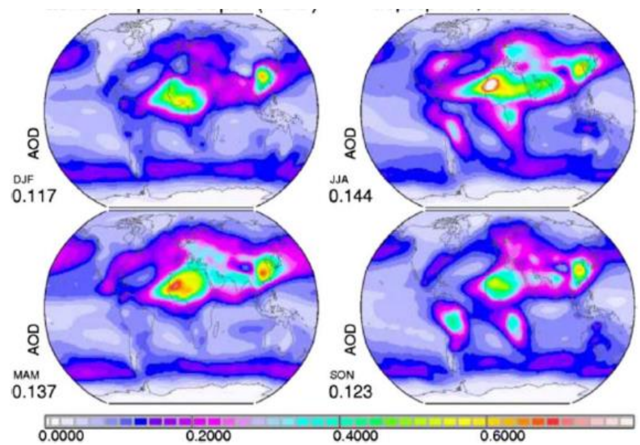
Tegen (1997)

irad_aero = 6



Kinne (2013)

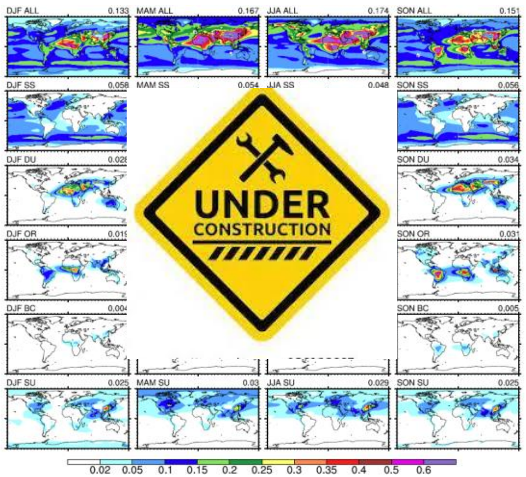
irad_aero = 13



Trang Pham-van (DWD)

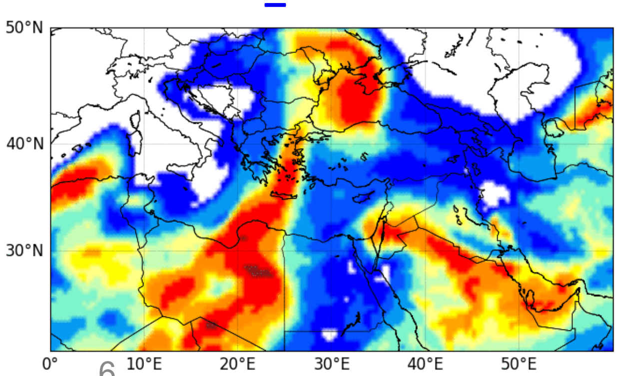
CAMS climtology

irad_aero = 7



CAMS forecast

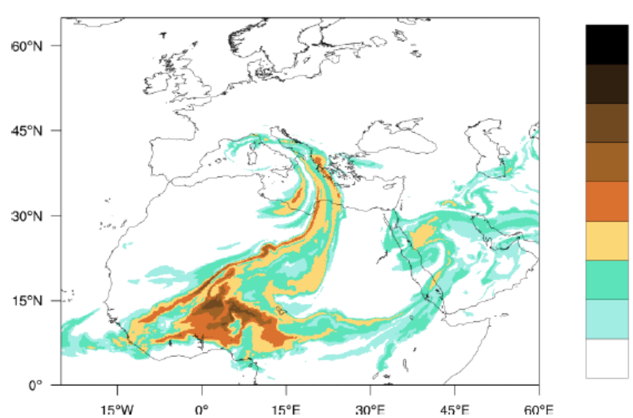
irad_aero = 8



5 days forecast

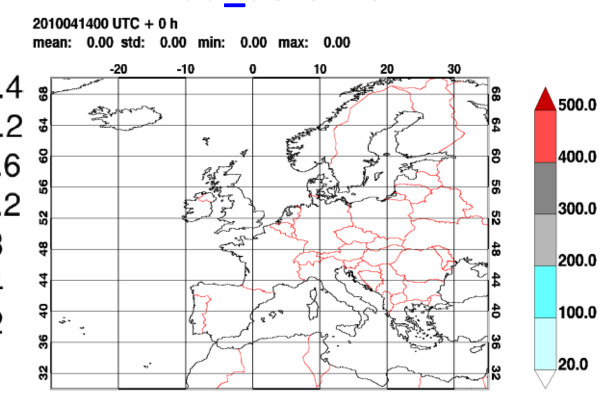
Prognostic 2D AOD

irad_aero=6 & iprog_aero=1



ICON-ART

irad_aero = 9



CAMS forecast advanteges

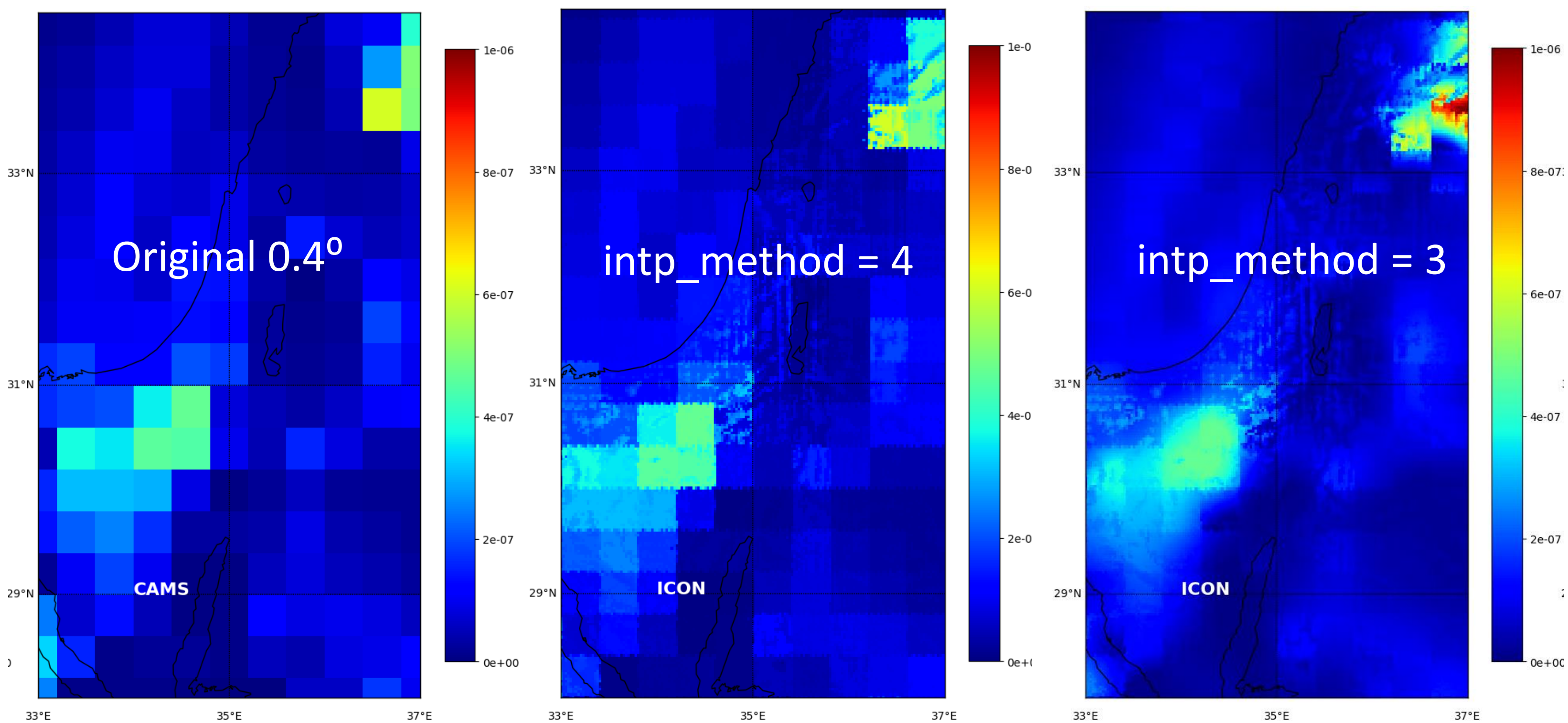
CAMS	Tegen Climatology
Vertical profile based on dynamics	Fixed vertical profile based on AOD
Optical properties calculated for each RRTM/ecRad WL intervals	Optical properties calculated at 550 nm and corrections made for other WL
Optical properties of hydrophilic aerosols are RH-dependent	Optical properties are RH-independent
Number concentrations are calculated explicitly from mixing ratios	Number concentrations are evaluated from AOD
11 species of aerosols	5 species of aerosols
Data assimilation is used	Fixed monthly climatology
Longwave scattering included	longwave scattering not included

Negligible additional CPU cost

BUT: Emissions, Advection, Convection, sedimentation etc. are done in CAMS model and not inside ICON

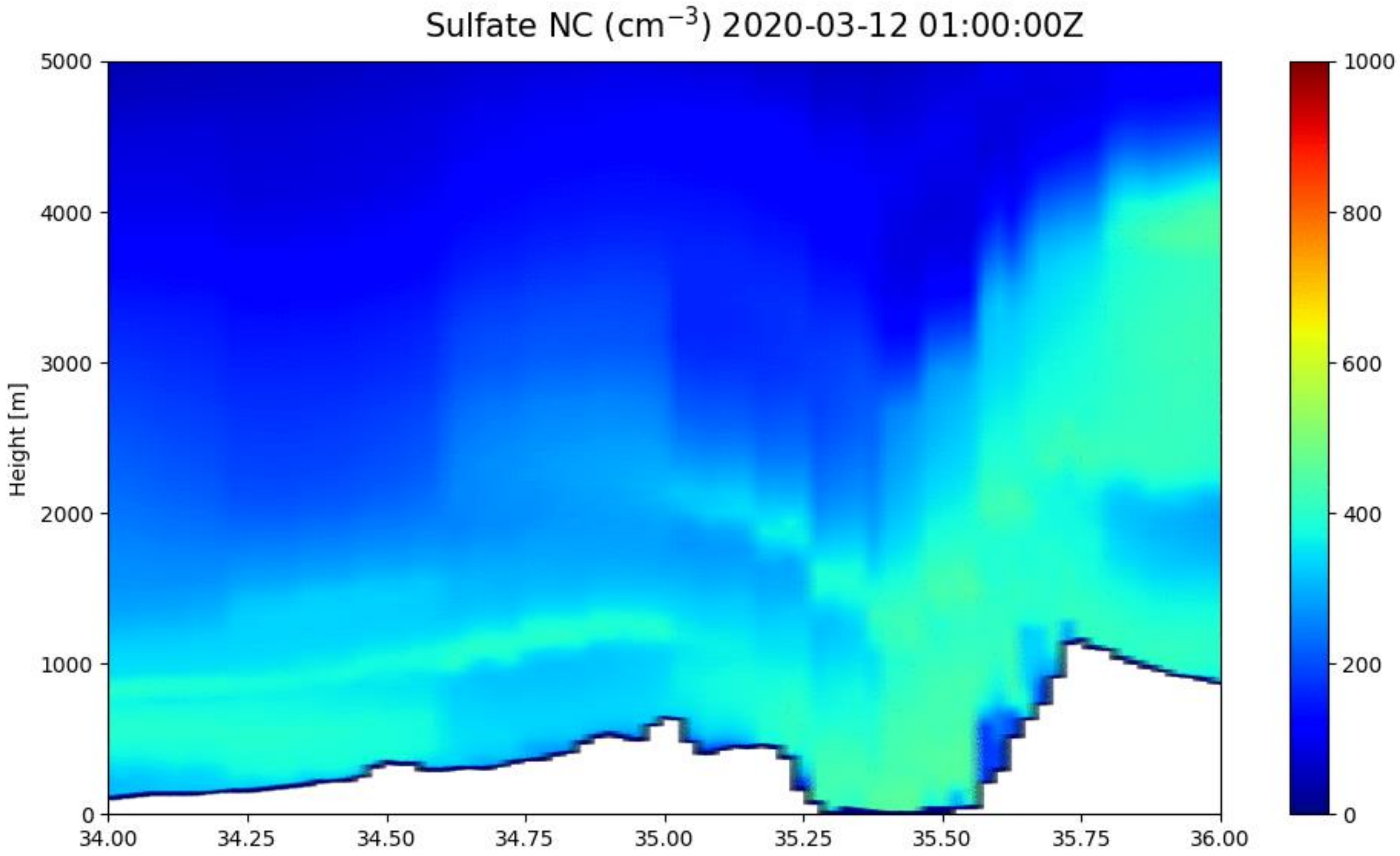
Horizontal Interpolation

- CAMS 3D mixing ratios – 5 days ahead, 3hr resolution are interpolated in space and time into 1 hr resolution latbc files using iconremap. The fields fill the whole domain.
- Step by step interpolation is done by ICON
- 11 species aermrXX fields are combined with the usual IFS latbc fields
- Recommendation: intp_method = 3 INTP_RBF_SCALAR (Radial Basis Function) instead of = 4 INTP_NNB_SCALAR (nearest-neighbor interpolation)



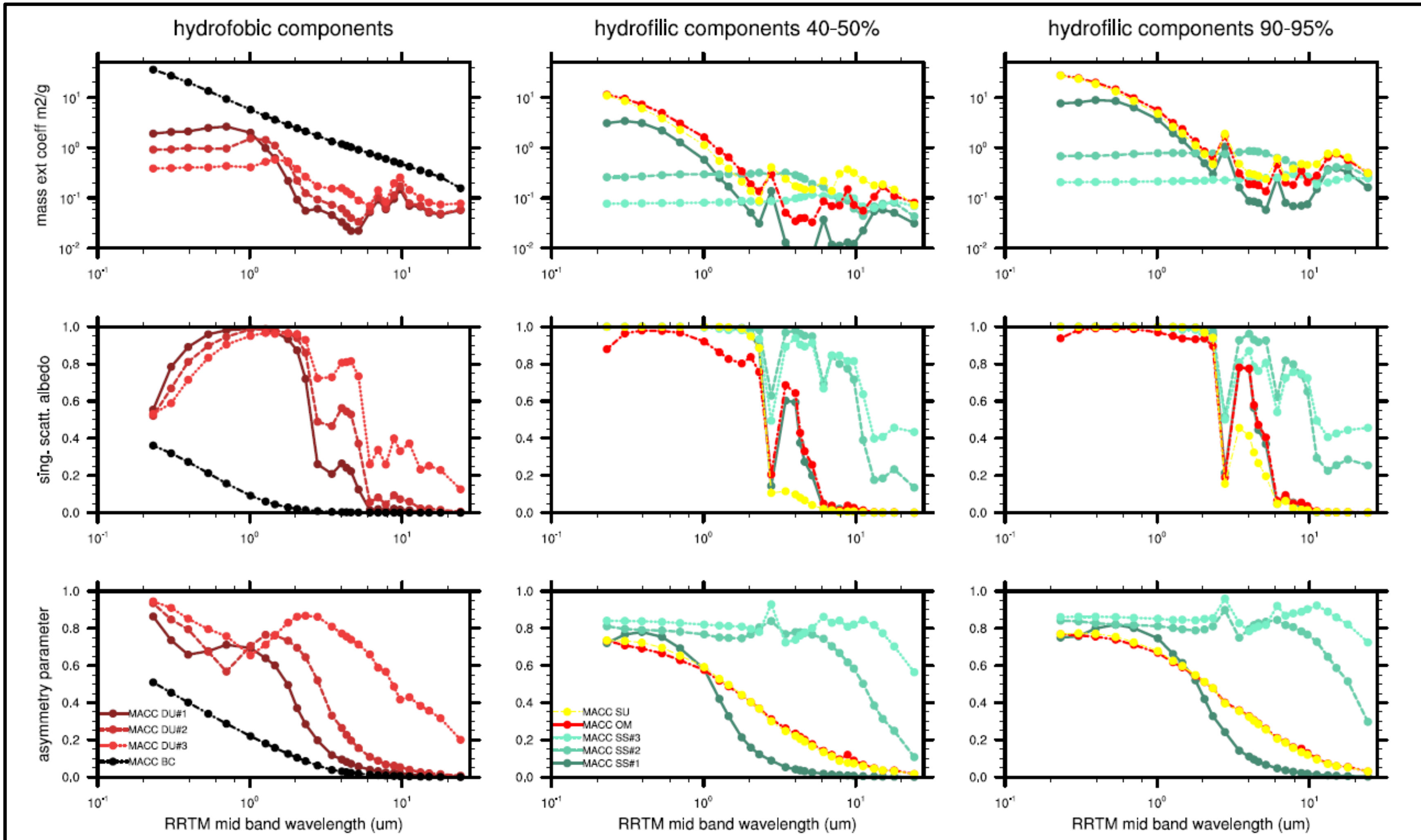
Vertical interpolation

From 137 levels (CAMS) to 65 levels (ICON)



Hydrophilic Optical properties

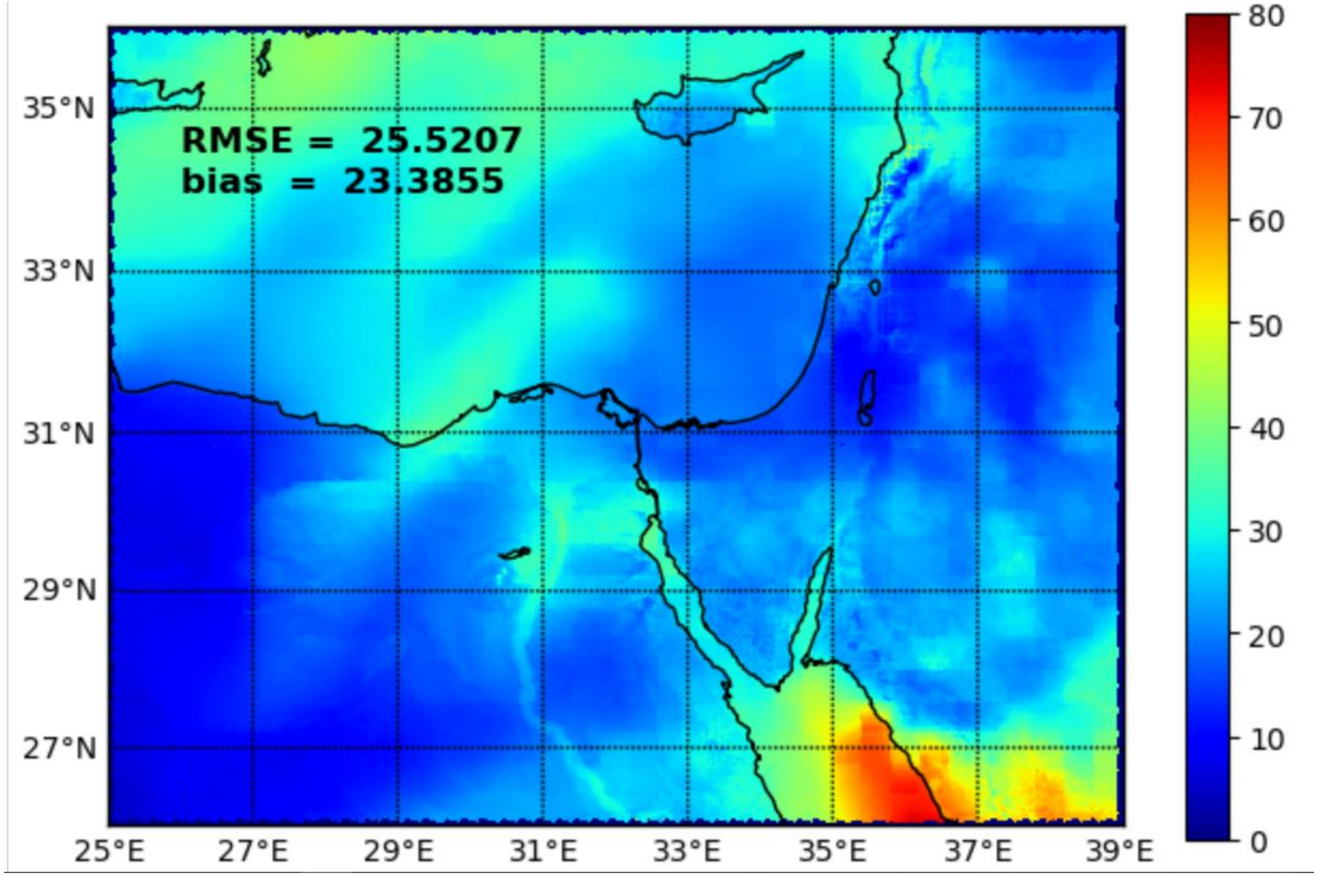
- 5 Hydrophilic aerosols (Sea-salt X 3, sulfate, black carbon) optical properties are RH dependent. Therefore, RH at each grid point is diagnosed.



Hydrophilic Optical properties

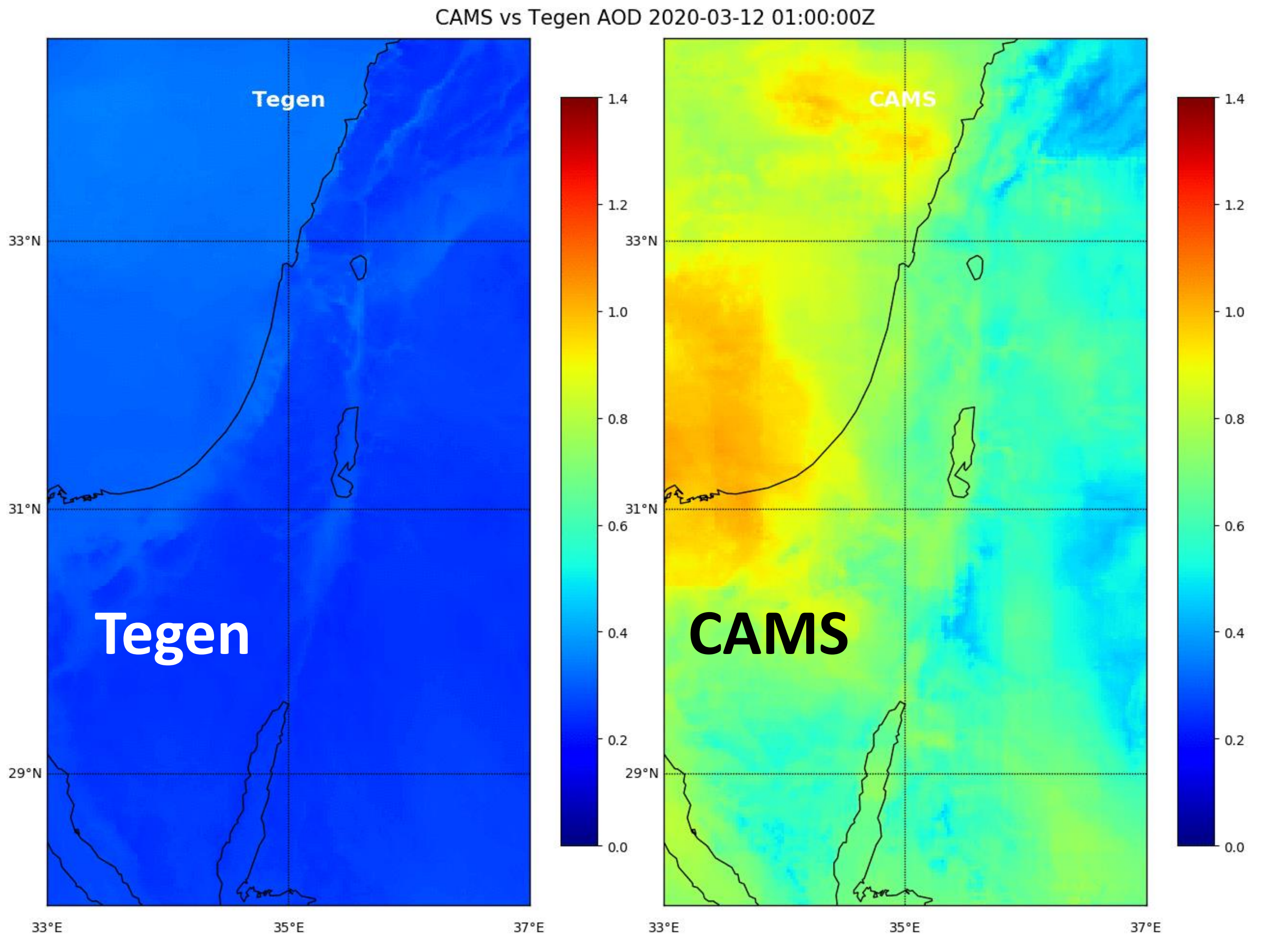
Shortwave surface downward radiation for clear skies

RH = 40% - RH = 100%

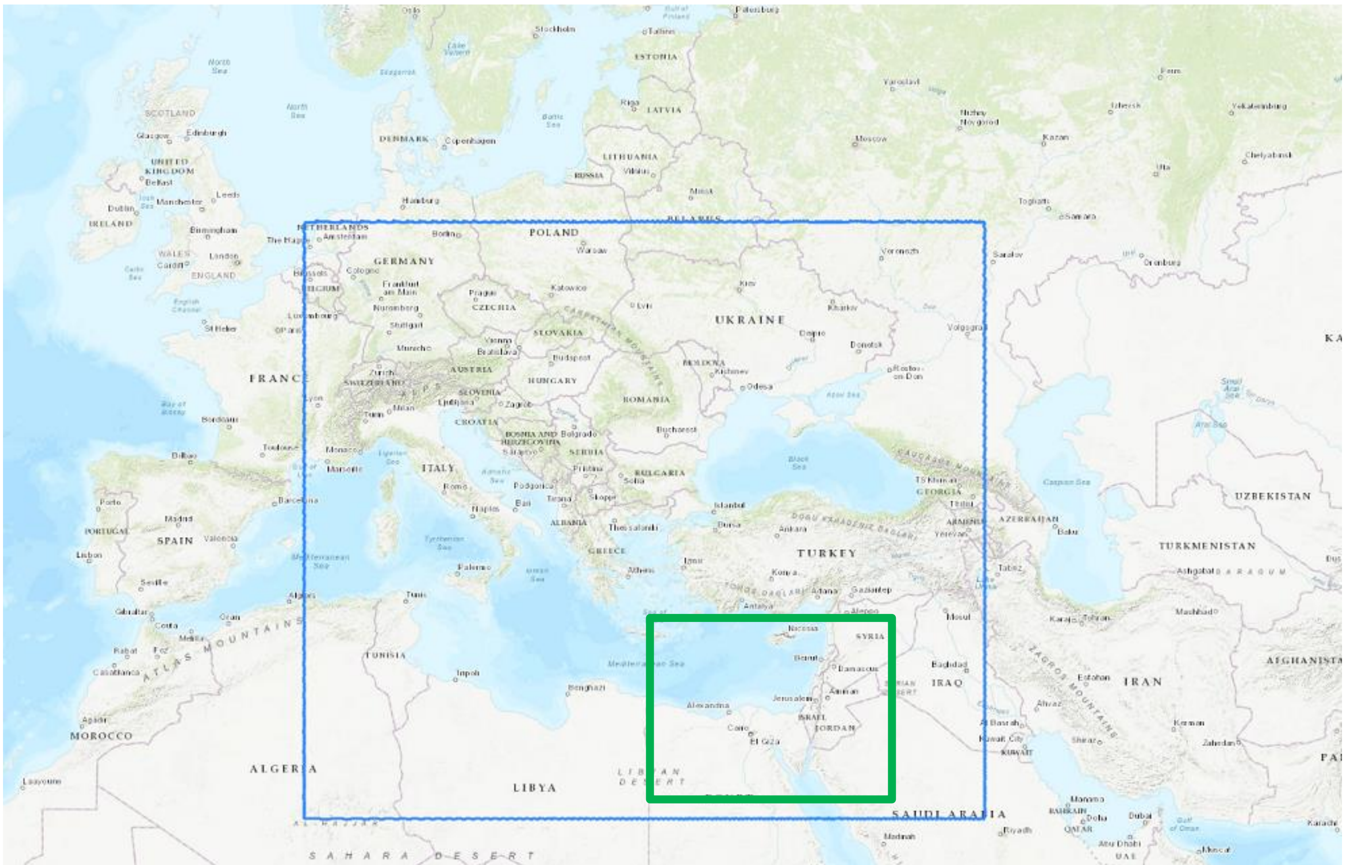


2D AOD results

- In all ICON_CAMS runs Tegen stratospheric aerosols background are included a recommended mode due to the positive bias of all models
- Tegen stratospheric aerosols background reduces the radiation ~3 W/m^2



Verification Domains

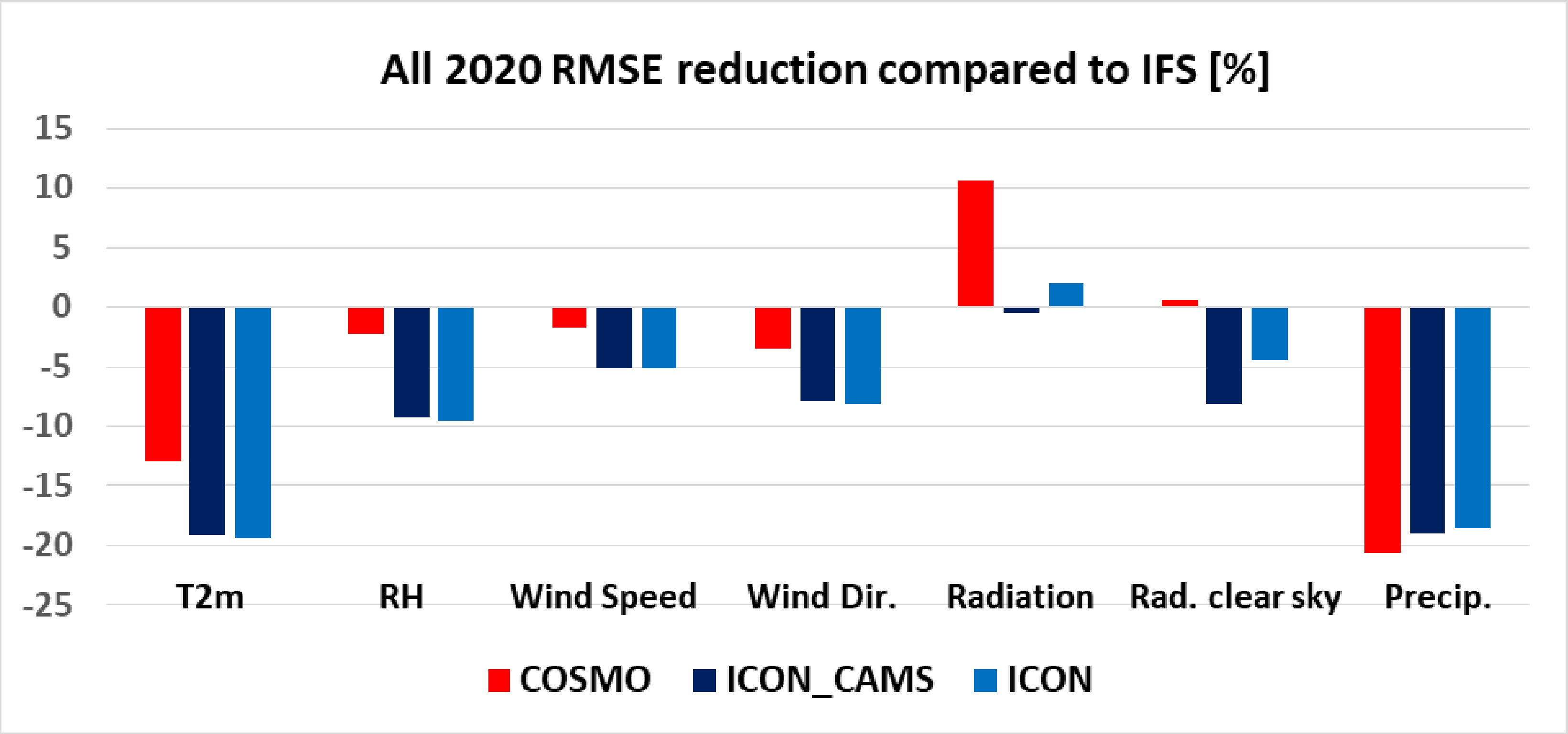


ICON-SEE verifications

Verifications in Israel domain only

COSMO, ICON-CAMS, ICON vs. IFS errors in [%]

(Lower is better)



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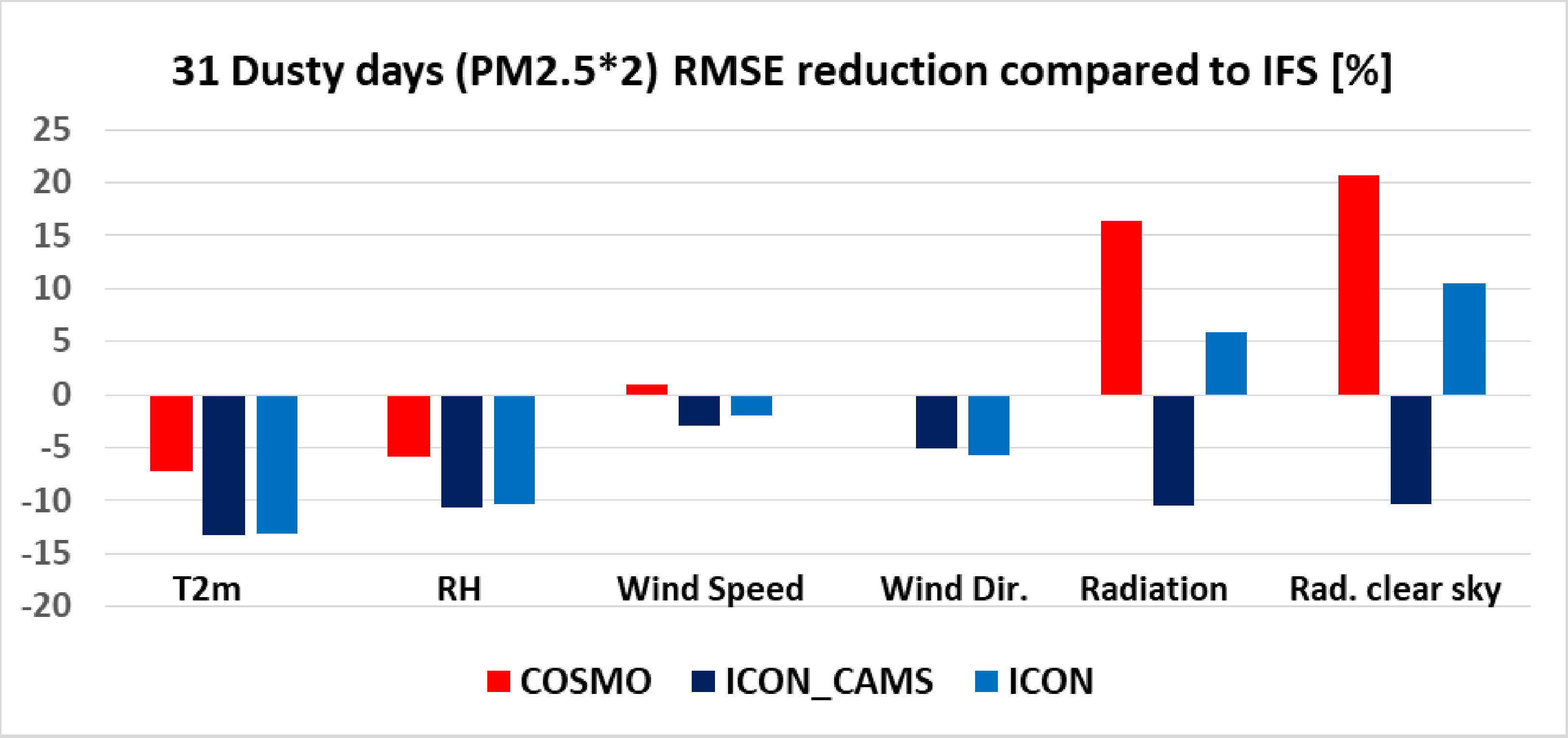
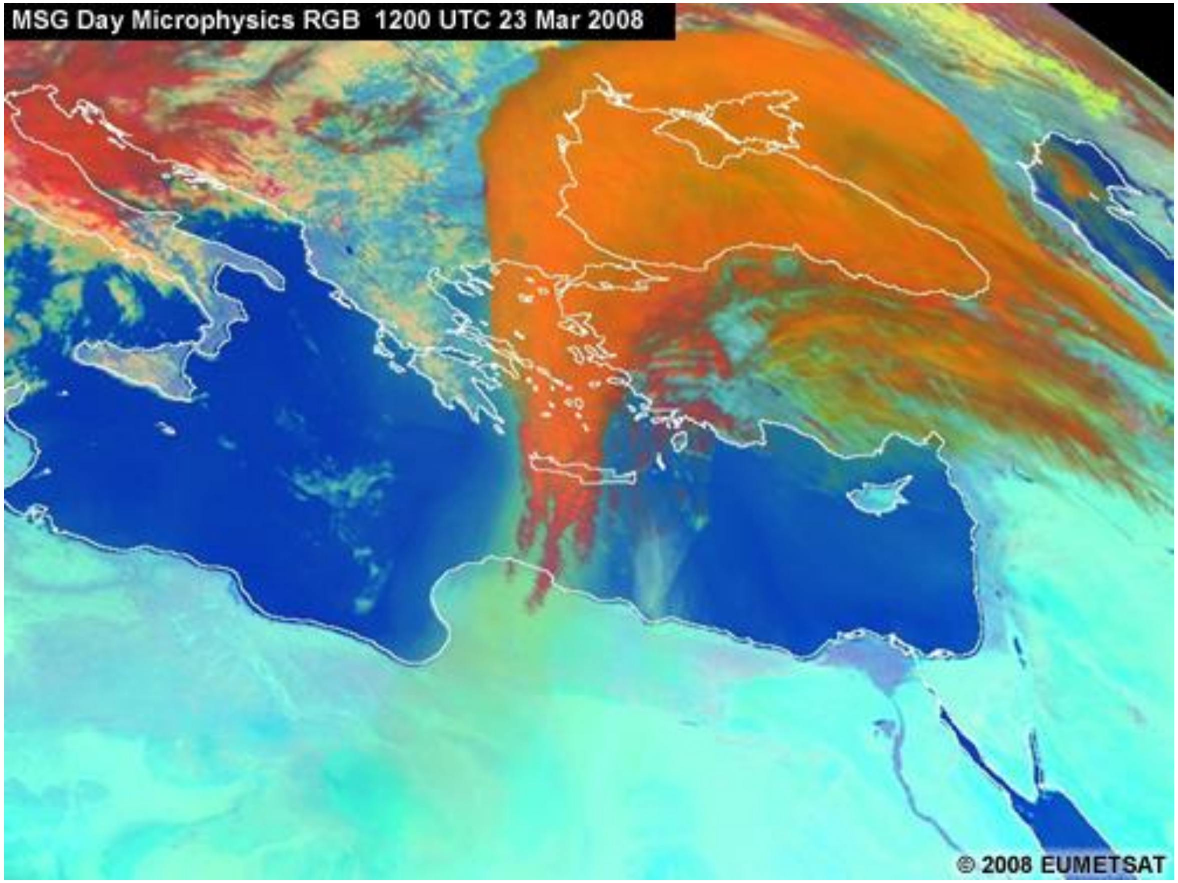


Ice nucleation

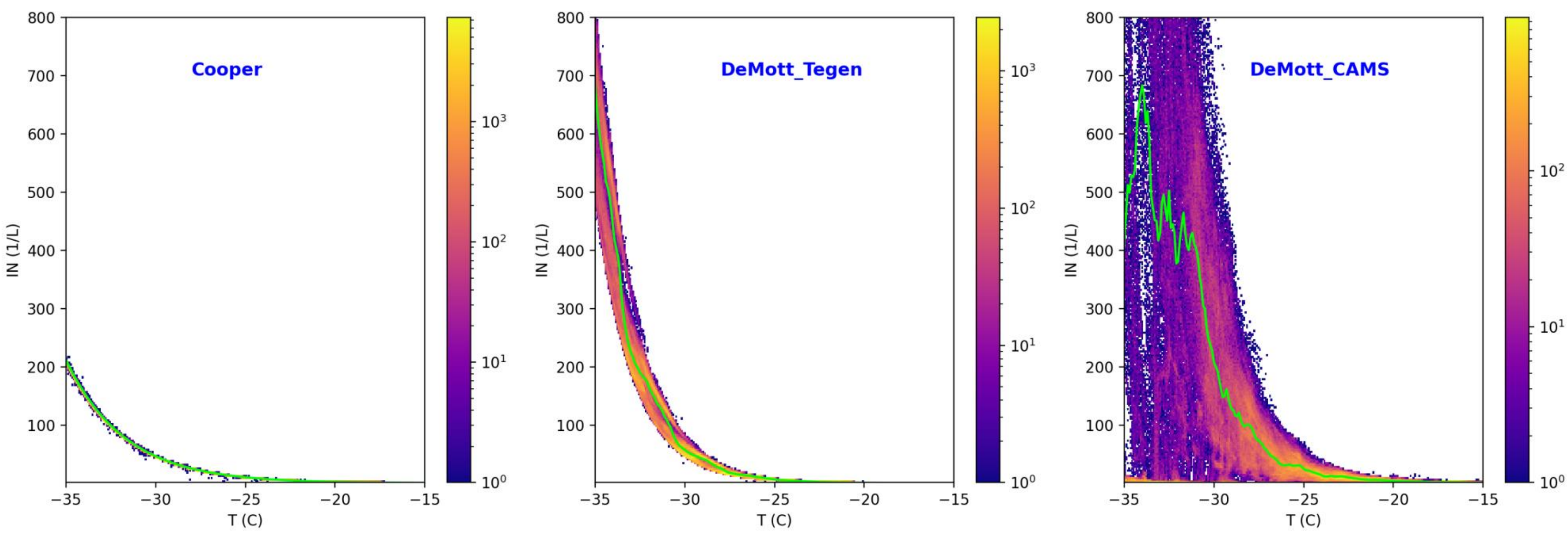


"…clouds that have ingested dust glaciate more quickly, forming a large number of very small ice particles. These have a higher reflectance than large ice particles in the "microphysical" channels (near-IR 1.6 and IR 3.9 micrometer) and appear as bright orange in the day microphysics RGB."

https://www.meted.ucar.edu/

ICON Ice nucleation with DeMott (2015) scheme

IN(T) for April 5, 2020

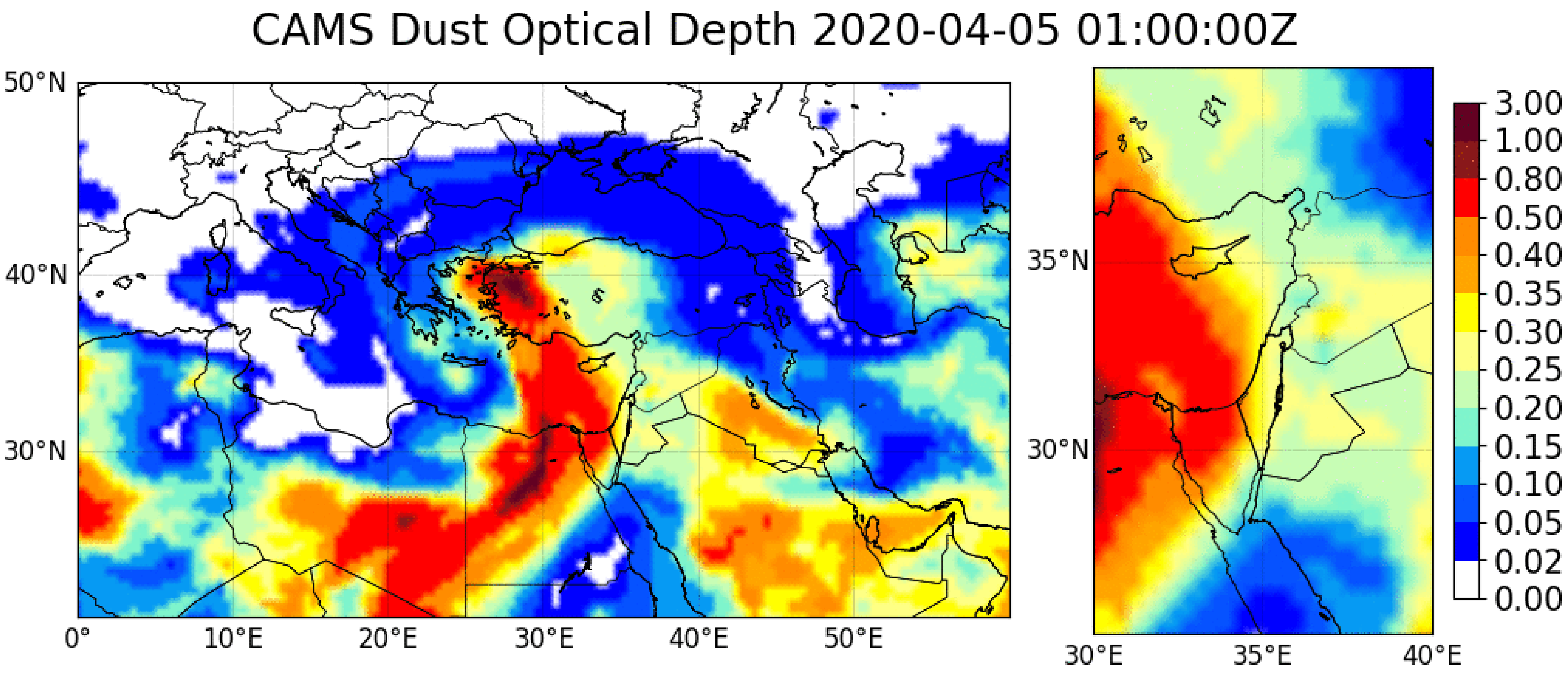


$$\mathbf{IN(T)} = 5 \cdot exp^{0.304(T_0 - T)}$$

$$\mathbf{IN(T}, ndust) = 1000 \cdot n_{dust}{}^{1.25} exp^{0.46(T_0 - T) - 11.6}$$

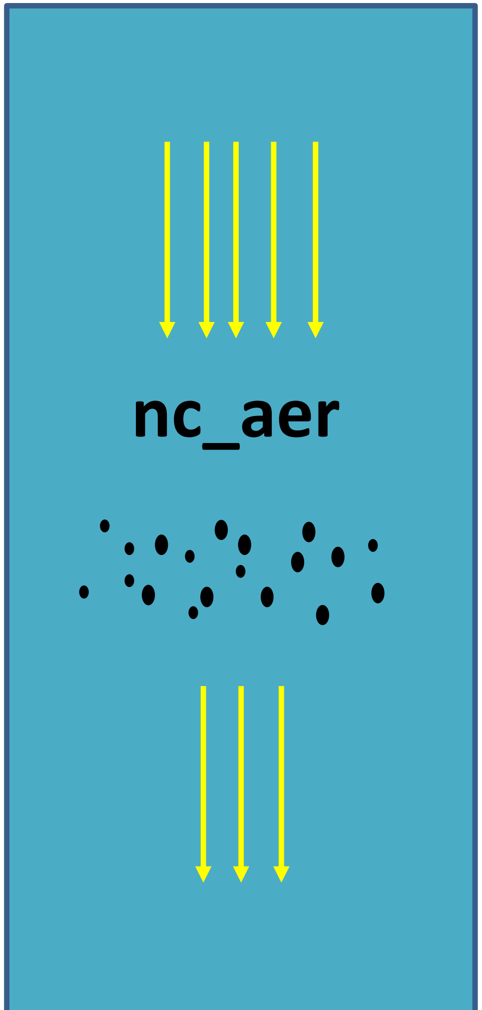
ICON Ice nucleation with DeMott (2015) scheme

ICON for April 5, 2020 – Polluted case IMS domain



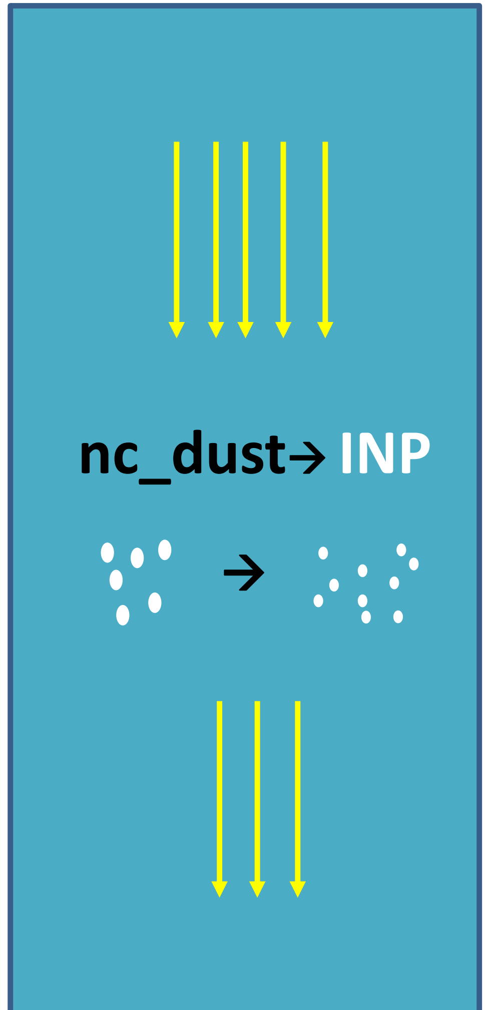
Aerosols effects on the atmosphere

Direct effect



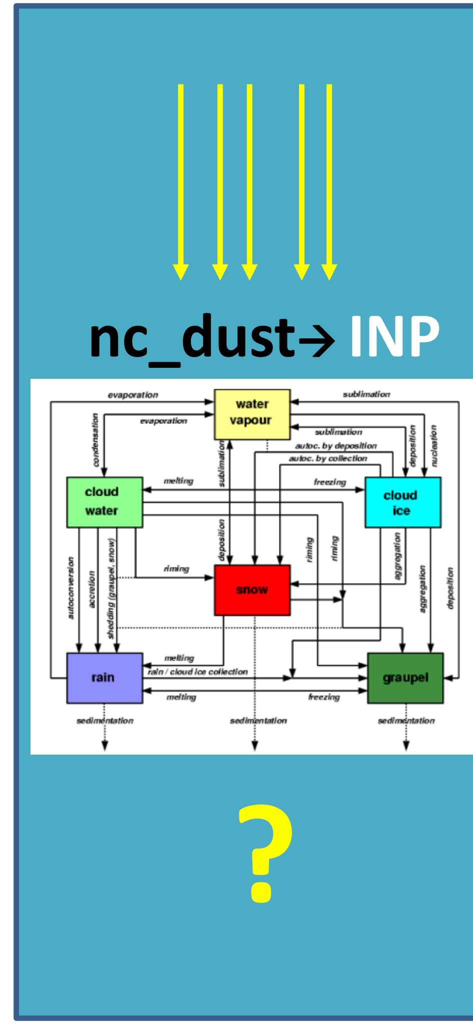
Cooling

Indirect effect



Cooling

Microphysics

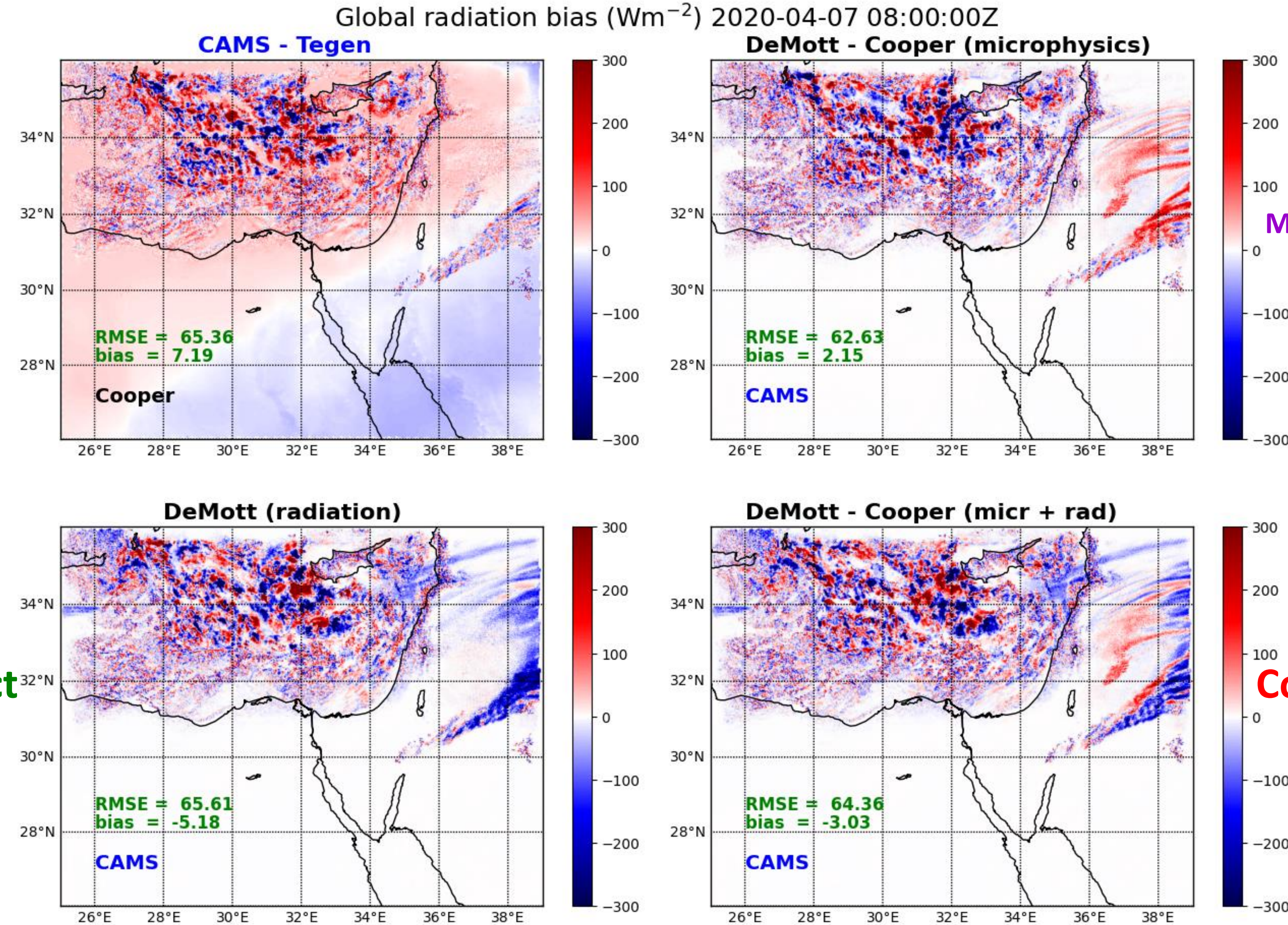


Cooling/Warming

ICON Ice nucleation with DeMott (2015) scheme

Direct effect

Indirect effect



Microphysics

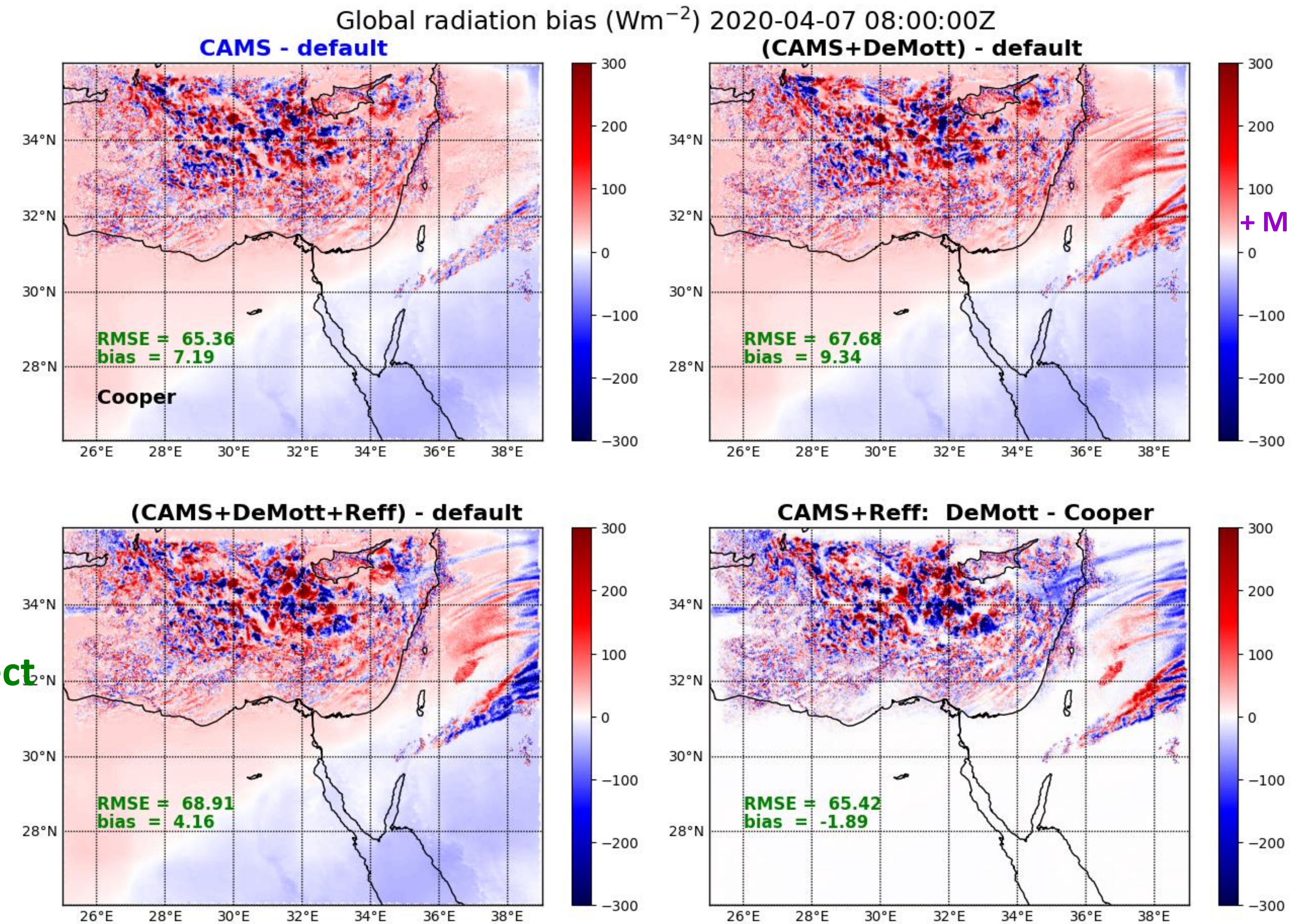
Combined effect

ICON Ice nucleation with DeMott (2015) scheme

Direct effect

+ Indirect effect

+ Microphysics

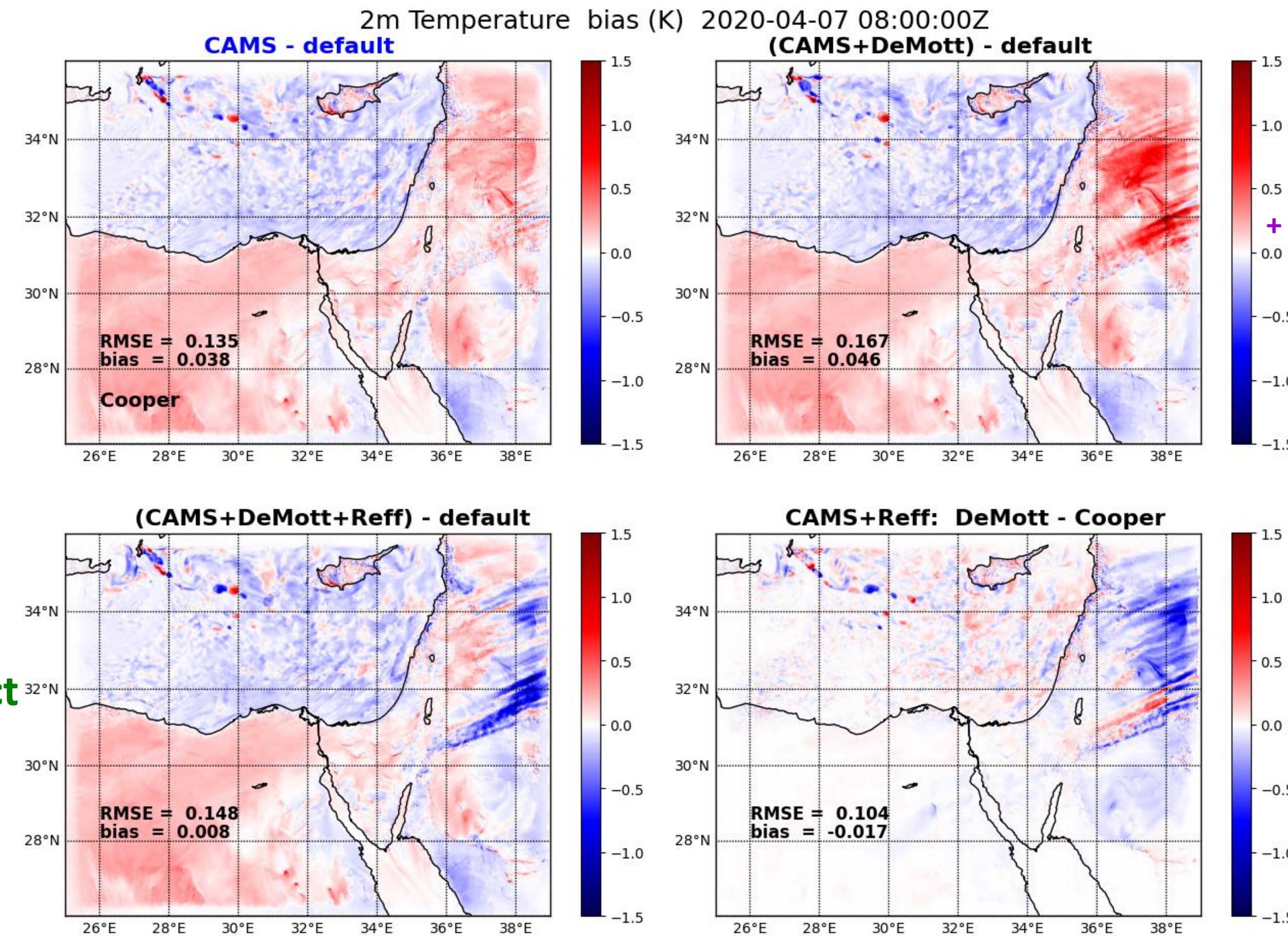


ICON Ice nucleation with DeMott (2015) scheme

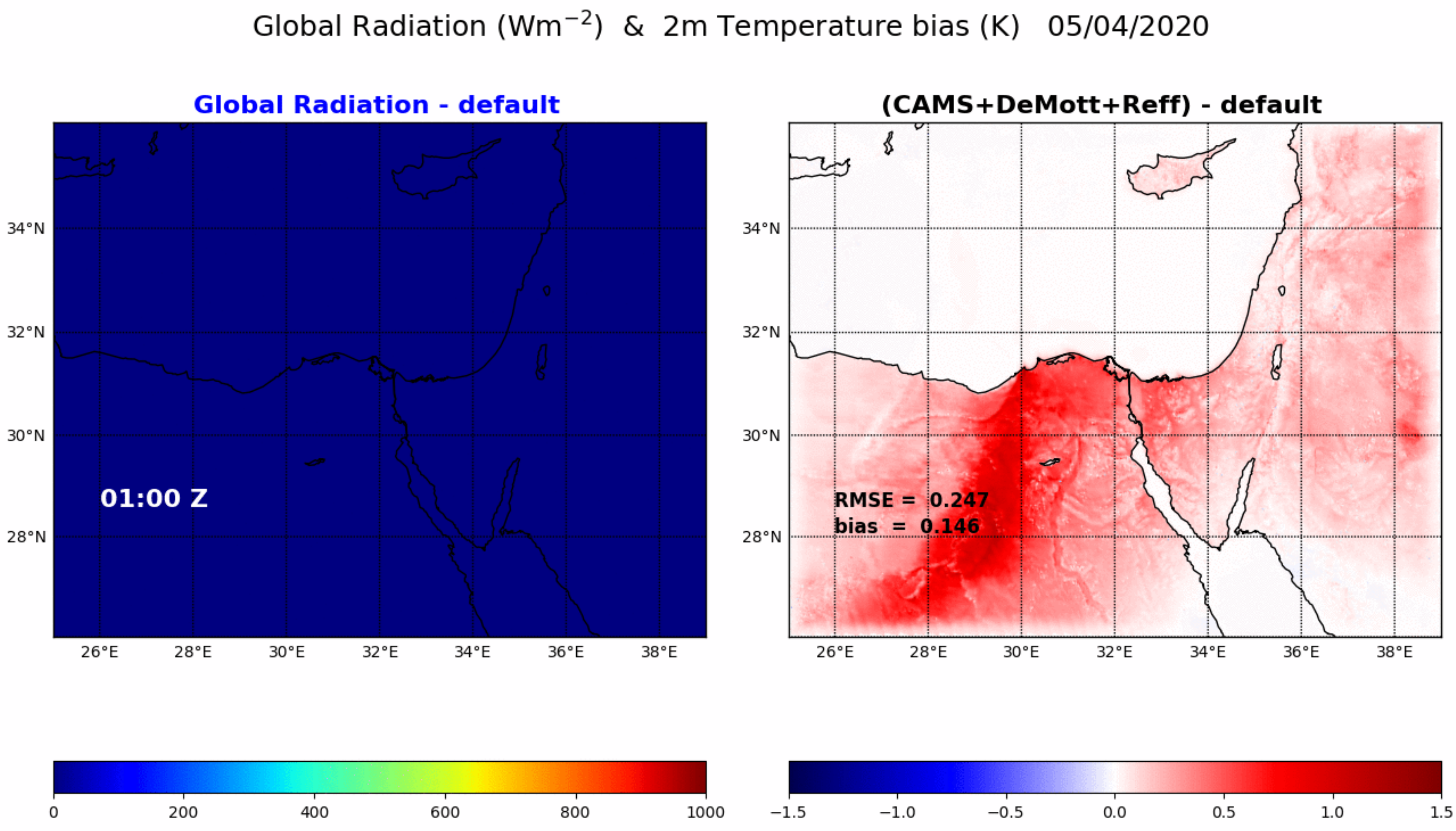
Direct effect

+ Indirect effect

+ Microphysics



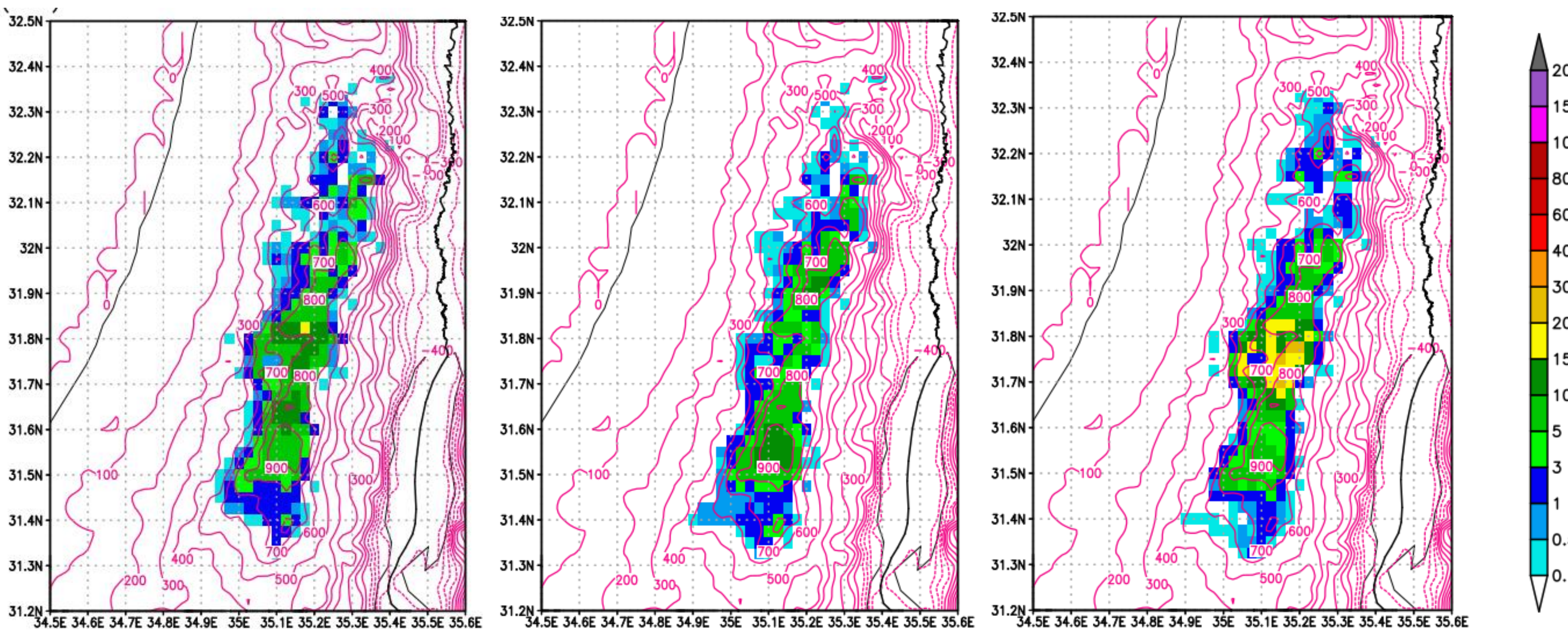
ICON Ice nucleation with DeMott (2015) scheme



ICON Ice nucleation with DeMott (2015) scheme

ICON for January 27, 2022 –SEE domain

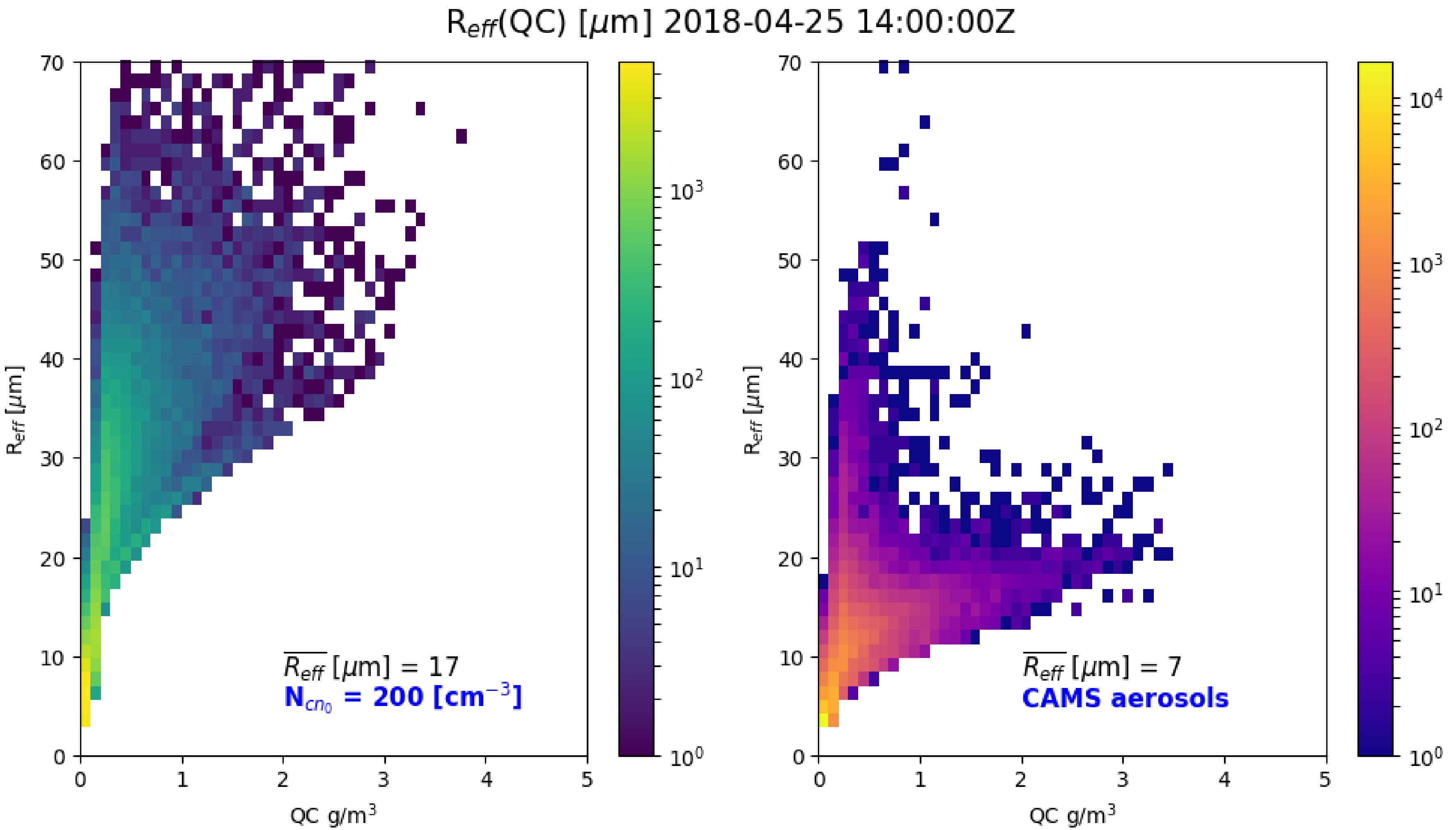
snow depth (cm) at center mountains +28h: Thu 27 JAN 04Z



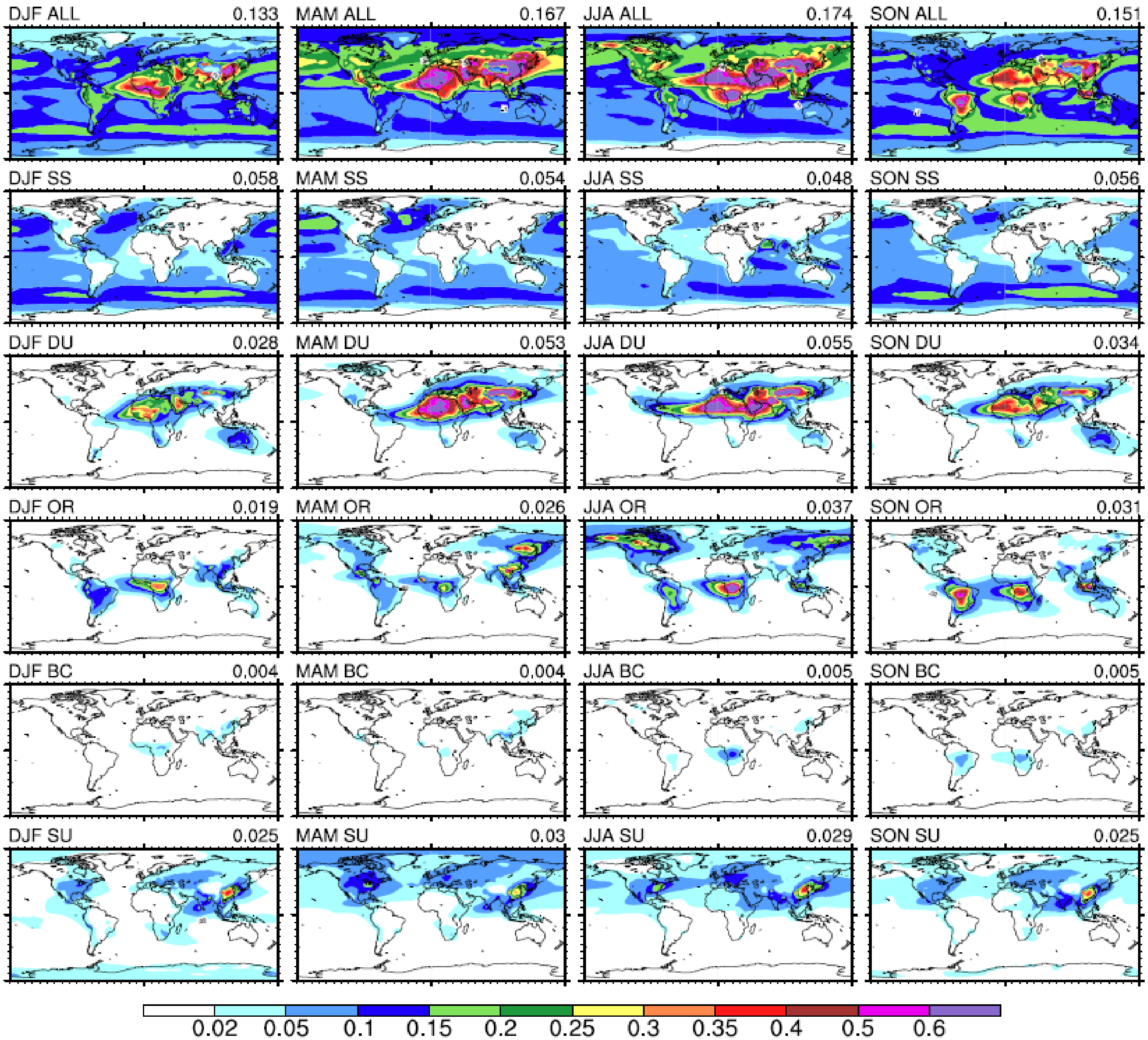
default CAMS CAMS_DeMott

Next step: New cloud droplets nucleation

COSMO: R_{eff} based on CAMS & Segal-Khain



CAMS climatology in ICON-ecRAD



2D Aerosol Optical Depth (D. Rieger)

Prognostic equation for 2D AOD $\psi_j(x,y)$, using vertically averaged horizontal wind $\overline{\boldsymbol{v}_{H,j}}$:

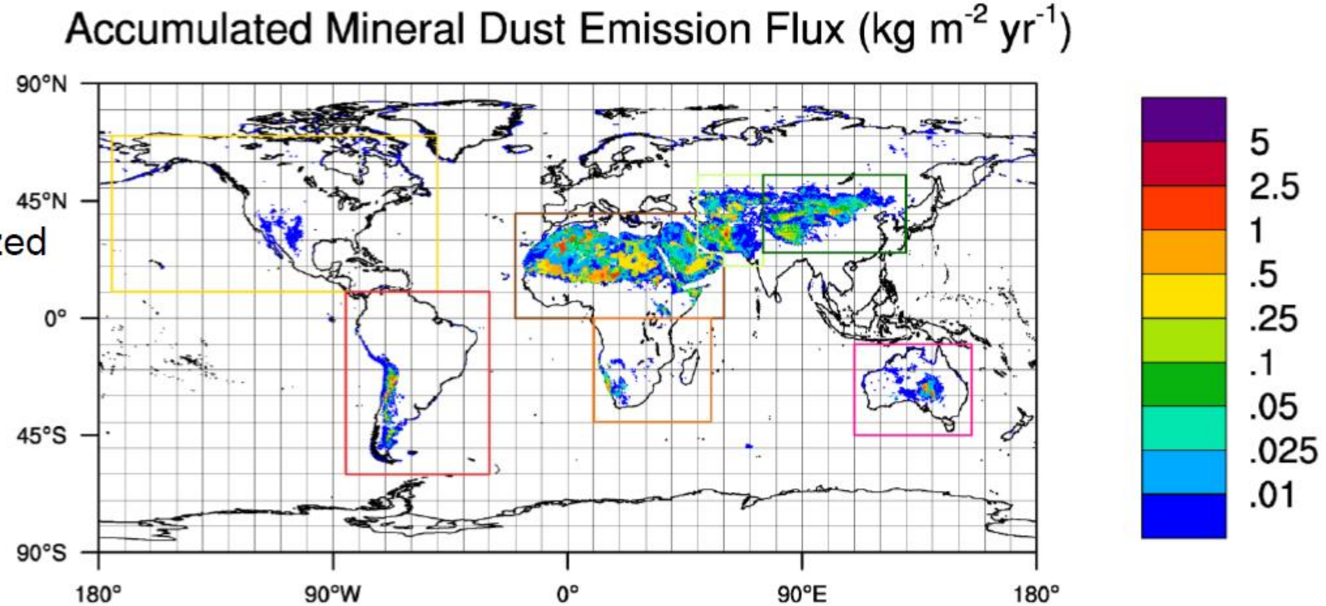
$$\frac{\partial \psi_j(x,y)}{\partial t} = \underbrace{\overline{\boldsymbol{v}_{H,j}} \nabla \psi_j(x,y)}_{\text{advection}} + \underbrace{S_{e,j} + S_{w,j}}_{\text{sources \& sinks (emission, washout)}} + \underbrace{f_{diff} \cdot \Delta \psi_j(x,y)}_{\text{artificial diffusion}} + \underbrace{\frac{[f_{clim,j} \cdot \psi_{clim,j}(x,y) - \psi_j(x,y)]}{\tau_{clim,j}}}_{\text{relaxation to climatology}}$$

Simulation:

- 10-day slices
- Whole year 2019
- R2B6 (40km)
- Init: Interpolated initialized analysis data from deterministic ICON

Result:

- $\boldsymbol{3533\ {}^{Tg}/_{yr}}$



Results of the Kok et al. 2014 scheme in ICON

A Simple Scheme for Sea Salt Optical Depth

Prognostic equation for 2D AOD $\psi_j(x,y)$, using vertically averaged horizontal wind $\overline{\boldsymbol{v}_{H,j}}$:

$$\frac{\partial \psi_j(x,y)}{\partial t} = \underbrace{\overline{\boldsymbol{v}_{H,j}} \nabla \psi_j(x,y)}_{\text{advection}} + \underbrace{S_{e,j} + S_{w,j}}_{\substack{\text{sources \& sinks} \\ \text{(emission, washout)}}} + \underbrace{f_{diff} \cdot \Delta \psi_j(x,y)}_{\text{artificial diffusion}} + \underbrace{\frac{[f_{clim,j} \cdot \psi_{clim,j}(x,y) - \psi_j(x,y)]}{\tau_{clim,j}}}_{\text{relaxation to climatology}}$$

- Improve sea salt AOD source function $S_{e,seas}$
- Use computationally cheap emission parameterization (*Grythe et al. , 2014)*
- Perform offline Mie calculations to derive optical properties
- Calculate AOD flux from emission flux

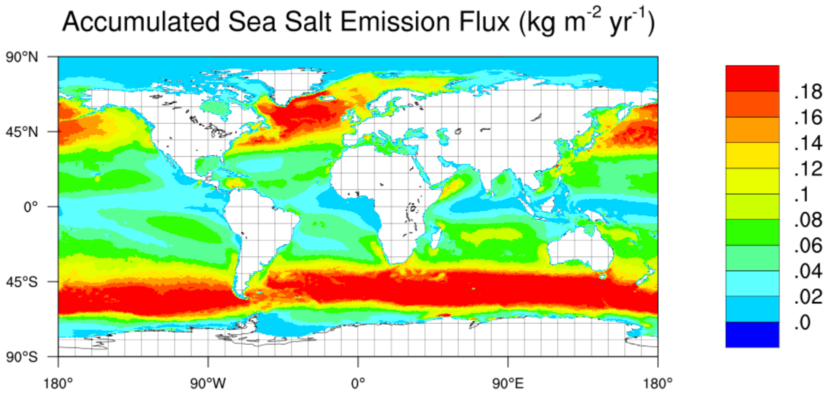
A Simple Scheme for Sea Salt Optical Depth

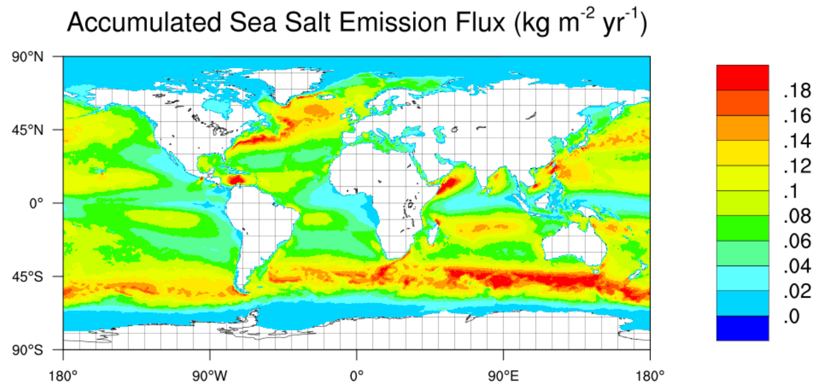
Sea salt emission scheme implemented successfully

- ➔ Grythe et al. (2014) without temperature correction (top)
- ➔ Grythe et al. (2014) with temperature correction by Jaegle et al. (2011) to account for the relatively high SSA concentrations found in the tropics (bottom)

2D-seas calculations are available in icon-nwp:master

- ➔ R2B6 Simulation for 2019
- ➔ Climatological values smaller than from CAMS (see next slide)
- ➔ Comparisons with AERONET data at remote stations
  show lower RMSE than CAMS





2D Aerosol optical depth

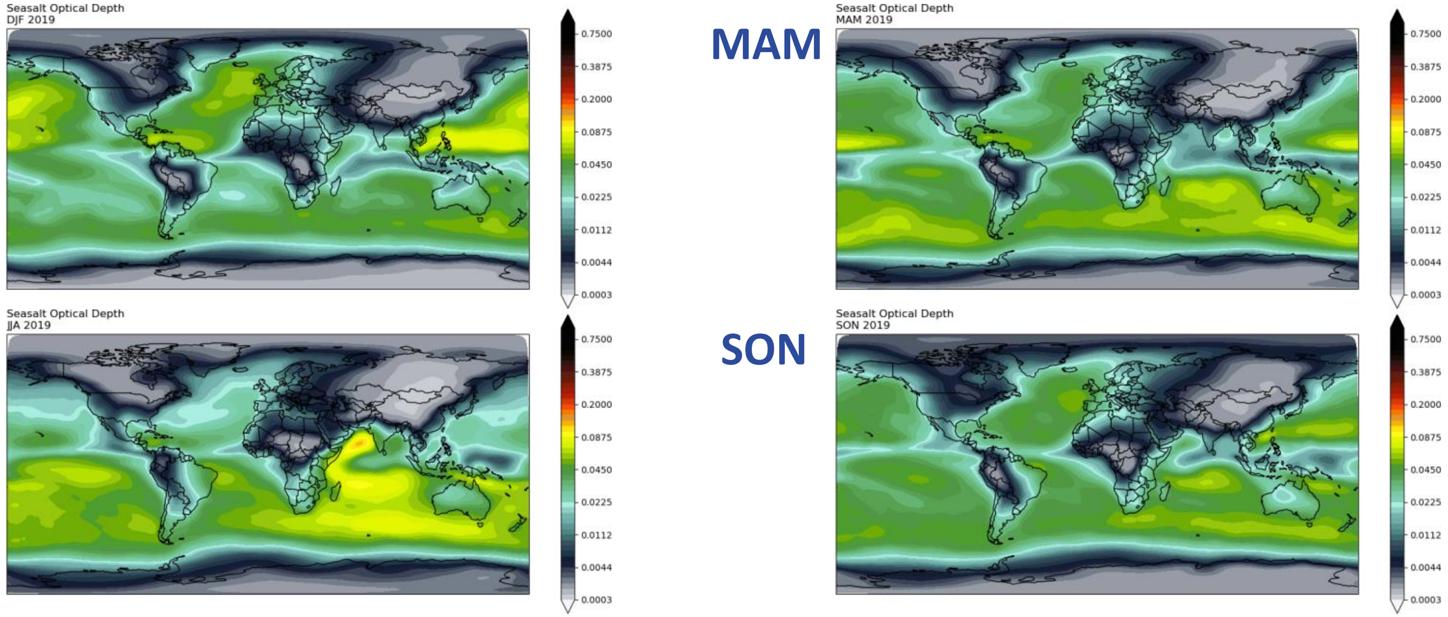
2D-seasalt AOD Results

DJF

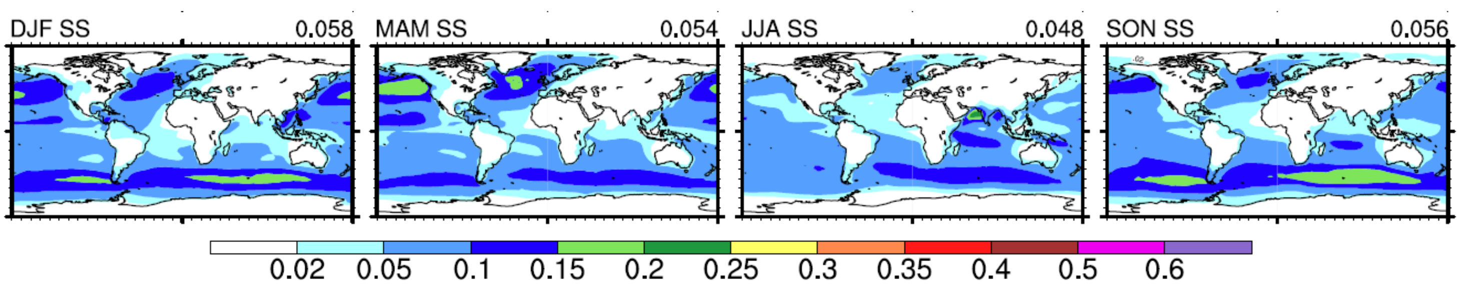
MAM

JJA

SON



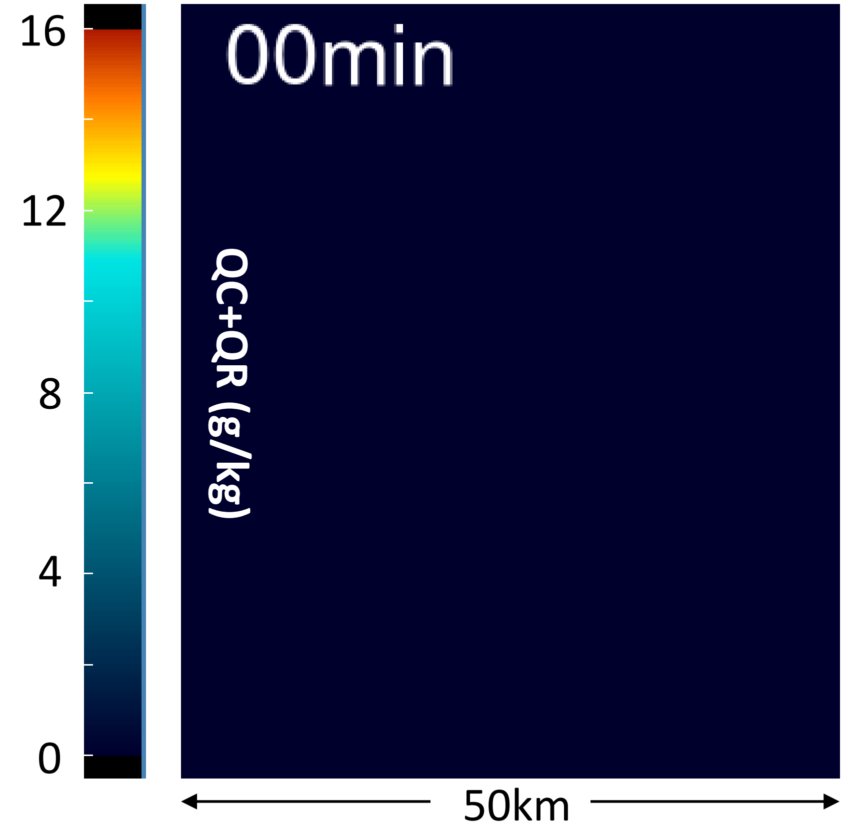
CAMS



From: Bozzo et al. (2017): Implementation of a CAMS-based aerosol climatology in the IFS, ECMWF Techn. Mem. 801

Spectral Bin Microphysics in ICON

- Warm-Phase Spectral-Bin Microphysics (SBM) scheme was implemented in ICON (not master).
- 66 bins: droplets + CCN tracers
- Runs ~7 times slower than 1M.
- SBM and 2M schemes compared: SBM shows reasonable behavior, strong sensitivity to CCN.
- Example: Cumulonimbus development (Weisman-Klemp 1982)

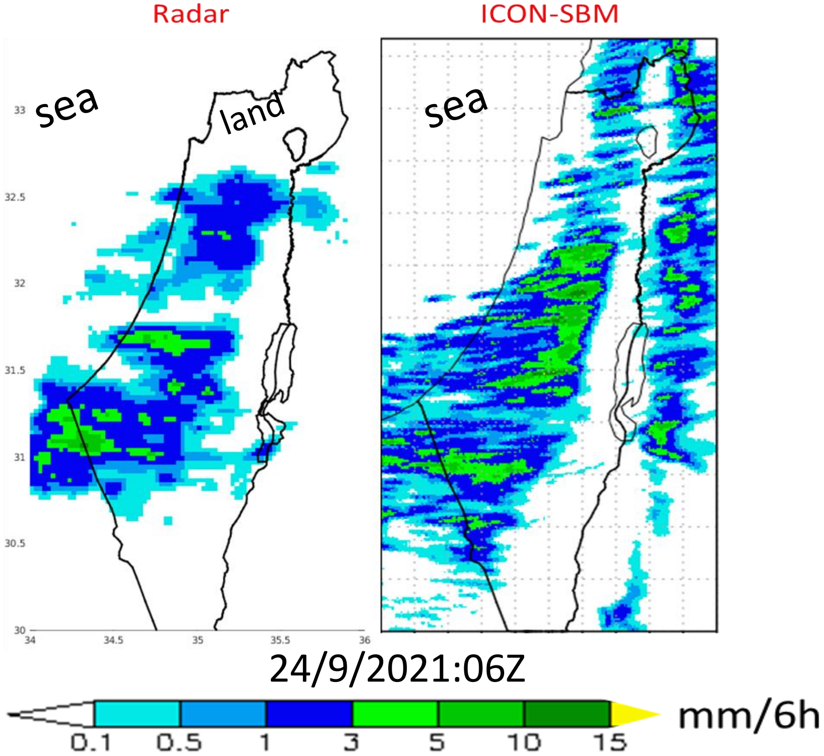


- **Published** in: Khain, P., J. Shpund, Y. Levi and A.P. Khain (2022): Warm-phase spectral-bin microphysics in ICON: reasons of sensitivity to aerosols. Atmos. Res., 279, 106388.

Pavel Khain, Koby Shpund, Yoav Levi, Alexander Khain
Thanks to: Axel Seifert, Daniel Reinert, Daniel Rieger

Spectral Bin Microphysics in ICON

- Preliminary: **real** “warm” case shows strong sensitivity to topography
- Ongoing: Mixed phase SBM
- A tool for model verifications, physical parametrizations, test cases, scientific research etc.



Thanks for your attention!