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

Harel Muskatel (IMS)

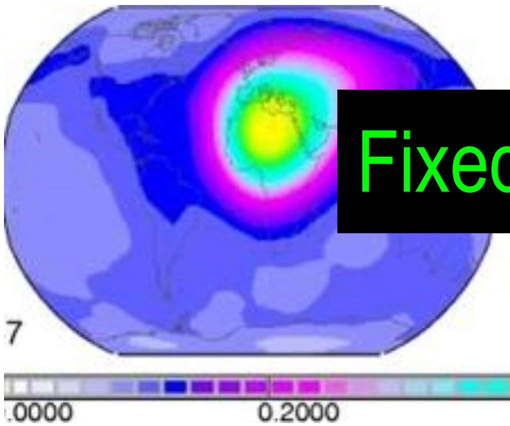
22nd COSMO General Meeting, September 09, 2020

BUT FIRST…

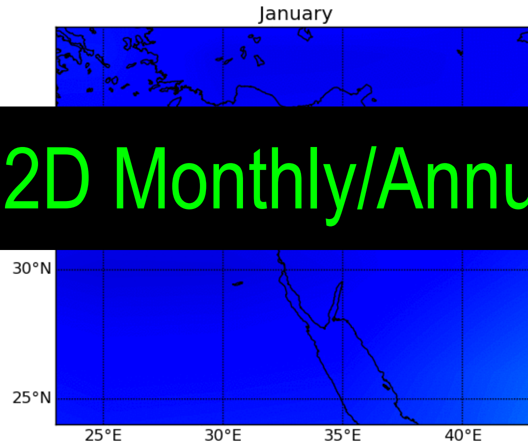
some $T^2(RC)^2$ issues

Aerosols Input for COSMO Radiation

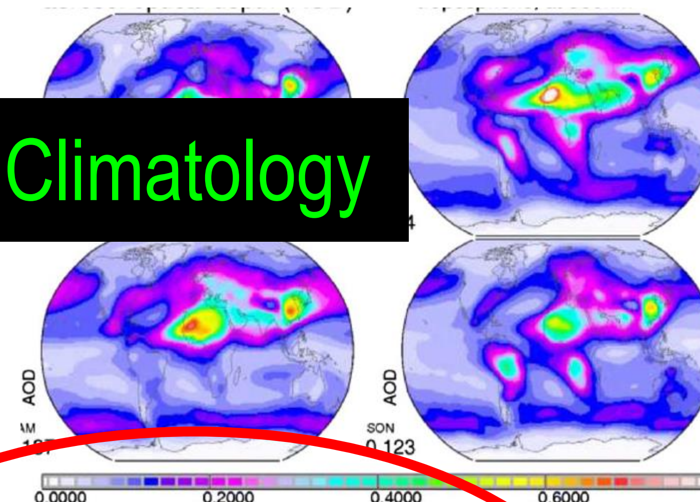
Tanre (1983)
itype_aerosol = 1



Tegen (1997)
itype_aerosol = 2

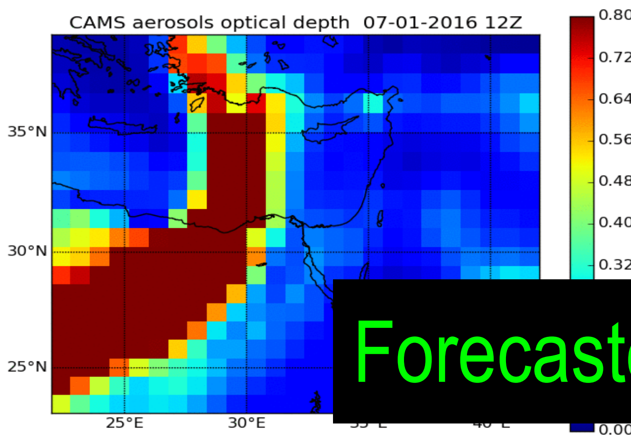


MACv2 (2013)
itype_aerosol = 3

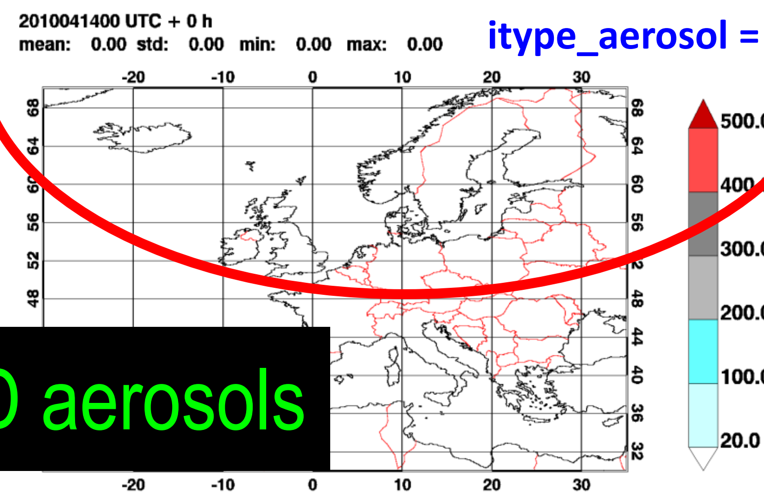


Fixed 2D Monthly/Annual Climatology

CAMS-ECMWF
itype_aerosol = 4



ICON-ART
itype_aerosol = 5



Forecasted 3D aerosols

New:

COSMO Cloud Optics Web-App

http://www.cosmo-model.org/content/tasks/operational/ims/cloudOptics/default.htm

Cloud Optical Properties

Last updated: August 2020

Introduction

The programs in these pages use advanced spectral averaging methods to calculate cloud optical properties.

The optical properties and the effective size and aspect ratio are calculated for each PSD in an ensemble of 7500 particle size distributions. The calculations, for each single wavelength data is based on Fu (DOI) and Hu & Stamnes (DOI). The collection of these 7500 points are fitted to a Padé approximation using a non-linear fitting algorithm selected to adequately reproduce asymptotic behavior

This way, we can extend the effective size range to include large hydro meteors categories such as snow, graupel and rain.

For a full discussion on the scientific aspects and numerical implementation see the Liquid and Ice Clouds Optical Properties Parametrizations in Numerical Weather Prediction Models

Related COSMO priority projects are $T^2(RC)^2$ and CAIIR.

Running

The authors of the programs doing the fitting, are Harel Muskatel from IMS (ice calculations) and Ulrich Blahak from DWD (liquid water calculations) You may contact them for further details.

On how to run the programs yourself, using the web interface, see this user manual. To run your own simulations, you will need a username and password. These are free and you can get them by contacting Harel Muskatel. When you have your credentials, you can start.

References

1. Muskatel, H. B., Blahak, U., Khain, P., Levi, Y. and Fu, Q., Liquid and Ice Clouds Optical Properties Parametrizations in Numerical Weather Prediction Models.
   Submitted to Royal Meteorological Society - Meteorological Applications, Aug 2020.
2. Fu, Q., 1996: An Accurate Parameterization of the Solar Radiative Properties of Cirrus Clouds for Climate Models.
   J. Climate, 9, 2058–2082.
3. Fu, Q., Yang, P., & Sun, W., 1998: An Accurate Parameterization of the Infrared Radiative Properties of Cirrus Clouds for Climate Models.
   Journal of Climate, 11(9), 2223-2237.
4. Fu, Q., 2007: A New Parameterization of an Asymmetry Factor of Cirrus Clouds for Climate Models.
   J. Atmos. Sci., 64, 4140–4150.
5. Hu, Y.X. and K. Stamnes, 1993: An Accurate Parameterization of the Radiative Properties of Water Clouds Suitable for Use in Climate Models.

Cloud Optical Properties: wavelength selection

Last updated: Mar 2020

Ranges selection

Liquid, Visible
allowed: 0.29µm ↦ 150µm

Liquid, Infrared
allowed: 0.29µm ↦ 150µm

Ice, Visible
allowed: 0.2µm ↦ 3.969µm

Ice, Infrared
allowed: 3.969µm ↦ 100µm

add spectrum range with wavelength from [ ] µm, to [ ] µm, for ice ○ or liquid ◉ in the Vis ◉ or IR ○ range

Done selecting

- The 4 areas (Liquid/Ice and Visible/Infrared) contain the wavelength ranges to calculate the optical properties for.
- To **add** a new wavelength range, fill the from µm and to µm boxes and choose between "ice" or "liquid" water.
- When the two boxes get filled, an add button will appear. Press it to add the range into the desired ones. Vis/IR spectrum is auto-selected.
- To remove an already present range, click its x button.

CONSORTIUM FOR SMALL SCALE MODELING

COSMO

Sep. 8
the GM2020

Operational | Home

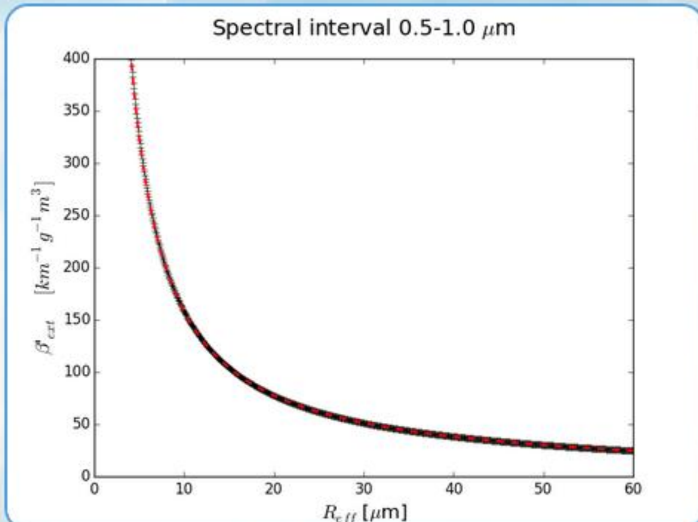
Cloud Optical Properties: results

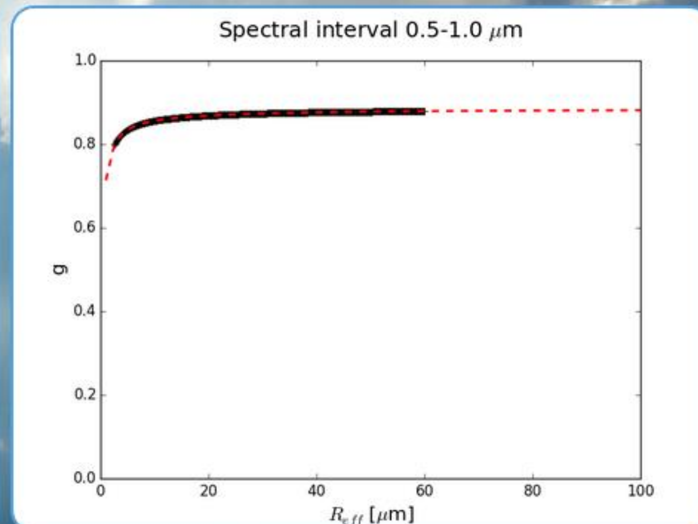
Last updated: Feb 2020

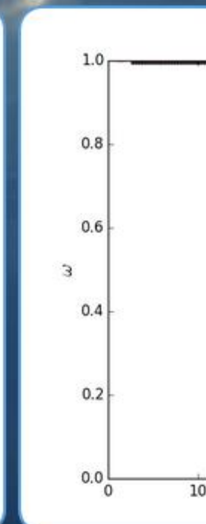
▶ CLICK ◀ an image to see its text; ▶ CTRL+CLICK ◀ it to redraw with custom axis ranges. Alternatively, get the collective text results.

Liquid

0.5 ↔ 1 µm







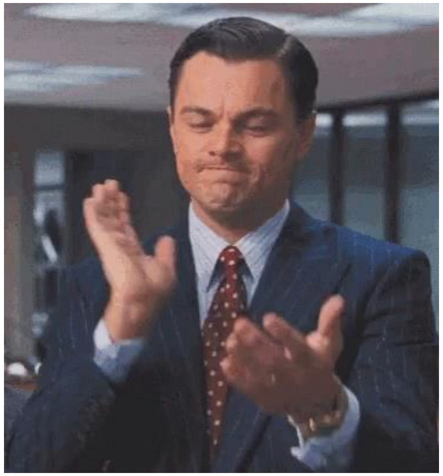
liq 0.5 ↔ 1µm: beta
beta=(a0+a1*R+a2*R^2+a3*R^3) / (a4+a5*R+a6*R^2+a7*R^3+a8*R^4)
Band : a0 a1 a2 a3 a4 a5 a6 a7 a8 AbsMaxErr MaxErr[%] AveErr[%]
(0.500-1.000) -8.498057e+02 -3.690528e+03 2.763773e+03 -4.006478e+01 -1.119932e+00 1.227676e+00 -3.142682e+00 1.822229e+00 -2.614157e-02 2.182262e

Ice

New:

COSMO Cloud Optics Web-App

http://www.cosmo-model.org/content/tasks/operational/ims/cloudOptics/default.htm



Many thanks to Theodore Andreadis

Clouds and Aerosols Improvements in ICON Radiation scheme - CAIIR

- **Project duration: March 2020 - February 2022**
- **Total FTEs : 6.6**

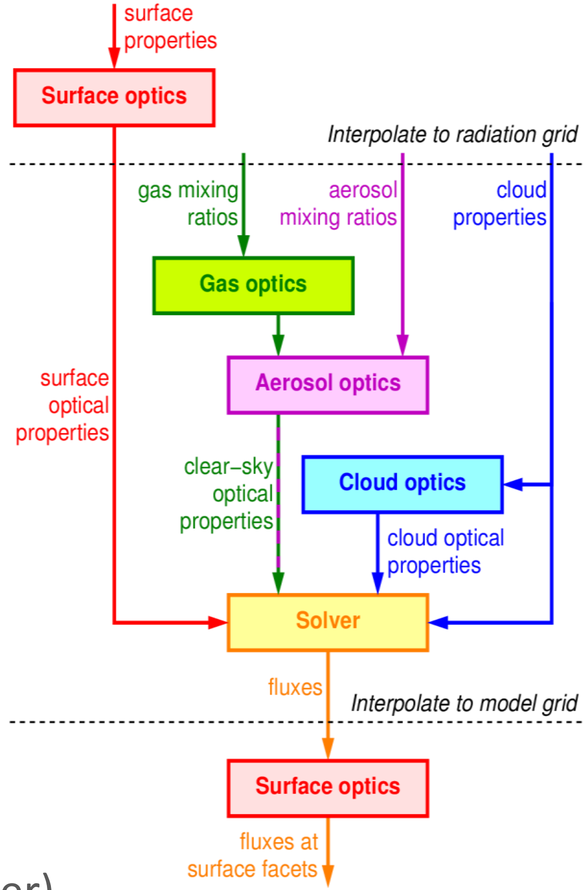
Participants:

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

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

New modular radiation scheme: ECRAD (Hogan & Bozzo, 2018)

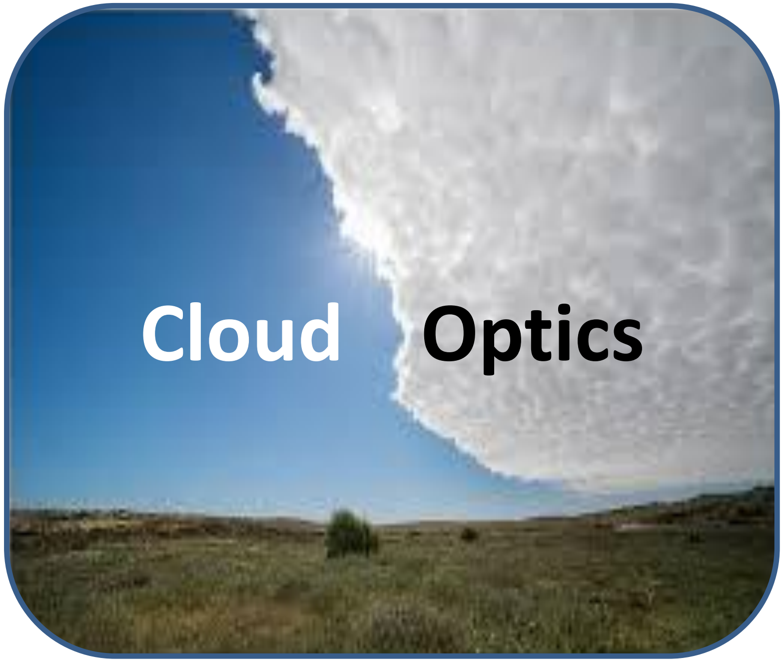
- **Gas optics:** RRTM-G (Iacono et al. 2008)
  - *Plan to develop new scheme with fewer spectral intervals*
- **Aerosol optics:** variable species number and properties (set at run-time)
- **Cloud optics:**
  - **liquid:** SOCRATES (MetOffice)
  - **ice:** Fu 1996, 1998 (default) , Yi et al. 2013 or Baran et al. 2014
- **3D effects** (SPARTACUS): globally warm by ca. 2 Wm^{-2} or 1K
- *Surface (under development) Rigorous and consistent treatment of urban and forest canopies*



- **Solvers:**
  - **McICA** (Pincus et al. 2003), **Tripleclouds** (Shonk & Hogan, 2008) or **SPARTACUS** (Schäfer et al. 2016, Hogan et al. 2016)
  - SPARTACUS makes ecRad the only global radiation scheme that can do 3D radiative effects
  - Longwave scattering optional
  - Can configure cloud overlap
  - Cloud inhomogeneity: stochastic subcolumns (McICA) or two cloudy regions (Tripleclouds / SPARTACUS), can configure width and shape of PDF

- **Implemented in ICON** (D. Rieger)
- planned: operational early 2021
- **Improves results in troposphere**
- **Ongoing tuning**

Slide content: Sophia Schäfer


Cloud
Optics

Liquid hydrometeors

COSMO:

- Original RG92 based on Stephens (1989) , Slingo & Schrecker (1982)
- COSMO - New optical properties after Hu and Stamnes (1993)

$$f(R_e) = a_1 {R_e}^{a_2} + a_3$$

- *Extended size range - including rain*

ecRAD:

1. SW- Slingo (1989) similar to RG92 (Valid only for: $R_e = [4.2\ \mu m, 16.6\ \mu m]$!)

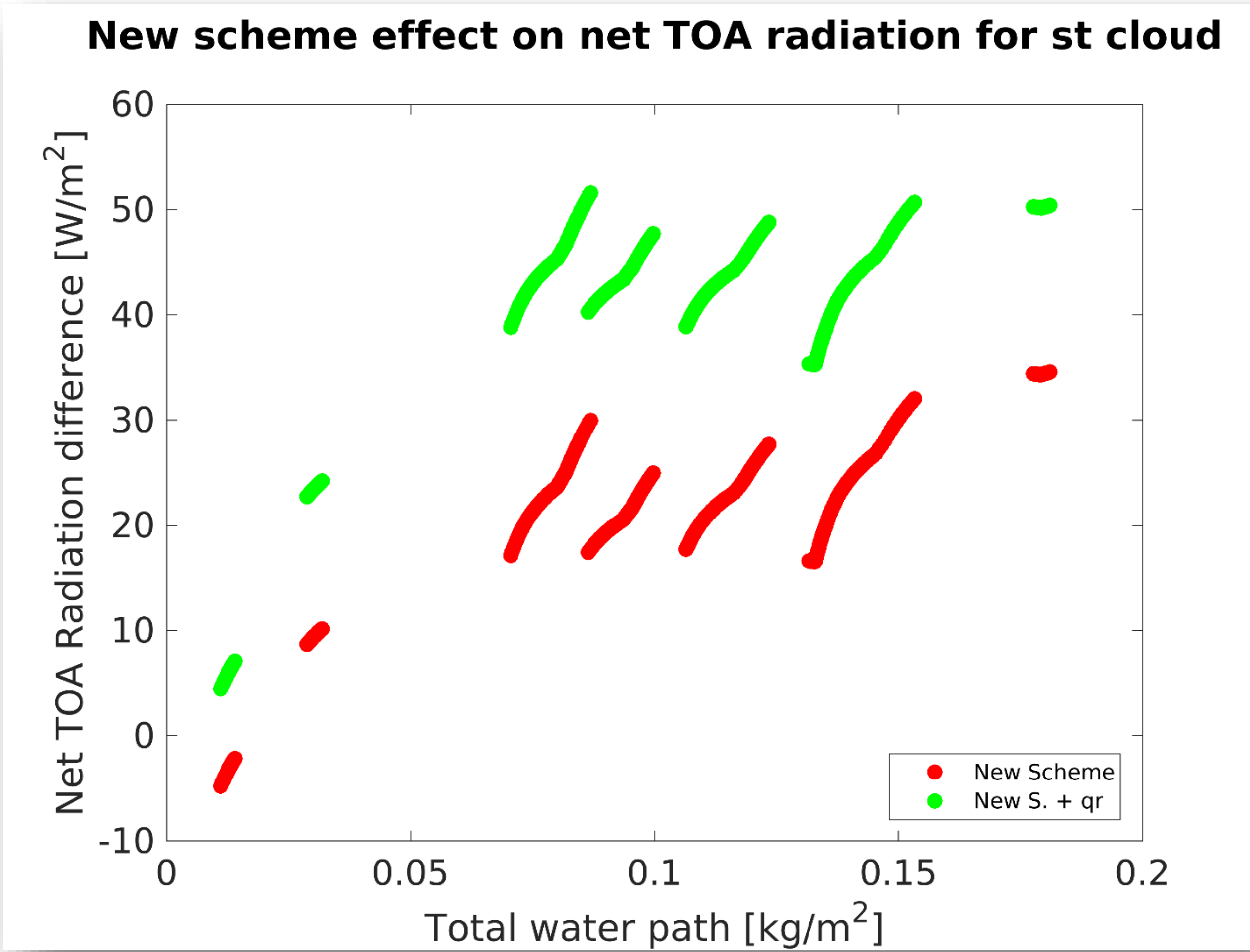
   LW- Lindner and Li (2000)

$$\begin{cases} \beta_{ext}/LWC = \sum_{i=-3}^{i=1} a_i r_e^i \\ 1 - \varpi = \sum_{i=-1}^{i=2} b_i r_e^i \\ g = \sum_{i=-1}^{i=2} c_i r_e^i \end{cases}$$

2. SOCRATES

$$\mathrm{f(R_e)} = \frac{\sum_{i=1}^{n} a_i \mathrm{R_e}^i}{\sum_{i=\mathrm{k}}^{m} b_i \mathrm{R_e}^i}$$

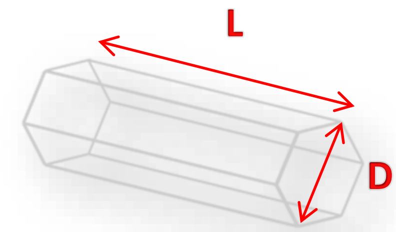
Liquid hydrometeors

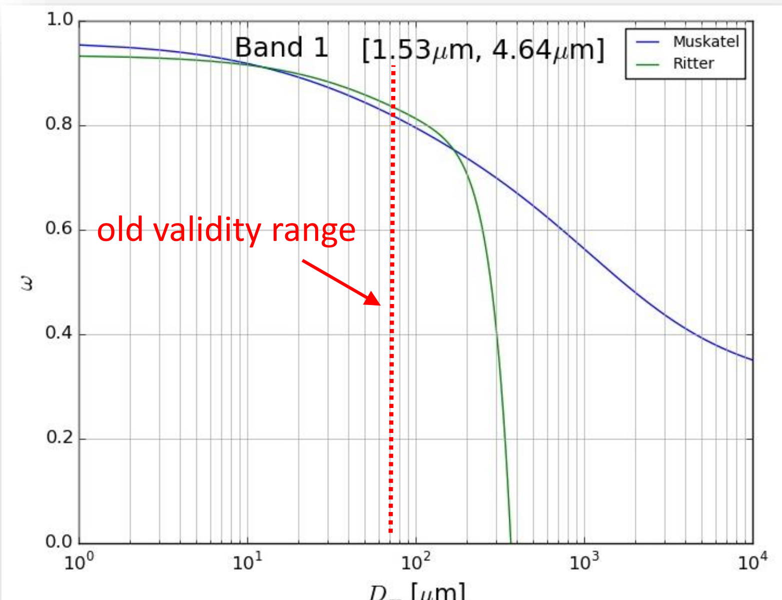


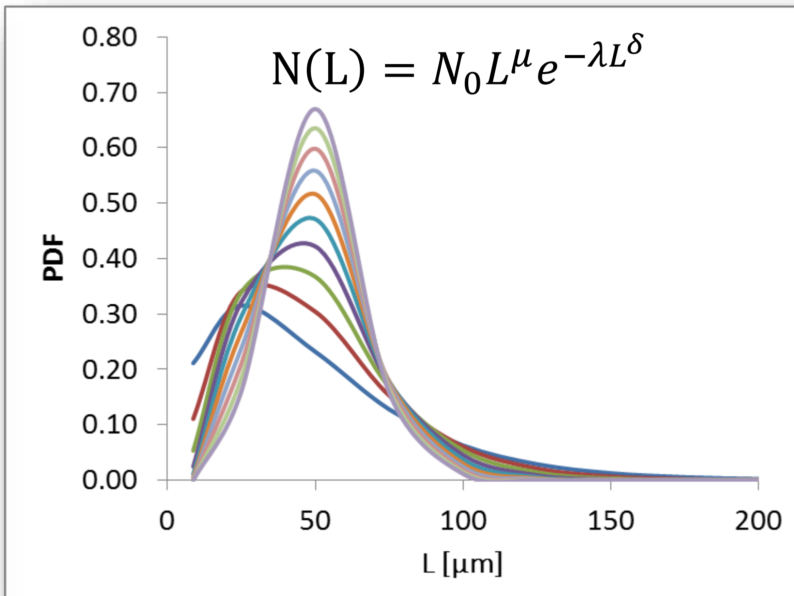
Warming effect of the new scheme compared with RG92!

Ice hydrometeors

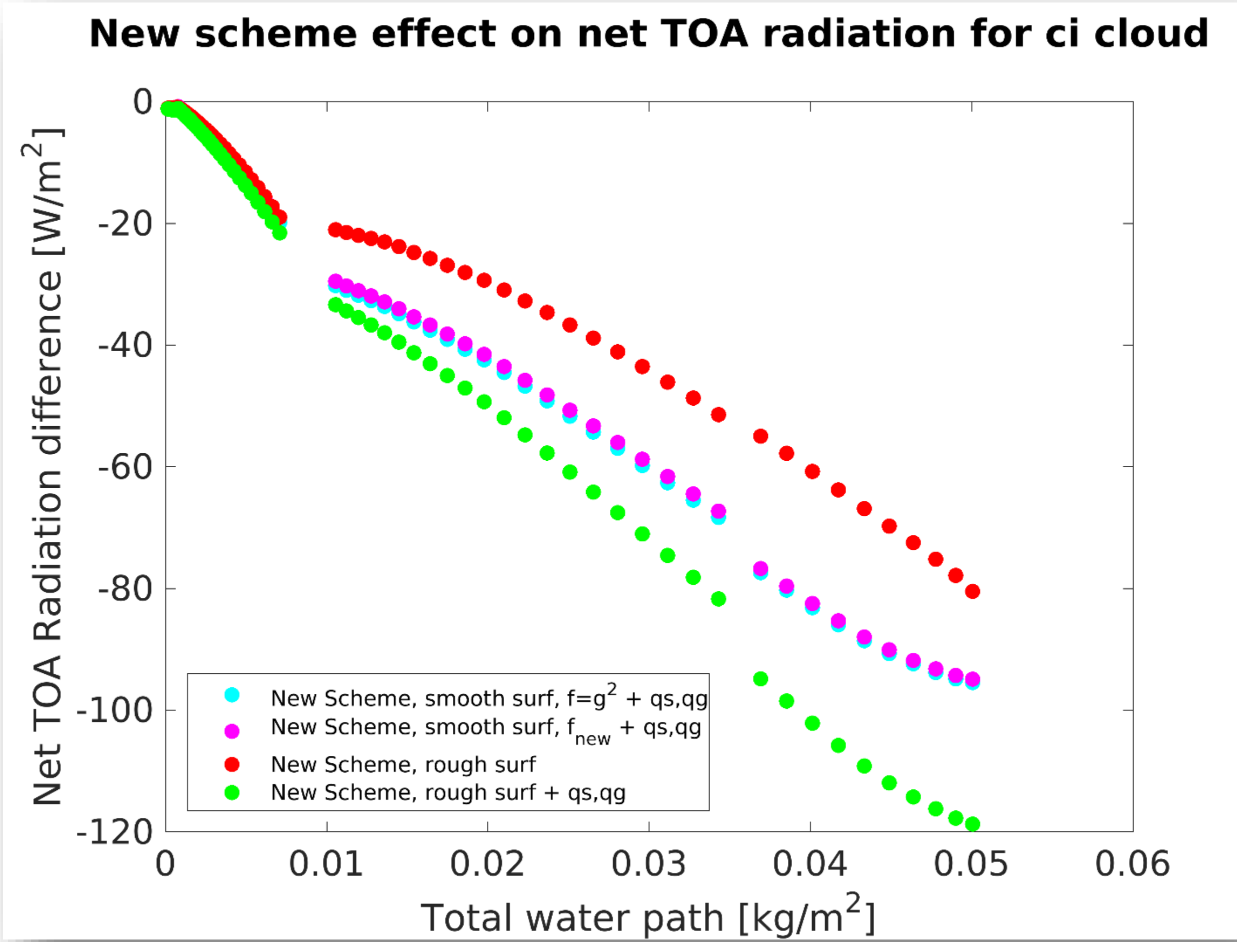
- Single particle optical properties after Fu
- Assuming randomly oriented hexagonal particles
- Using AR and D_{ge} as the bulk parameters:
- Size range expended using 7000 generalized gamma distributions
- Include snow and graupel in the radiation scheme
- Option: rough or smooth particle surfaces







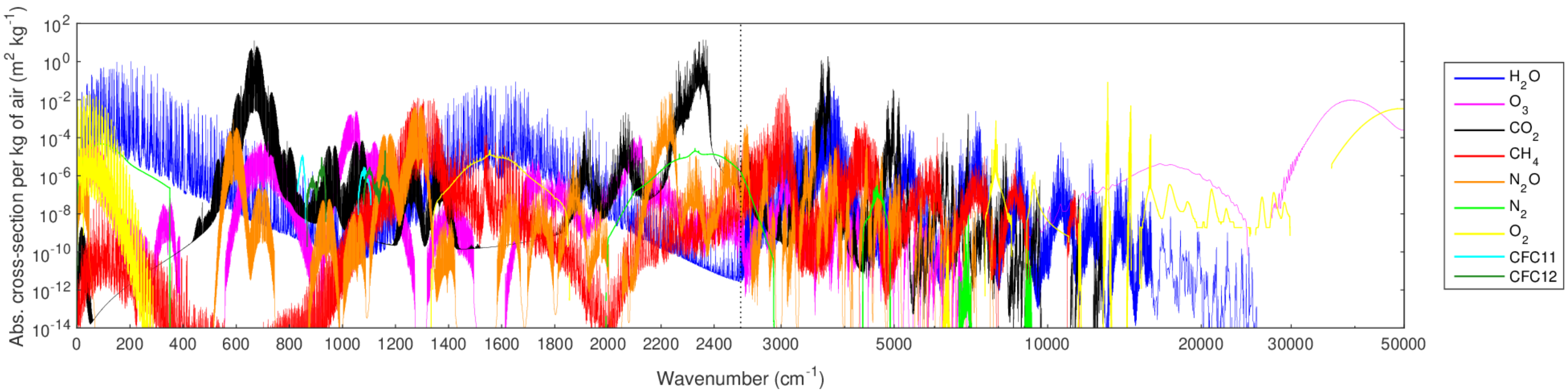
Ice hydrometeors

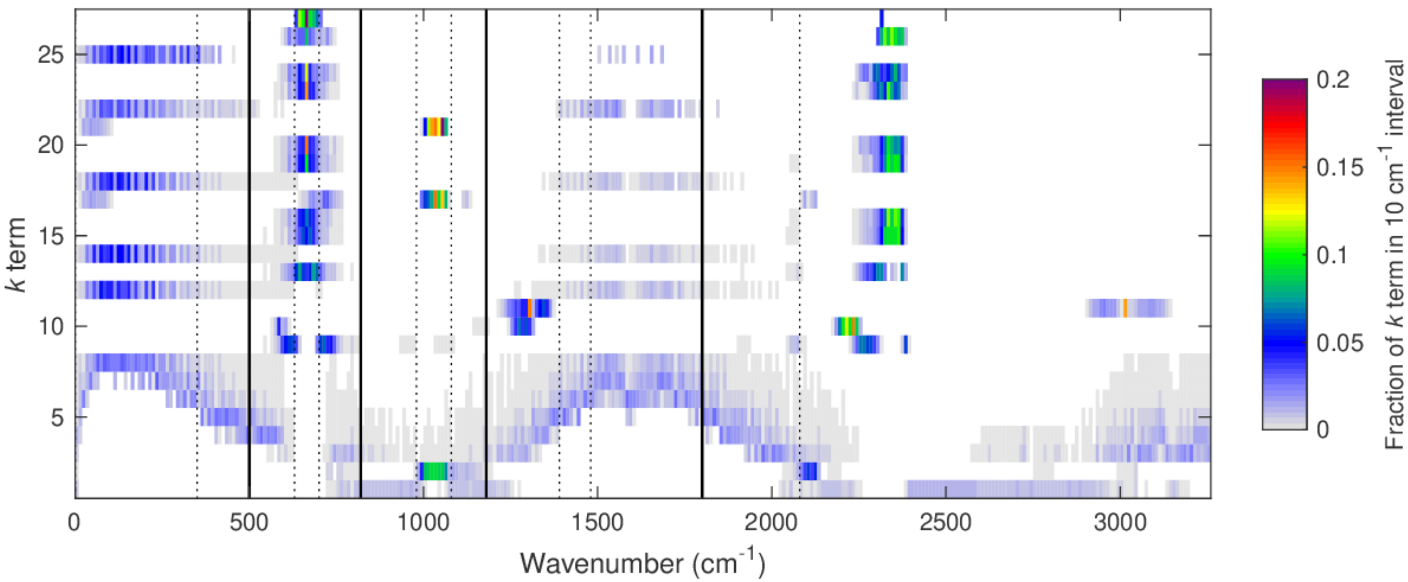


Cooling effect vs. RG92

Manuscript submitted to RMetS-App (2020)

CKDMIP: Correlated K-Distribution Model Intercomparison

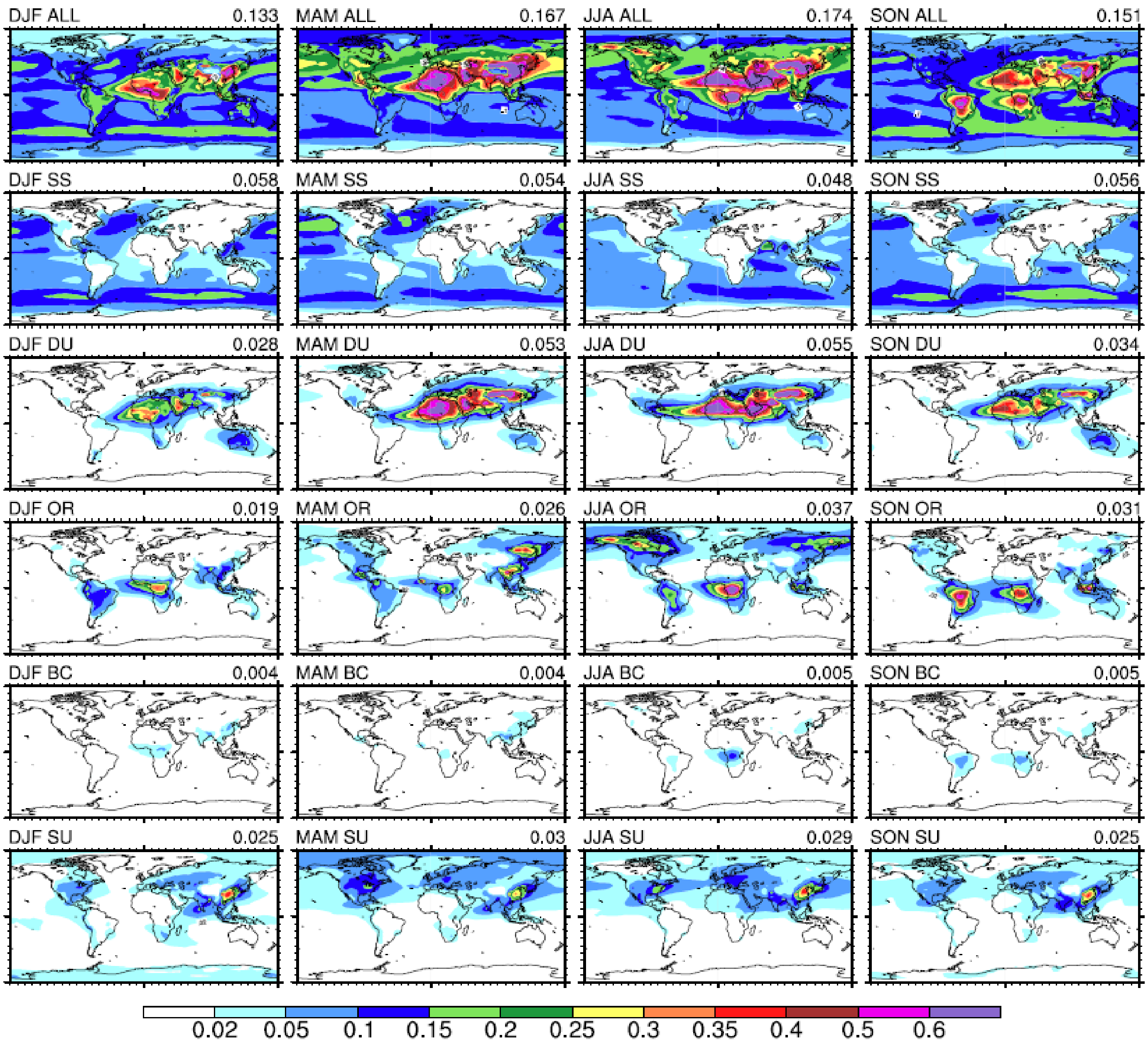




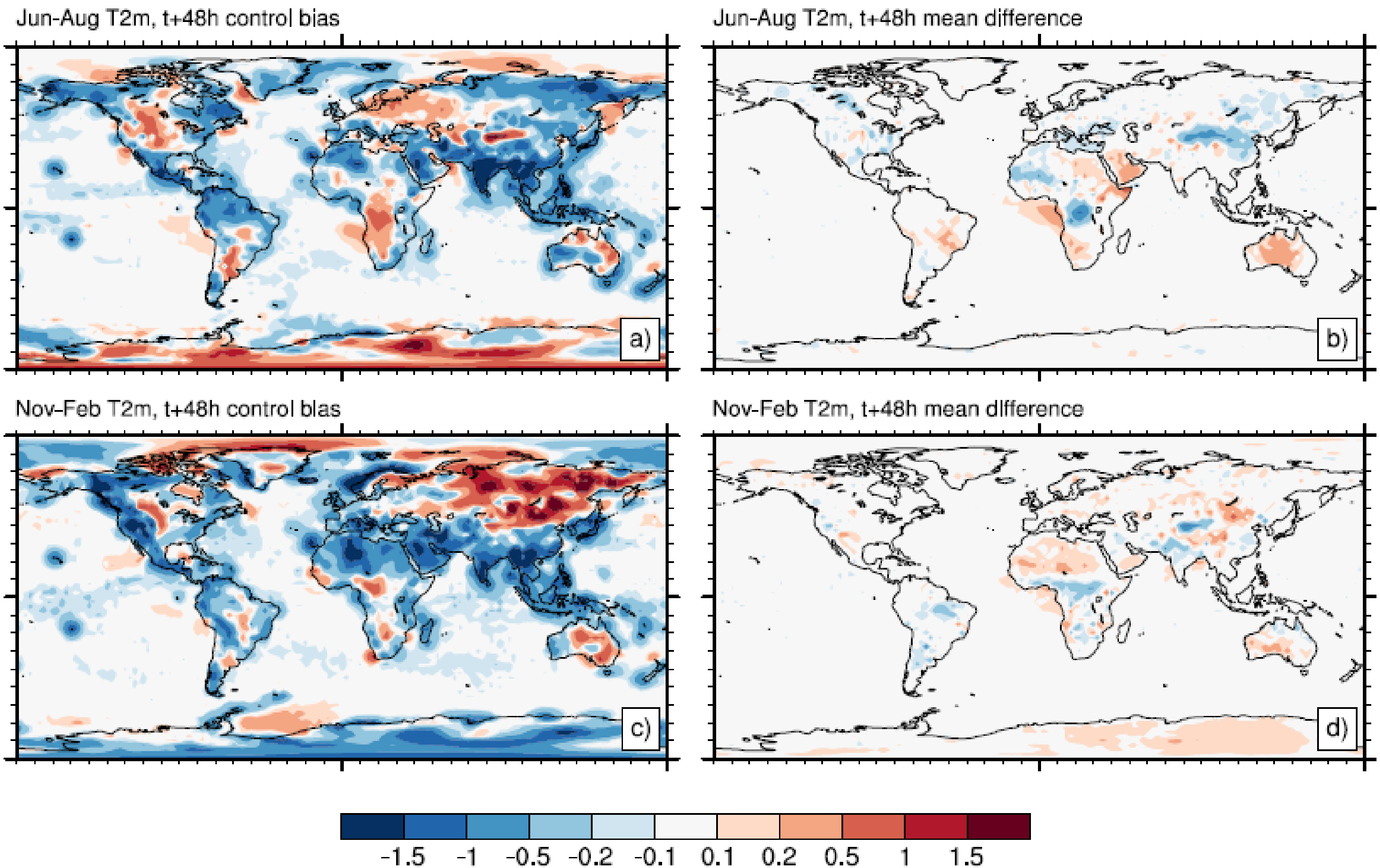
https://confluence.ecmwf.int/display/CKDMIP/


Aerosols

Task 5: CAMS climatology in ICON-ecRAD (RHM)



Task 5: CAMS climatology in ICON-ecRAD (RHM)



Bozzo et al., 801 ECMWF Memorandum, 2017

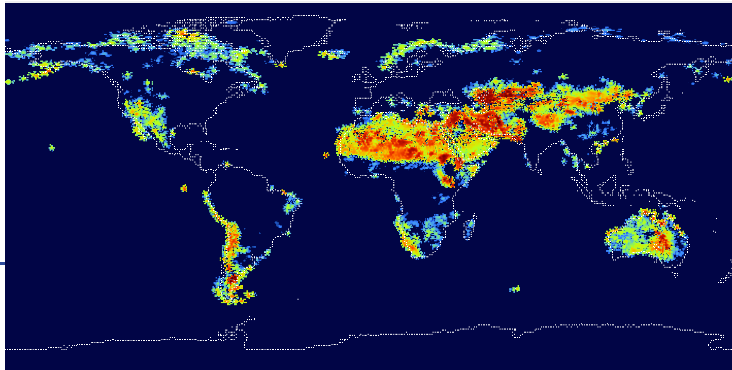
CAIIR Task 6, 2D-Aerosol (D. Rieger)

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

$$\frac{\partial \psi_j(x,y)}{\partial t} = \underbrace{\overline{\boldsymbol{v}_{H,j}} \nabla \psi_j(x,y)}_{\text{advection}} + \underbrace{S_{e,j}}_{\text{sources (emission)}} + \underbrace{S_{w,j}}_{\text{sinks (washout)}} + \underbrace{\frac{\left(f_{clim,j}\psi_{clim,j}(x,y) - \psi_j(x,y)\right)}{\tau_{clim,j}}}_{\text{relaxation to climatology (Tegen)}}$$

Subtask 6.1: Improve mineral dust AOD source function $S_{e,dust}$

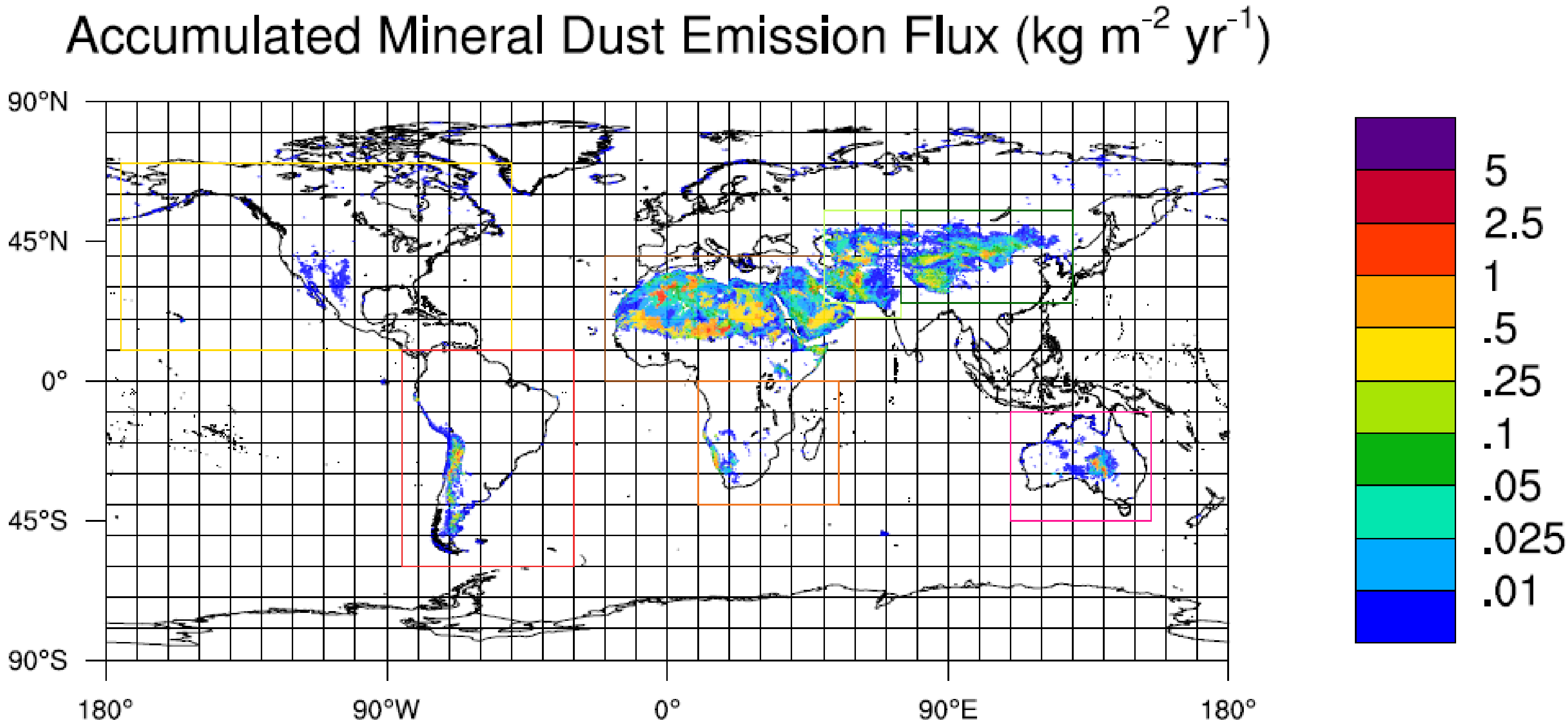
- Use cheap emission paramaterization, e.g.:
  Kok et al. (2014) - An improved dust emission model–Part 1: Model description and comparison against measurements. Atmos. Chem. and Phys., 14(23), 13023-13041
- Perform offline Mie calculations to derive optical properties
- Calculate AOD flux from emission flux



Accumulated dust flux (1 year, arbitrary units, non-equidistant scale) for Kok et al. parameterization in ICON (preliminary results)

CAIIR Task 6, 2D-Aerosol

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



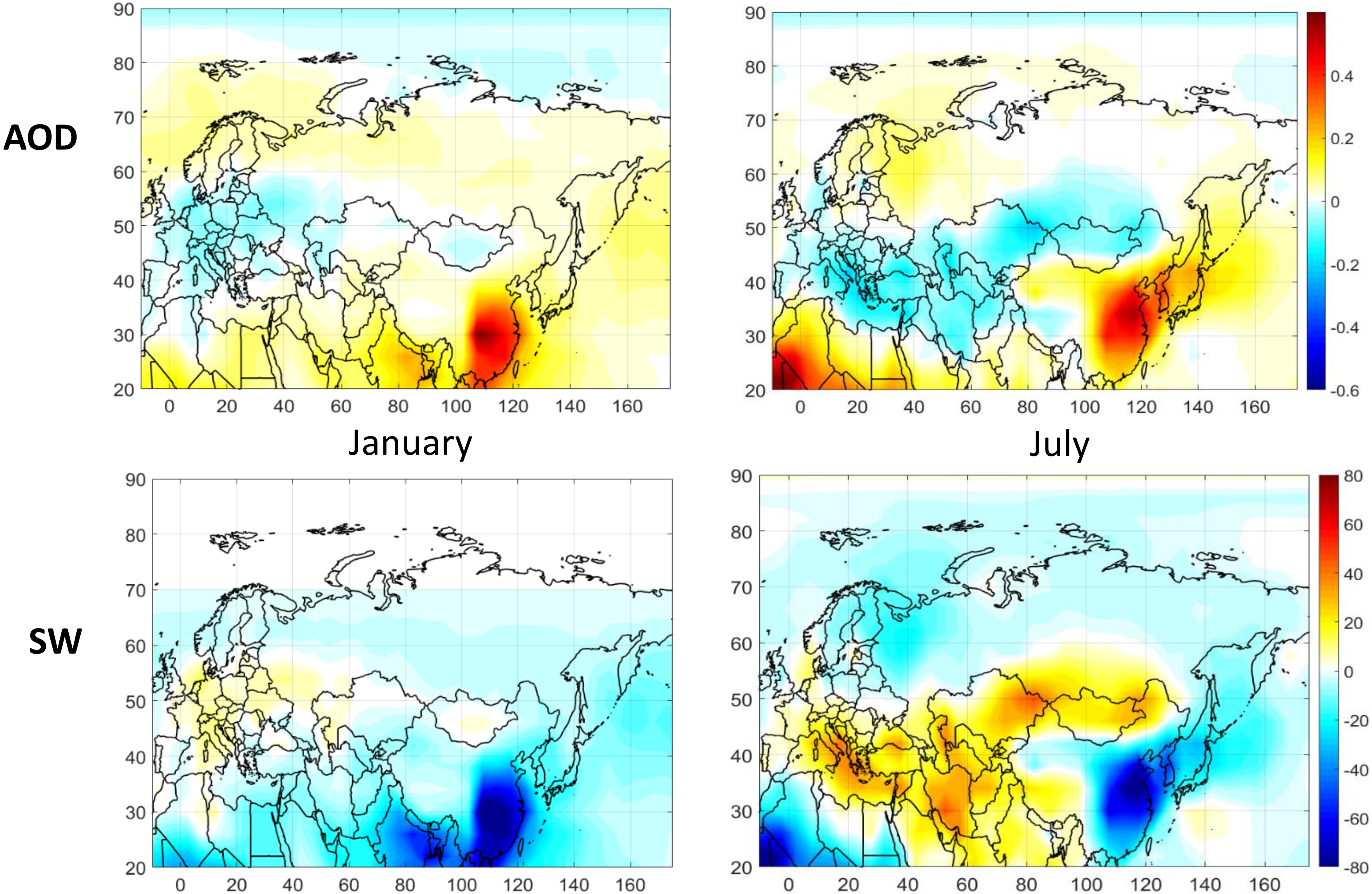
Subtask 6.2: Improve sea salt AOD source function $S_{e,ssa}$ based on an established emission parameterization

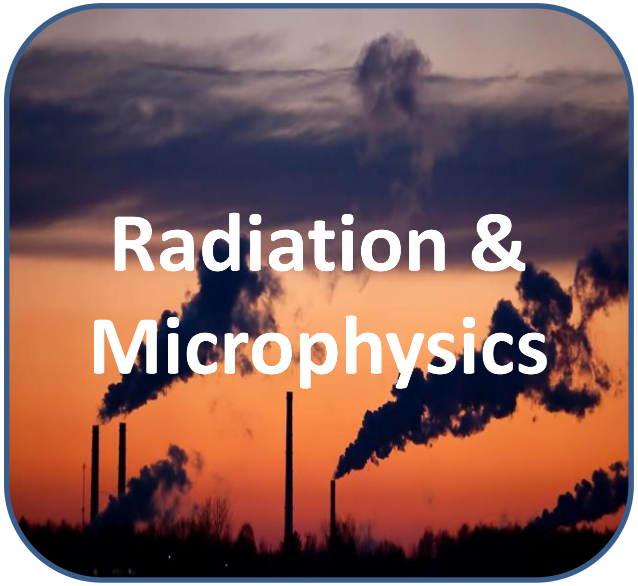
Subtask 6.3: Improve anthropogenic AOD source function $S_{e,anth}$
e.g., based on emission dataset, extensive literature review required

Task 7: Implement MACv2 climatology in ecRAD (RHM)

Kinne-MACv2 (2013) vs. Tegen (1997)

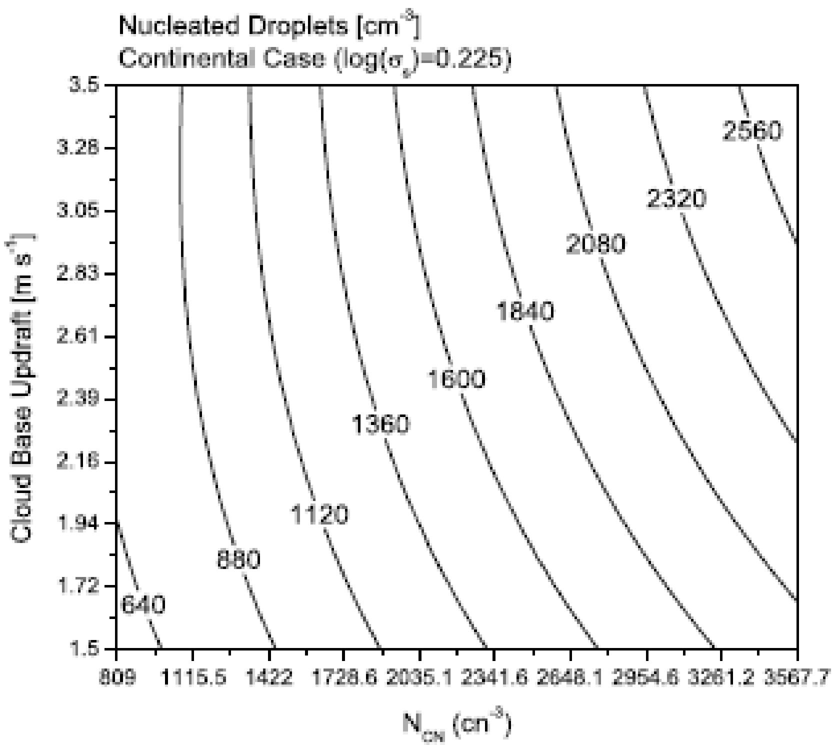
AOD at 550 nm & SW in clear skies, noon using CLIRAD




Radiation &
Microphysics

Droplet concentration: Segal & Khain (2006) scheme

- Cloud nuclei profile $n_{CN}(z)$ is estimated from Tegen/CAMS aerosols
- Activation of n_{CN} to n_{CCN} is estimated from Segal & Khain (2006)
- 4D look-up table: $n_{ccn}^{SK} = f(n_{cn}, log(\sigma), r_{mod}, w_{CB})$



Segal & Khain (2006)

Segal & Khain scheme in COSMO

- In „active“ clouds ($w_{nuc} > w_{cb,min}$ and $q_c > 0$ or clc_con > 0 over several adjacent height layers), activation is at cloud base and n_{CN} decreases exponentially above cloud base (→ autoconversion, accreation)

$$n_C(z) = \begin{cases} n_{CCN,SK}\Big(n_{CN}(z_{cb}), w_{nuc}(z_{cb})\Big) \exp\left(-\frac{z-z_{cb}}{\Delta z_{a,1/e}}\right) & \text{if } w \geq w_{cb,min} \wedge q_C(z) > 0 \wedge z \geq z_{cb} \\ n_{CCN,SK}\Big(n_{CN}(z), \max[w_{nuc}(z), w_{cb,min}]\Big) & \text{else} \end{cases} \qquad \left[\mathrm{kg}^{-1}\right]$$

- Effective updraft speed w_{nuc} for nucleation, including turbulence, radiative cooling an parameterized convection:

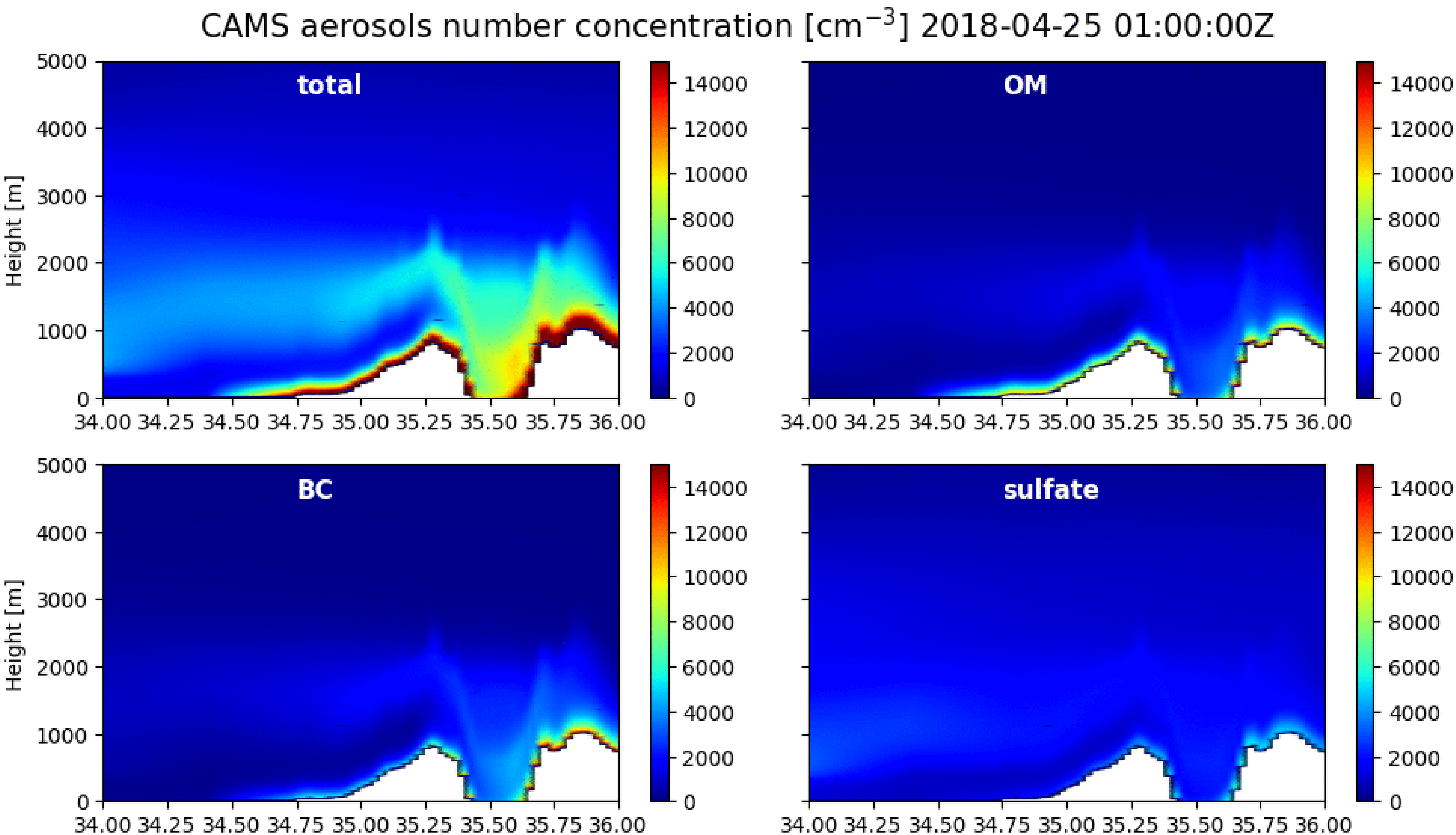
$$w_{eff} = \overline{w} + 0.7\sqrt{\frac{2\,TKE}{6}} - \frac{c_p}{g}\left.\frac{\partial T}{\partial t}\right|_{\text{radiation}}$$

$$w_{nuc} = \max\left[w_{eff}, w^*\right]$$

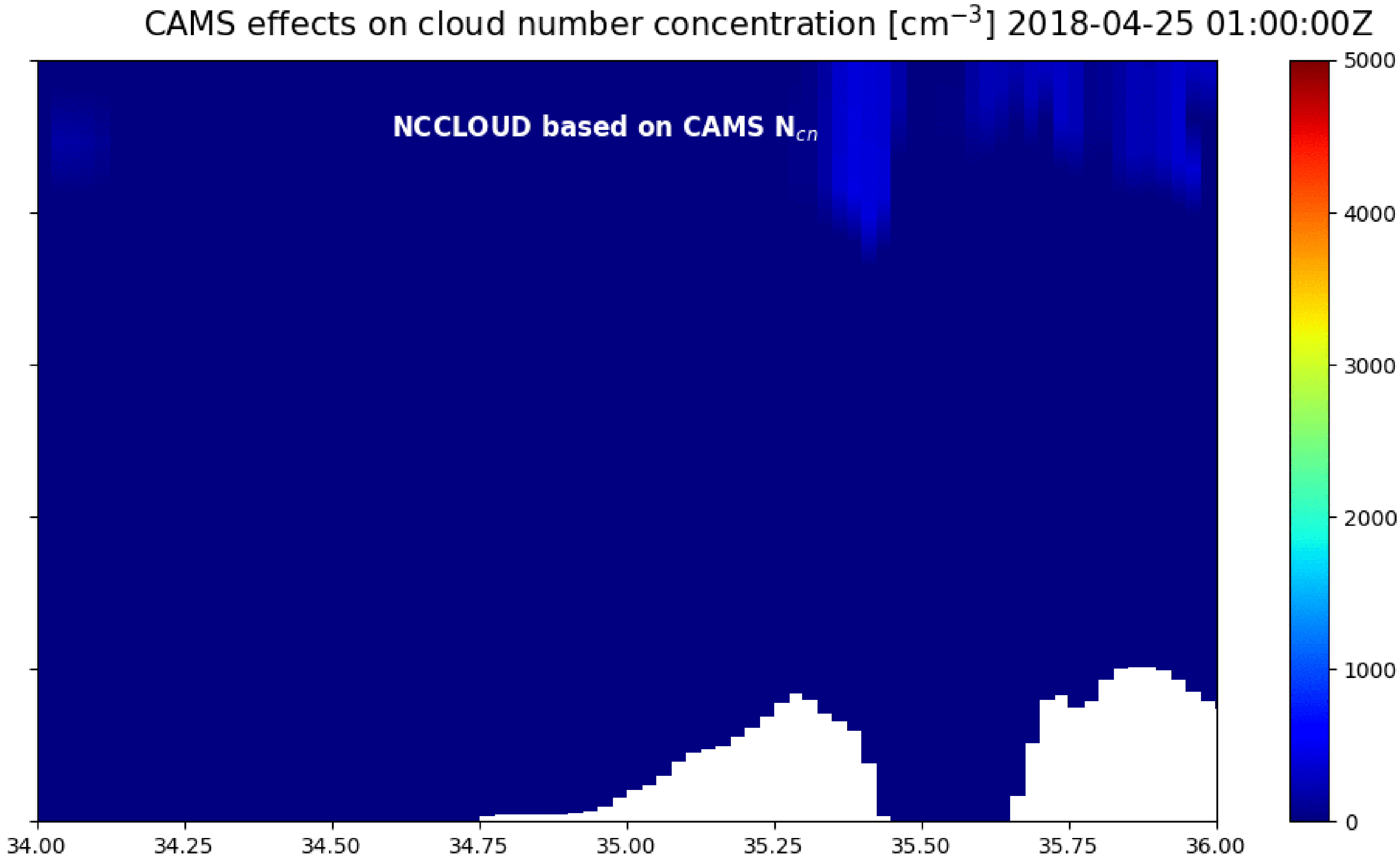
$$w^* = \left(-g\, z_{topcon}\frac{\overline{w'\Theta'_{v,S}}}{\overline{\Theta_{v,S}}}\right)^{1/3}$$ (convective velocity scale by Deardorff)

→ z_{top_con}: PBL height as determined from $\Theta_v < \Theta_{v,surf}$+0.5 K, or upper bound of lowest continuous „clc_con“ layer

CAMS Forecasted Aerosols number concentration



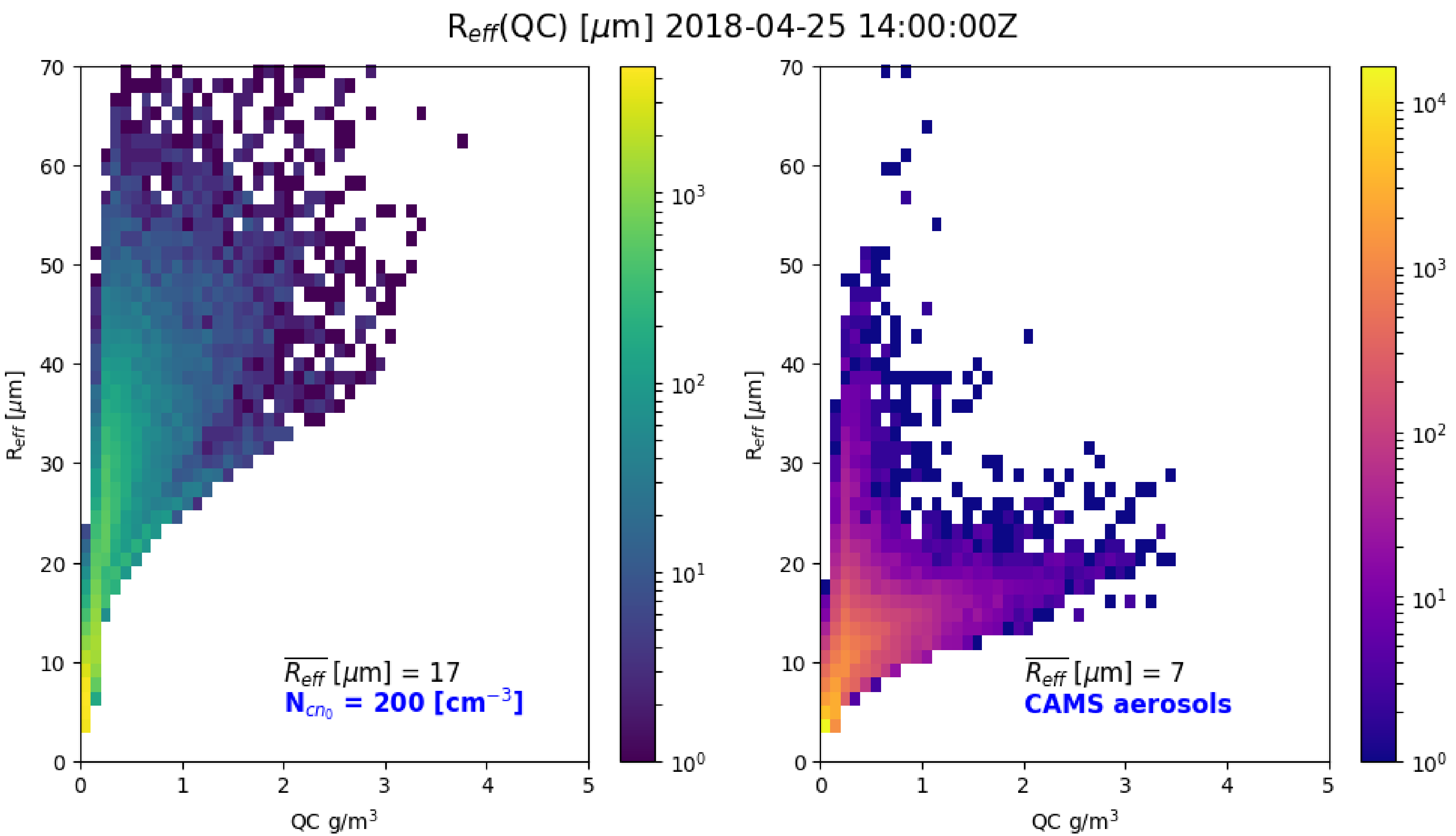
New cloud droplets number concentration



icloud_num_type_gscp/rad = 4

R_{eff} based on CAMS & Segal-Khain

Peak event April 25 14Z



Case study: April 25-27, 2018

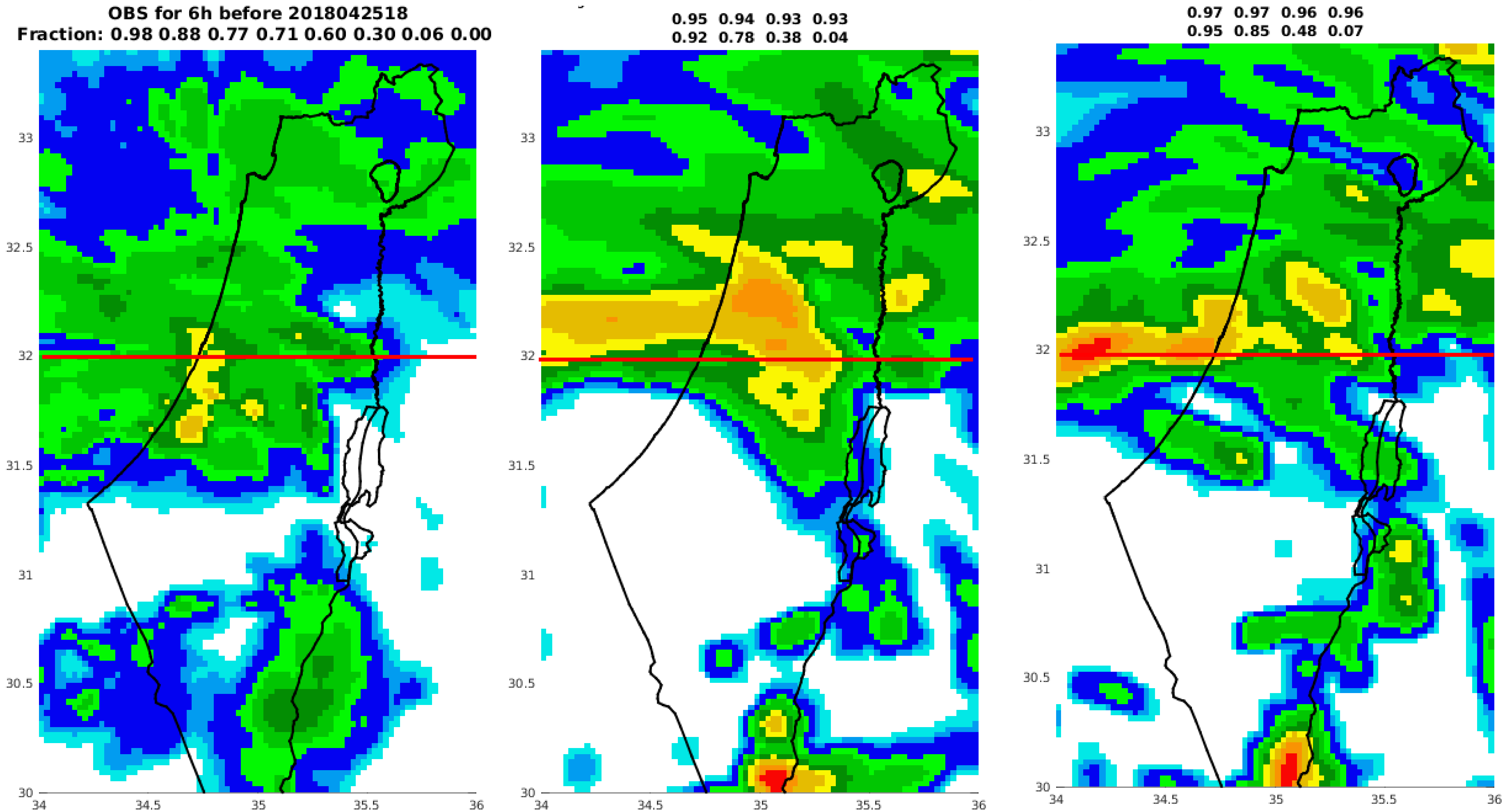
New cloud_rad

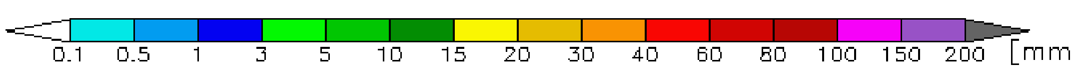
CAMS background aerosols

CAMS & SK Ncn → rad + microphysics

OBS

COSMO oper

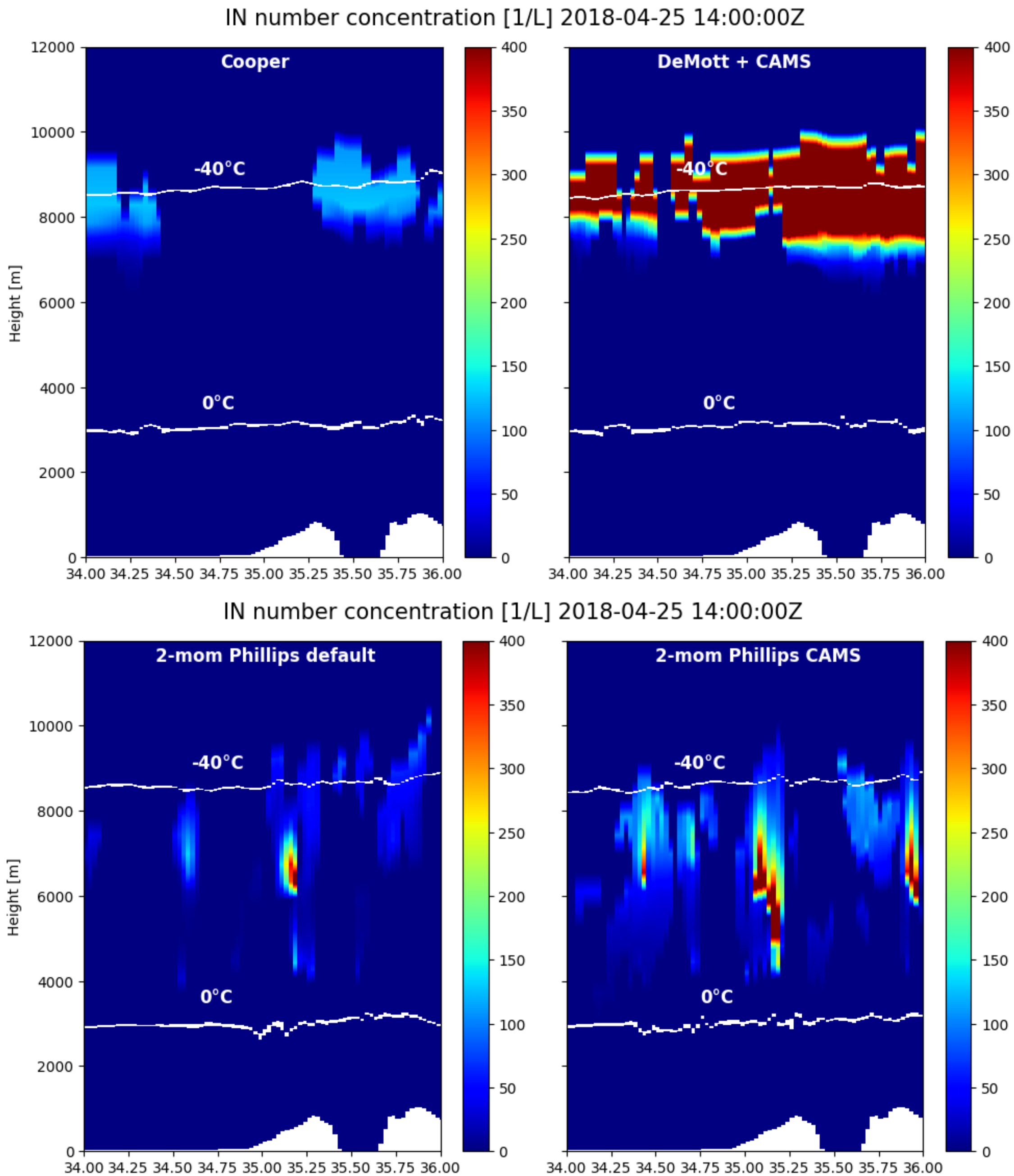




INP number concentrations (for IWC > 0.03 gm^{-3})

1-mom
Cooper

$\mathrm{IN(T)} = 5 \cdot e^{0.304(T_0 - T)}$



1-mom
DeMott + CAMS

$\mathrm{IN(T)} = 1000 \cdot n_{dust}{}^{1.25} e^{0.46(T_0 - T) - 11.6}$

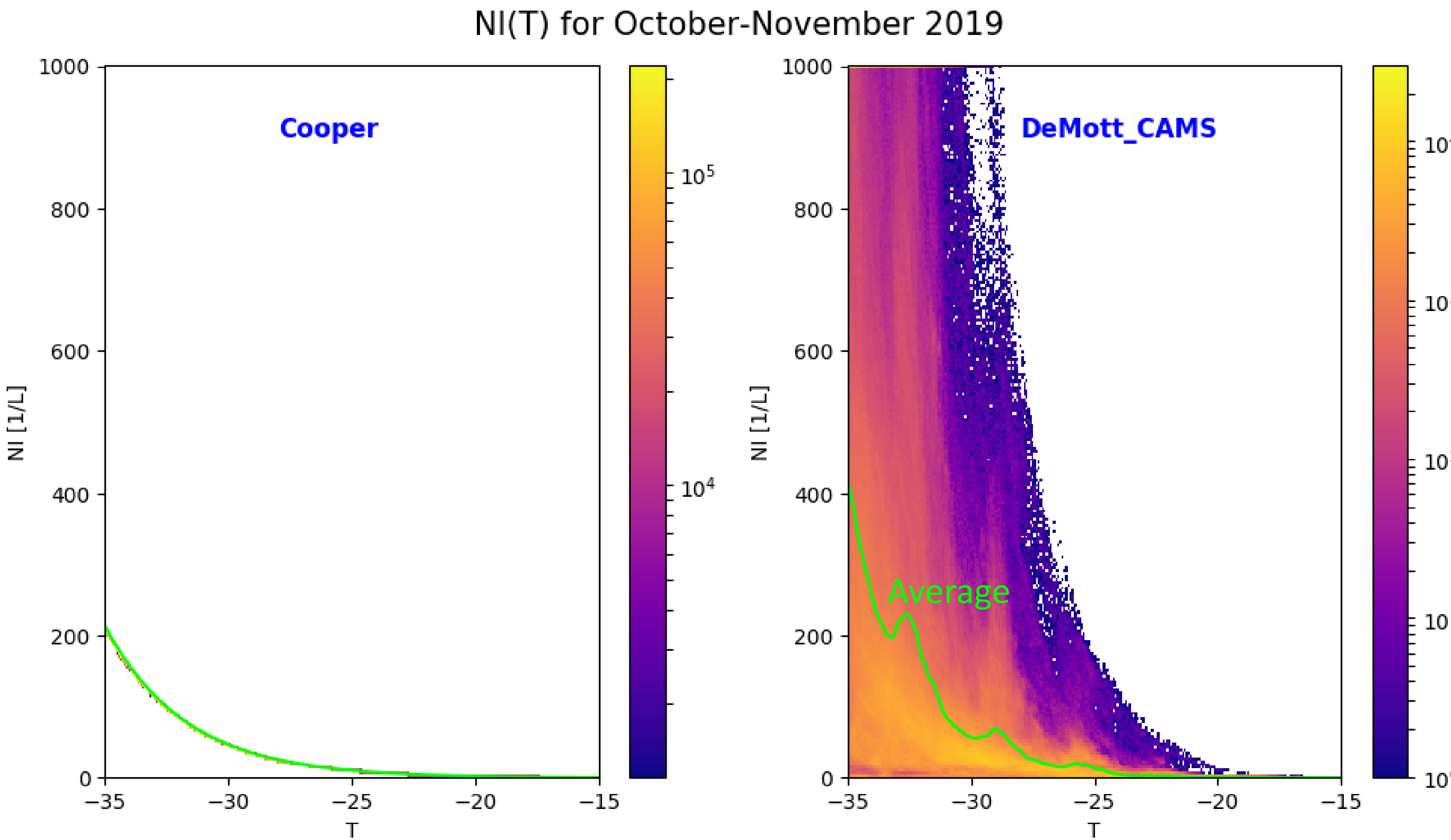
2-mom
Phillips (2008)
IN=f(S,n_{aer}=const)

$\mathrm{nc_{dust}} = 0.162\ cm^{-3}$
$\mathrm{nc_{soot}} = 15\ cm^{-3}$,
$\mathrm{nc_{organic}} = 177\ cm^{-3}$

2-mom
Phillips (2008)
IN=f(S,$n_{aer,CAMS}$)

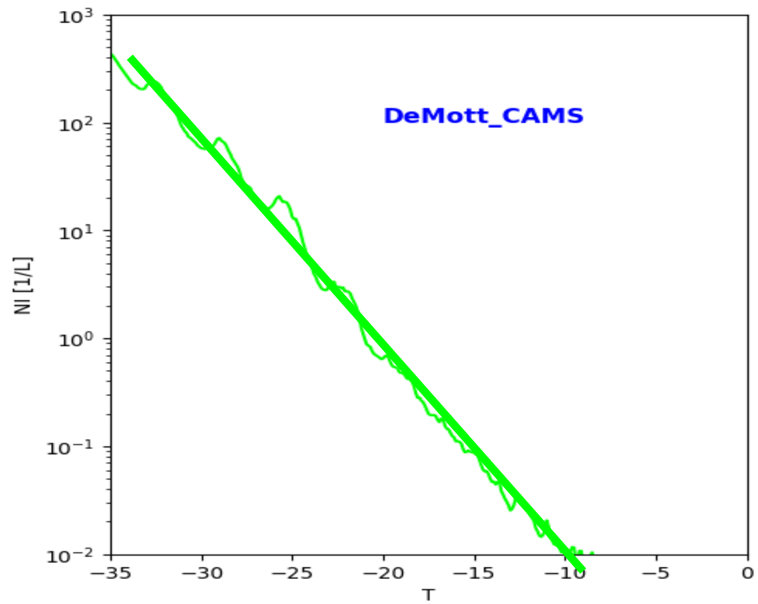
IN(T) occurrences (for grid points with IWC > 0.03 gm^{-3})

Results for 45 test cases Oct-Nov 2019

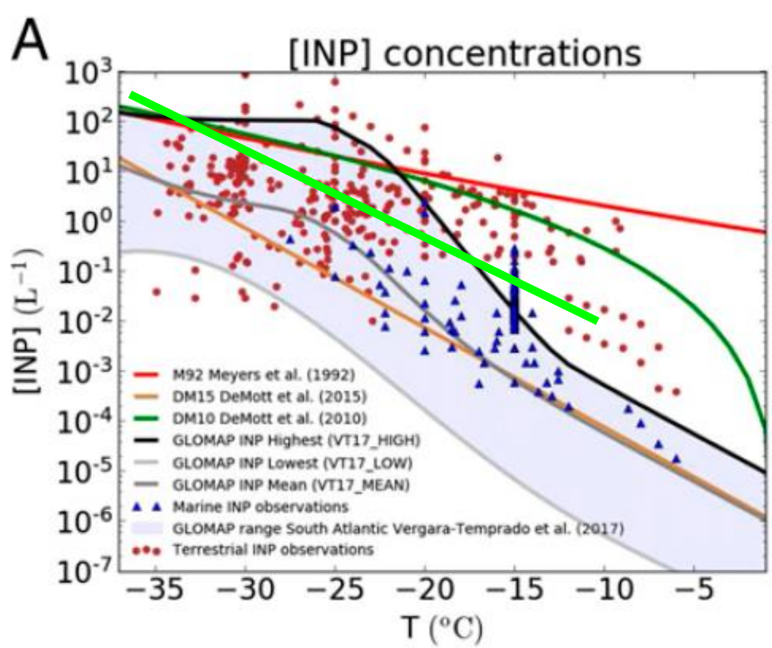


INP(T) Model vs. OBS

COSMO model results for 45 test cases Oct-Nov 2019

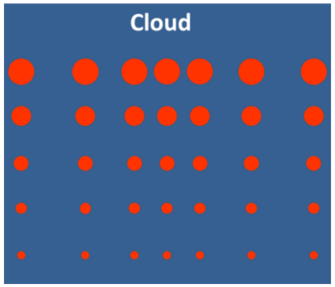


Vergara-Temprado, J. et al., PNAS 115.11 (2018)

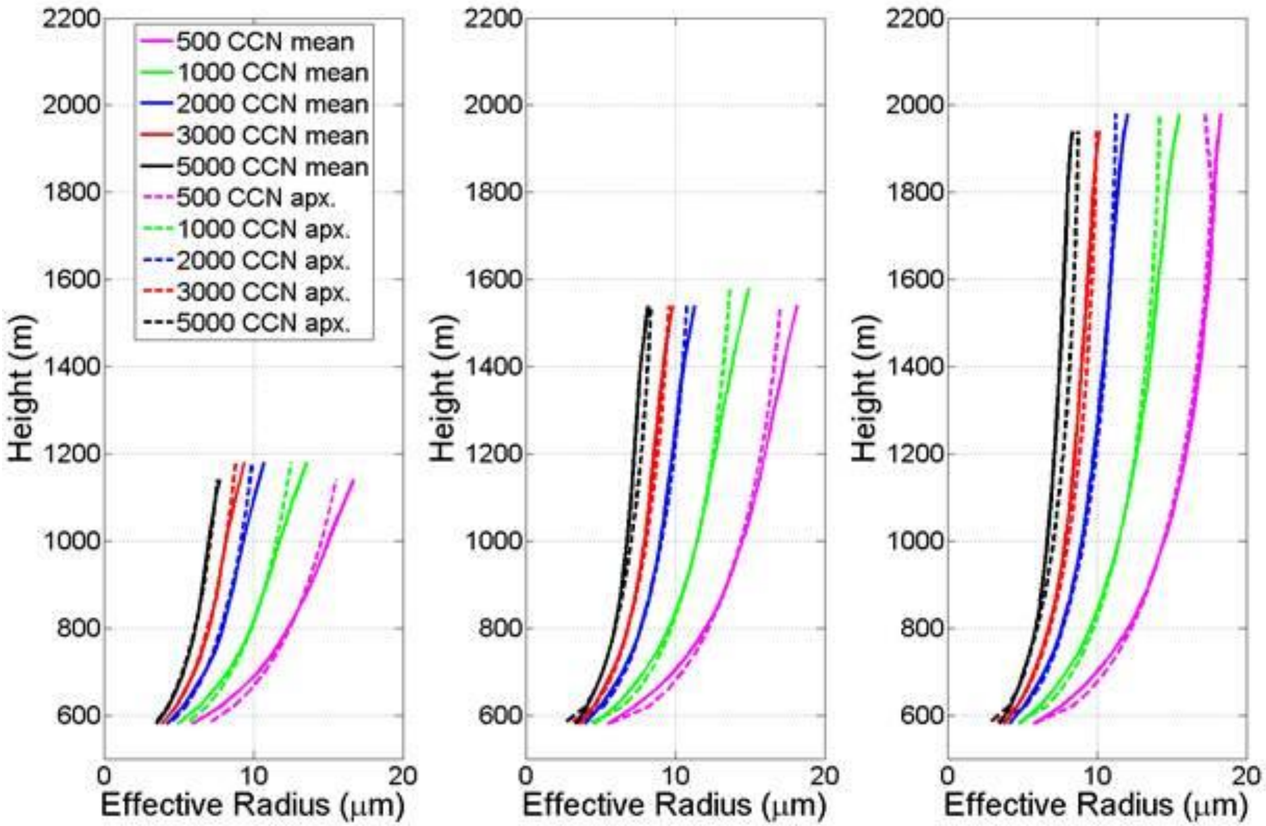


R_{eff} in Sub-Grid Scale Clouds (P. Khain)

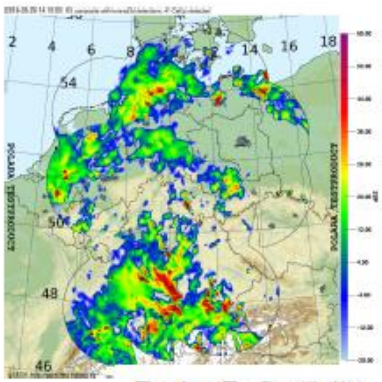
R_{eff} is does not change much horizontally and can be analitically estimated



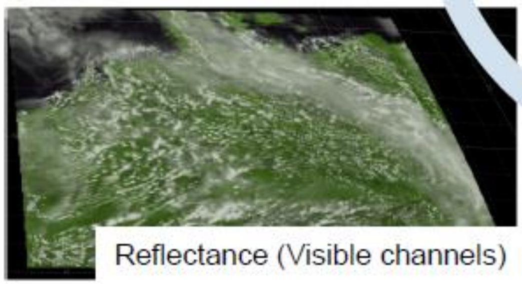
$$\overline{R_{eff}} = fct(CCN_{cloud\ base}, H_{above\ c.base}, T)$$



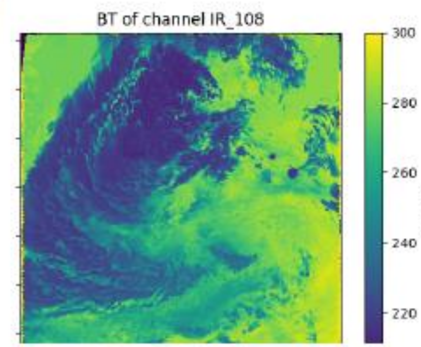
Unified Effective Radius Calculation in ICON



Radar Reflectivity

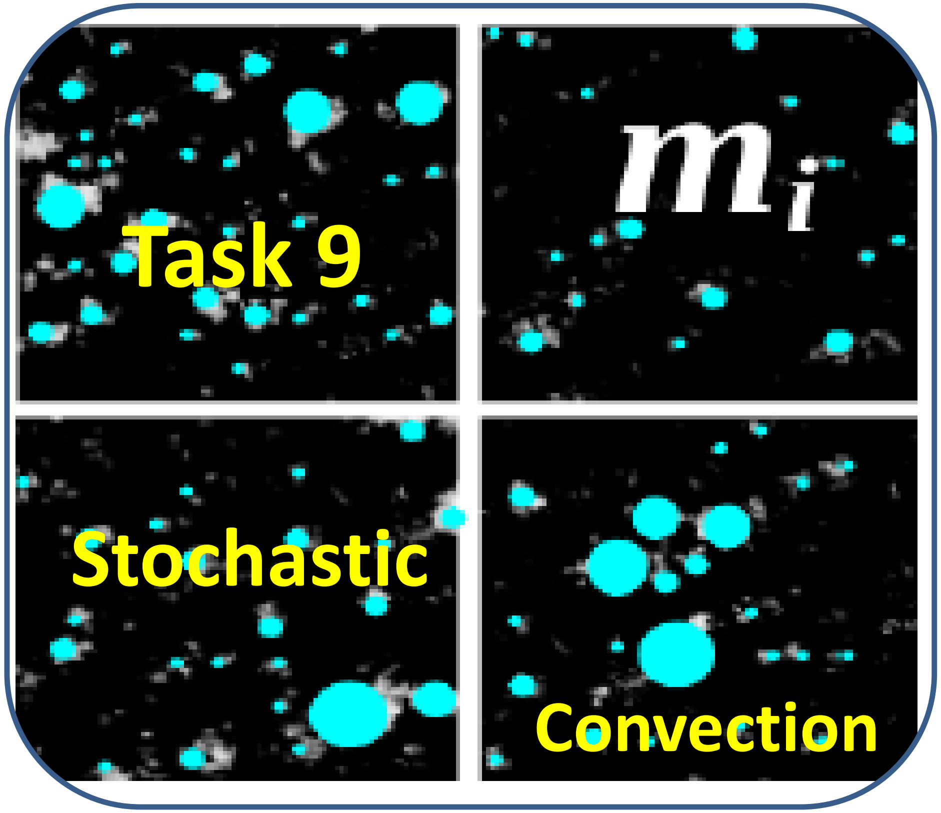


Reflectance (Visible channels)



Brightness Temperature (IR channels)

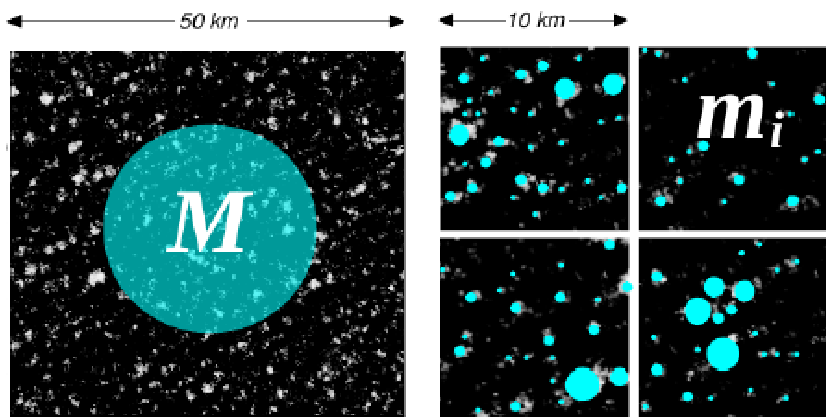
Slide content: Alberto de Lozar


Task 9
m_i
Stochastic
Convection

Re-analysis of SGS clouds using the Stochastic Convection Scheme (Sakradzija et al. 2016, 2018)

➔ Traditional closure assumptions for convection no longer hold at high resolution

Grid box area **too small** to contain a complete ensemble of convective clouds

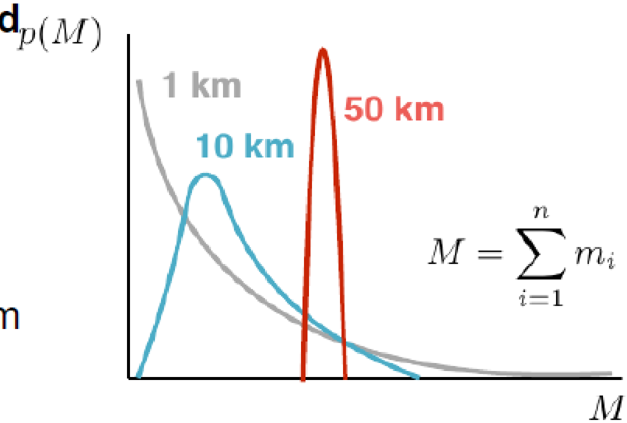


➔ Convection is **not** in equilibrium with the large-scale state (closure)

➔ The **mass flux on large scales** (where traditional assumptions are a good approximation) is determined with the **classical parameterisation** (Tiedtke-Bechtold/IFS)

➔ At **individual grid points**, a **stochastic cloud ensemble** is generated whose mass flux (averaged across larger scales) converges to that of the classical parameterisation

➔ Bonus: The **ensemble automatically adapts to the grid resolution**. The smaller the grid spacing, the greater mass flux departures from the cloud ensemble mean



Taken from Maike Ahlgrimm presentation

Stochastic convection scheme (P. Khain)

Subtask 9.1 Testing the stochastic convection scheme

- Verified against observations/soundings
- Find the weaknesses and the advantages of the stochastic parametrization over the default Tiedke-Bechtold scheme

Subtask 9.2 Estimating the cloud cover from the SC scheme

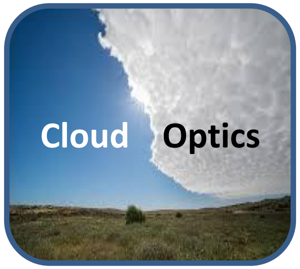
- The detrainment approach will be implemented in the new scheme to deduce the cloud cover of shallow convection
- Verification against observations
- Simulated in idealized fair weather situations, and compared to idealized LES simulations of cloud cover

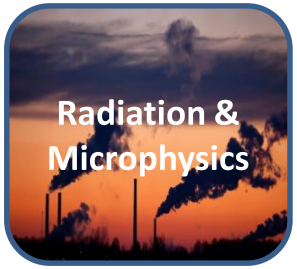
Subtask 9.3 Precipitation from the SC parametrization

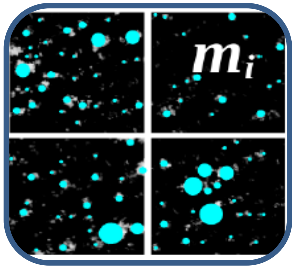
- Utilize the sub-grid variability of the stochastic parametrization to estimate the sub-grid PDF of cloud and rain water contents.
- Grid-box averaged microphysical rates will be estimated
- Estimation of precipitation from shallow convection vs. Tiedke-Bechtold

CAIIR Project Plan

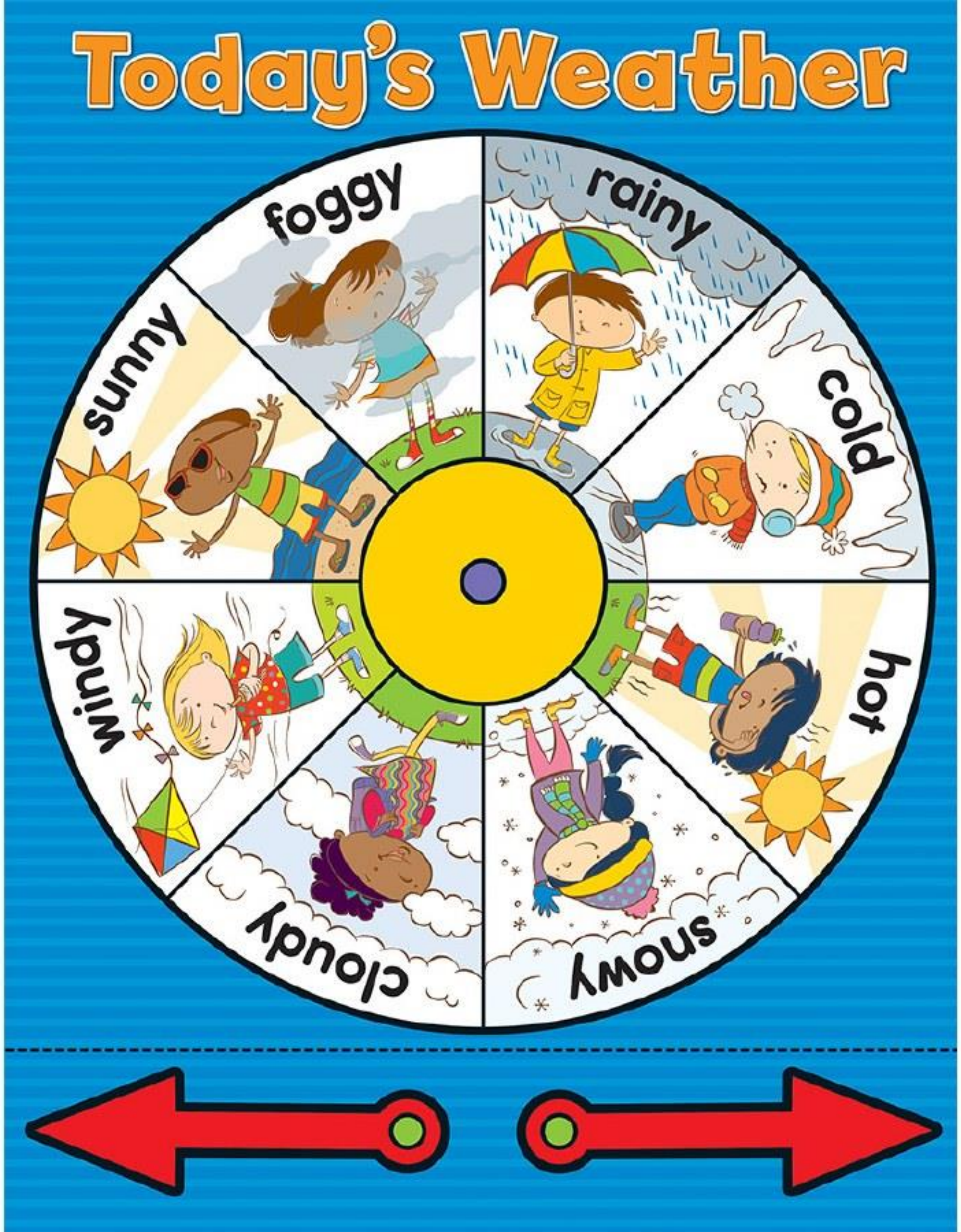
- Cloud optics
- Aerosols inputs: CAMS forecasted, CAMS climatology, 2D advection scheme, MACv2 climatology
- Microphysics – R_{eff} and LWC revised, Realistic cloud formation
- Stochastic convection scheme
- Model testing (RHM) and tuning (P. Khain)







Thank


Today's Weather
foggy
rainy
cold
hot
snowy
cloudy
windy
sunny

You!