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Testing & Tuning of Revised Cloud Radiation Coupling: $T^2(RC)^2$ PP

Phase 2 Activities

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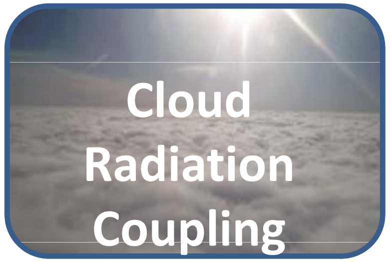
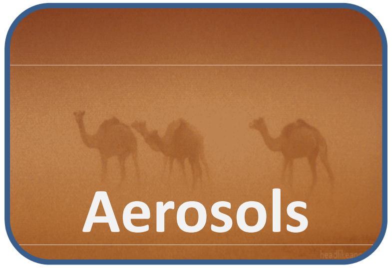
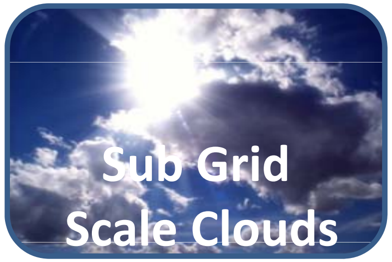
20th COSMO General Meeting, Saint-Petersburg, September 3, 2018

$T^2(RC)^2$ road map

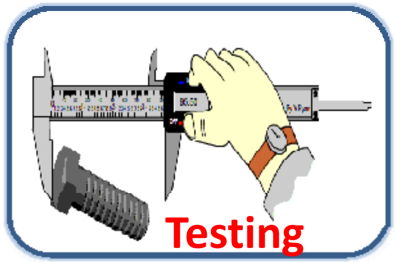
Revised Cloud/aerosols Radiation Coupling







Testing & Tuning



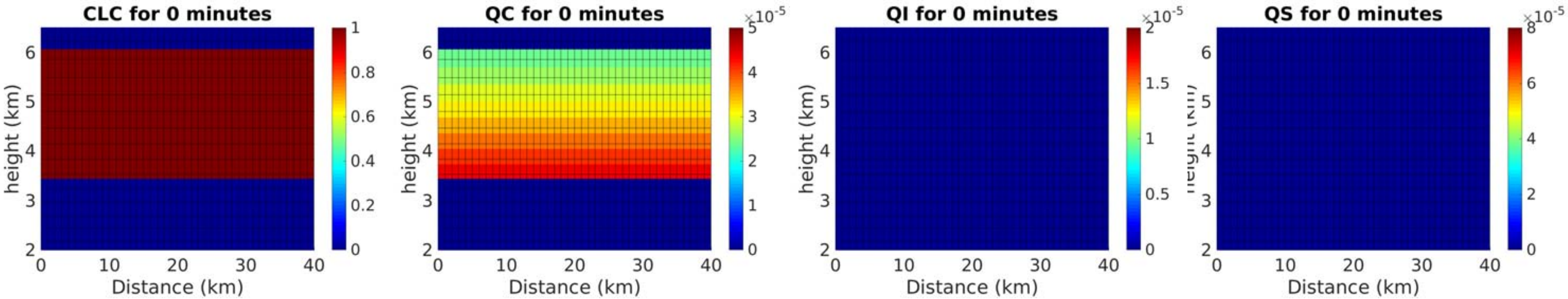
Run Time Optimization

Choosing Parameters for Fine Tuning

- 32 new tuning parameters
- Use idealized COSMO framework to create different cloud types
- Decide which parameters are the most important for each cloud type
- True/False switches & continuous parameters

Cirrus	Warm Stratus	Mixed phase	Fair weather Cu	Anvil of CB
p1,p2,p3,p6,p7,p9,p10,p11,p14,p16,p23,p24,p25,p29,p30,p31,p32	p1,p2,p6,p8,p15,p17,p18,p19,p26,p27, p28,p32	p1,p2,p3,p6,p7,p8,p9,p10,p11,p14,p15,p16,p17,p18,p19,p23,p24,p25,p26,p27,p28,p29,p30,p31,p32	p2,p6,p7,p8,p15,p17,p18,p19,p32	p1,p2,p3,p6,p7,p9,p10,p11,p14, p16,p23,p24,p25,p29,p30,p31,p32

Mixed phase cloud



A List of 8 most important parameters

lrad_incl_qrqsqg	.1
iradpar_cloud	.2
lrad_use_largesizeapprox	.3
lrad_ice_smooth_surfaces	.4
lrad_ice_fd_is_gsquared	.5
itype_aerosol	.6
icloud_num_type_rad	.7
radqcfact	.8
radqifact	.9
rad_arearat_ls_i	.10
rad_arearat_ls_s	.11
rad_arearat_ls_g	.12
rad_arearat_ls_h	.13
rhobulk_ls_ini_i	.14
reff_ini_c	.15
reff_ini_i	.16
cloud_num_rad	.17
zref_cloud_num_rad	.18
dz_oe_cloud_num_rad	.19
tqc_thresh_rad	.20
tqi_thresh_rad	.21
tqs_thresh_rad	.22
rhos_n0shigh_rad	.23
rhos_n0slow_rad	.24
n0s_low_rad	.25
rhoc_nchigh_rad	.26
rhoc_nclow_rad	.27
ncfact_low_rad	.28
rhoi_nihigh_rad	.29
rhoi_nilow_rad	.30
nifact_low_rad	.31
qvsatfact_sgscl_rad	.32

true / false switches (.1–.7)

continuous parameters (.8–.32)

→

(2) Operational / new scheme

(1) Include rain, snow & graupel

(7,17) Number concentration of cloud droplets

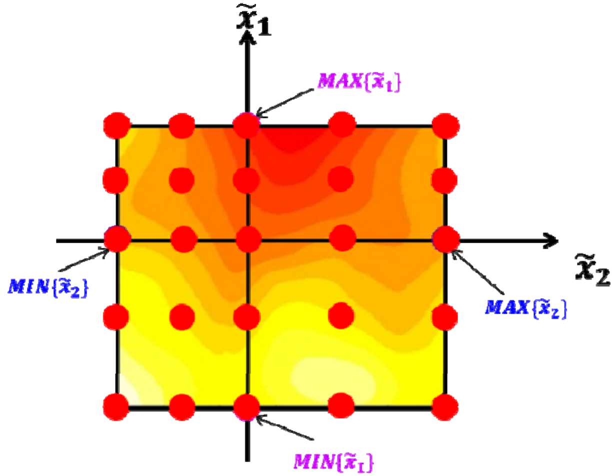
(15,32) Sub-grid water clouds properties

(8,9) Sub-grid scale variability

Calibrated versions and parameters

- COSMO-DE 2.8km 5.1 four "cloudrad" versions, driven by ICON-EU analyses.
- 30M BU in ECMWF computers: 4 months (Feb, Apr, Jun, Sep) 2016 **– like running COSMO for 25 year in a row**

$$\tilde{R}(\tilde{x}_1,\tilde{x}_2,\tilde{x}_3,\tilde{x}_4) \cong \sum_{p=1}^{4} \frac{a_{p,1}+a_{p,2}\tilde{x}_p+a_{p,3}\tilde{x}_p^{2}}{a_{p,4}+a_{p,5}\tilde{x}_p+a_{p,6}\tilde{x}_p^{2}} + \frac{1}{2}\sum_{p=1}^{4}\sum_{i\neq p} b_{p,i}\tilde{x}_p\tilde{x}_i$$



Key switches (yellow) | Tuned continuous parameters (cyan) | **Calibrated versions**

Parameter meaning	Parameter	Basic version	CAMS version	SK basic version	SK-SAM version
Tegen/CAMS CCN	itype_aerosol	2	4	2	2
Use Segal Khain parametrization for the droplets number concentration	icloud_num_type_rad	1	1	2	2
Use constant SGS droplets effective radius	luse_reff_ini_c_as_reffc_sgs	TRUE	TRUE	FALSE	FALSE
Use adiabatic profiles for droplets microphysics in convective SGS clouds	luse_qc_adiab_for_reffc_sgs	FALSE	FALSE	FALSE	TRUE
LWC reduction due to SGS variability	radqcfact [0.4 0.5 0.9]	X	X	X	X
IWC reduction due to SGS variability	radqifact [0.4 0.5 0.9]	X	X	X	X
SGS droplets effective radius	reff_ini_c [3 5 20]·10^{-6}	X	X		
SGS LWC scale factor	qvsatfact_sgscl_rad [0.005 0.01 0.02]	X	X	X	X
Droplets number concentration for radiation	cloud_num_rad [0.5 2 5]·10^{8}	X	X		
SGS droplets effective radius scale of adiabatic profile	reff_avg_fact [0.5 0.9 1]				X
SGS droplets concentration scale of adiabatic profile (clouds dilution)	qnc_avg_fact [0.1 0.38 1]				X

Optimal parameters - CMSAF

	Basic	CAMS	SK basic	SK-SAM
radqcfact	0.739	0.497	0.471	0.483
	0.474	0.5	0.478	0.515
	0.528	0.5	0.475	0.478
	0.61	0.52	0.471	0.496
radqifact	0.506	0.488	0.493	0.482
	0.485	0.488	0.484	0.859
	0.484	0.494	0.495	0.486
	0.493	0.497	0.506	0.489
reff_ini_c (*10^{-6})	6.458	5.714		
	5.971	5.635		
	5.409	5.415		
	5.265	5.484		
qvsatfact _sgscl_rad	0.008	0.013	0.017	0.016
	0.014	0.012	0.017	0.01
	0.011	0.011	0.016	0.017
	0.009	0.011	0.017	0.01
cloud_num_rad (*10^{8})	1.591	1.089		
	1.273	1.063		
	1.082	1.079		
	1.186	1.011		
reff_avg_fact				0.932
				0.93
				0.941
				0.933
qnc_avg_fact				0.325
				0.404
				0.35
				0.823

Optimal parameters - RADSFC

	Basic	CAMS	SK basic	SK-SAM	
radqcfact	0.7	0.598	0.479	0.724	Feb. 2016
	0.471	0.478	0.479	0.735	Apr. 2016
	0.735	0.471	0.485	0.517	Jun. 2016
	0.476	0.534	0.474	0.507	Sep. 2016
radqifact	0.532	0.506	0.485	0.479	Feb. 2016
	0.493	0.508	0.477	0.489	Apr. 2016
	0.497	0.483	0.868	0.5	Jun. 2016
	0.482	0.528	0.515	0.479	Sep. 2016
reff_ini_c (*10^{-6})	6.257	5.512			Feb. 2016
	6.08	5.695			Apr. 2016
	6.084	5.545			Jun. 2016
	6.667	5.56			Sep. 2016
qvsatfact _sgscl_rad	0.008	0.009	0.017	0.008	Feb. 2016
	0.015	0.015	0.017	0.009	Apr. 2016
	0.009	0.014	0.016	0.015	Jun. 2016
	0.017	0.009	0.018	0.01	Sep. 2016
cloud_num_rad (*10^{8})	1.211	0.979			Feb. 2016
	1.36	1.211			Apr. 2016
	1.422	1.228			Jun. 2016
	1.518	1.087			Sep. 2016
reff_avg_fact				0.937	Feb. 2016
				0.913	Apr. 2016
				0.916	Jun. 2016
				0.931	Sep. 2016
qnc_avg_fact				0.372	Feb. 2016
				0.384	Apr. 2016
				0.331	Jun. 2016
				0.838	Sep. 2016

Entire period (4 month)

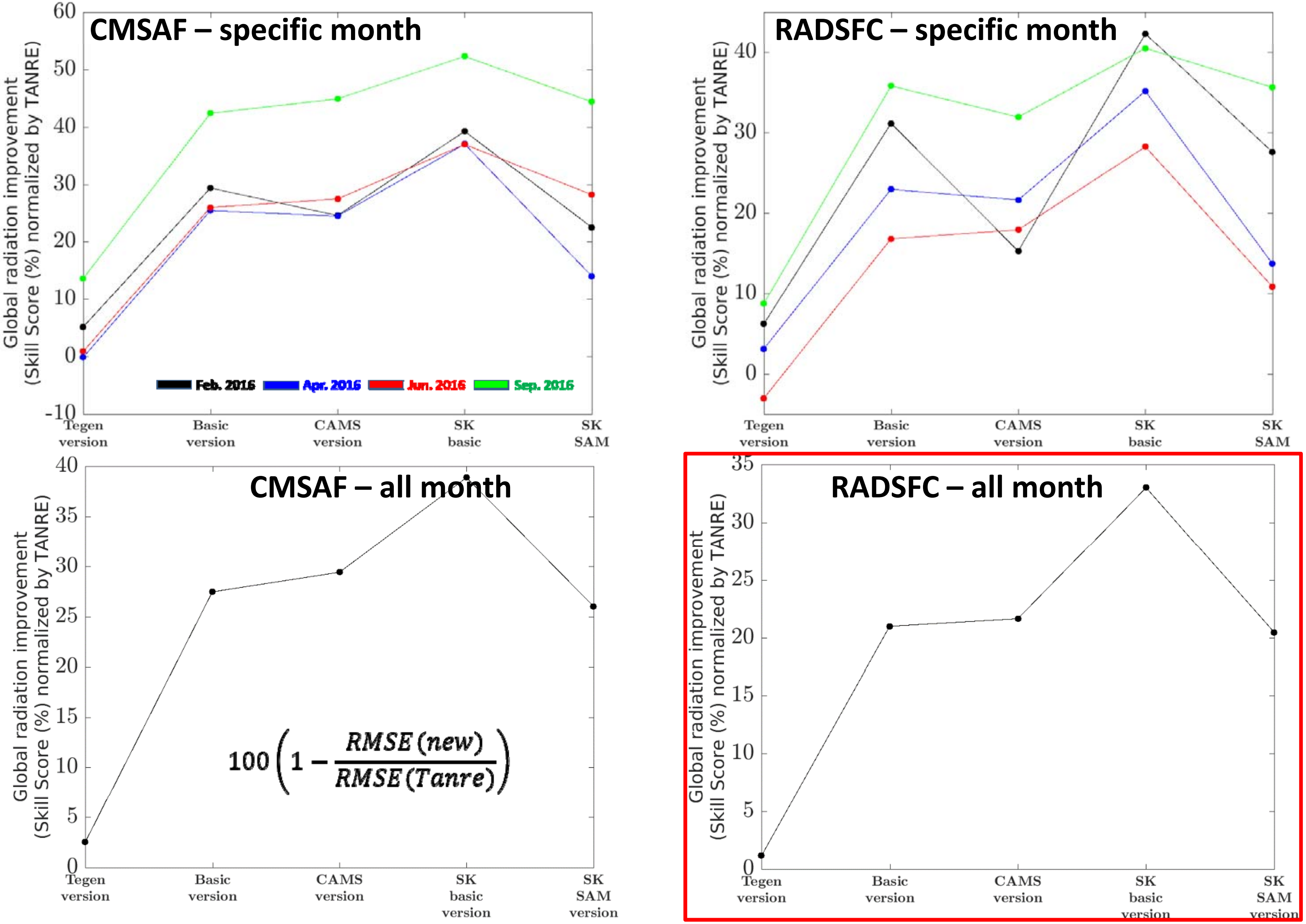
Optimal parameters - CMSAF

	Basic	CAMS	SK basic	SK-SAM
radqcfact	0.52	0.497	0.471	0.478
radqifact	0.482	0.492	0.489	0.483
reff_ini_c (*10^{-6})	5.432	5.491		
qvsatfact_sgscl_rad	0.011	0.012	0.016	0.017
cloud_num_rad (*10^{8})	1.089	1.058		
reff_avg_fact				0.934
qnc_avg_fact				0.352

Optimal parameters - RADSFC

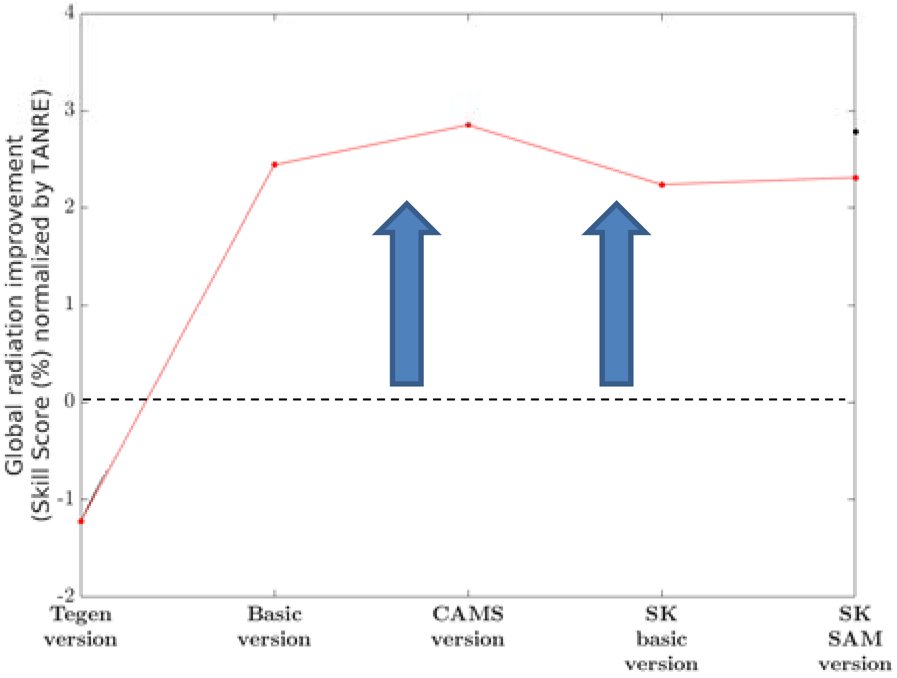
	Basic	CAMS	SK basic	SK-SAM
radqcfact	0.712	0.475	0.483	0.493
radqifact	0.498	0.489	0.501	0.496
reff_ini_c (*10^{-6})	5.955	5.618		
qvsatfact_sgscl_rad	0.009	0.014	0.017	0.018
cloud_num_rad (*10^{8})	1.317	1.191		
reff_avg_fact				0.926
qnc_avg_fact				0.369

Improvement for “tunable” cases only

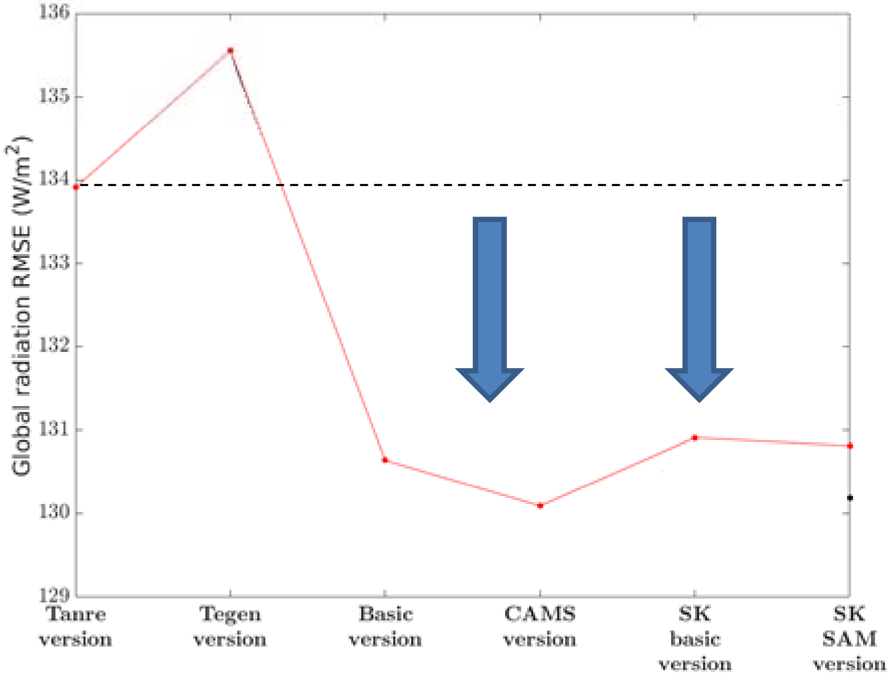


Improvement for all the cases

$$100\left(1-\frac{RMSE(new)}{RMSE(Tanre)}\right)$$



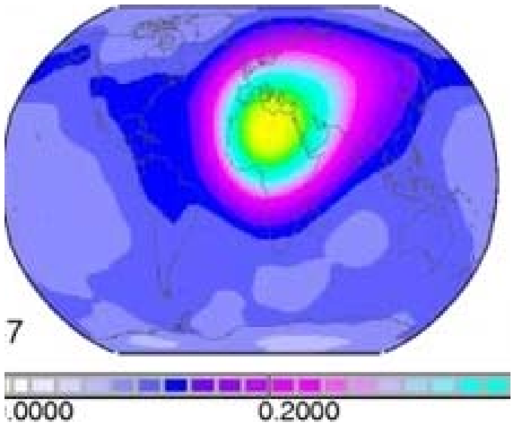
$$RMSE(new)$$



Aerosols input for COSMO radiation

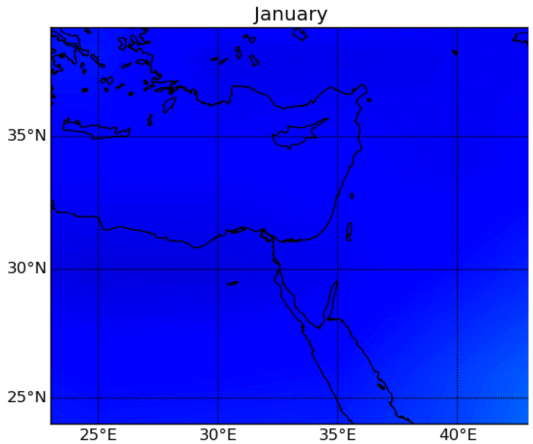
Tanre (1983)

itype_aerosol = 1



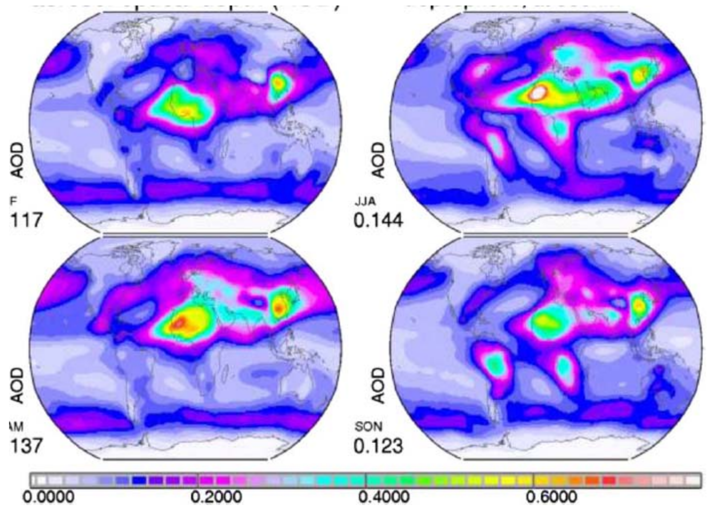
Tegen (1997)

itype_aerosol = 2



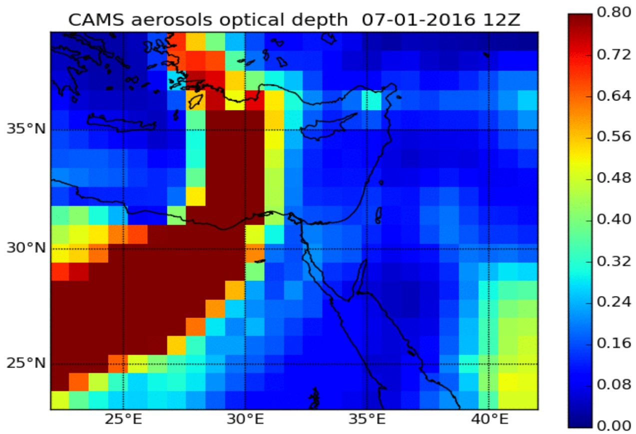
MACv2 - Kinne (2013)

itype_aerosol = 3



CAMS-ECMWF

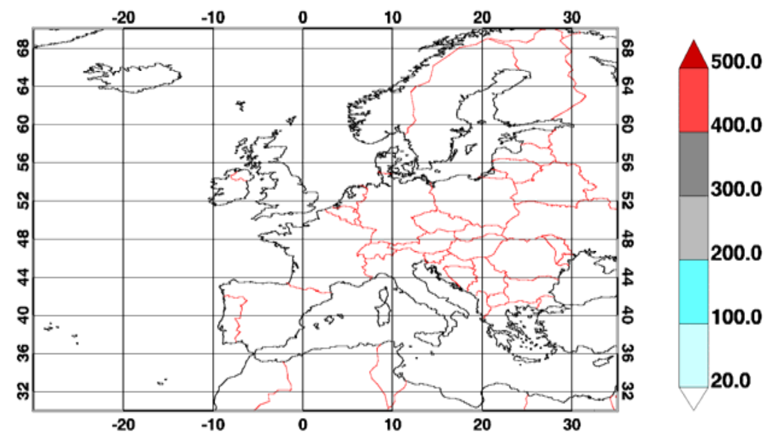
itype_aerosol = 4



ICON-ART

2010041400 UTC + 0 h
mean: 0.00 std: 0.00 min: 0.00 max: 0.00

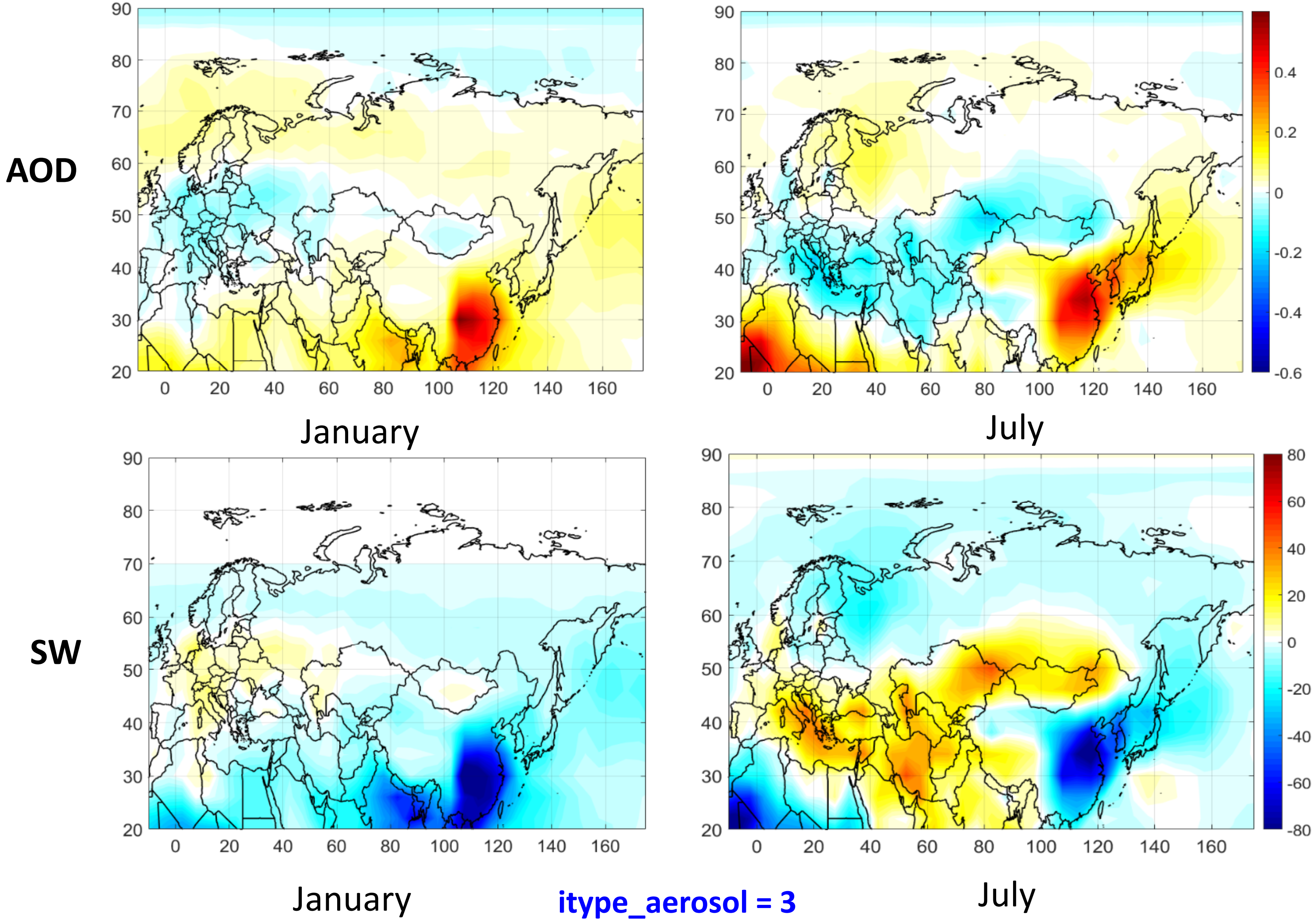
itype_aerosol = 5




Tiksi
Lindenberg
Moscow
Bet-Dagan- Nes_Ziona
Eilat-Yotvata

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

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

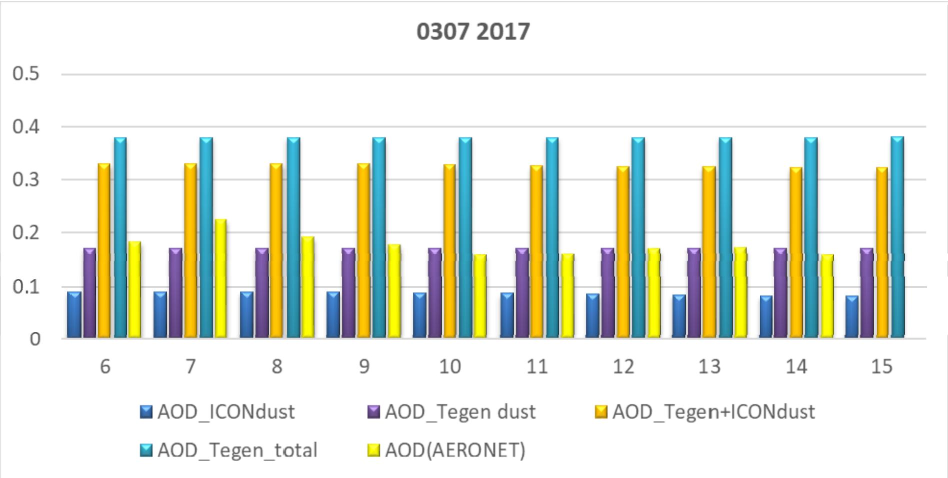


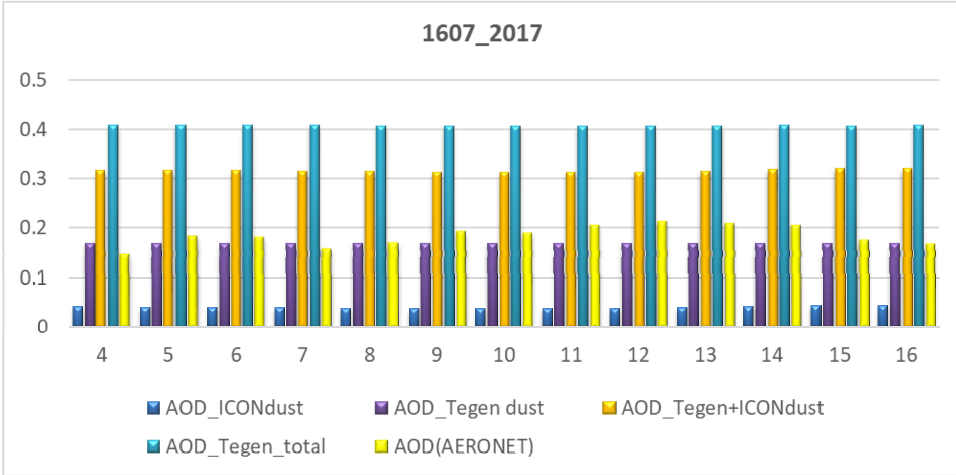
itype_aerosol = 3

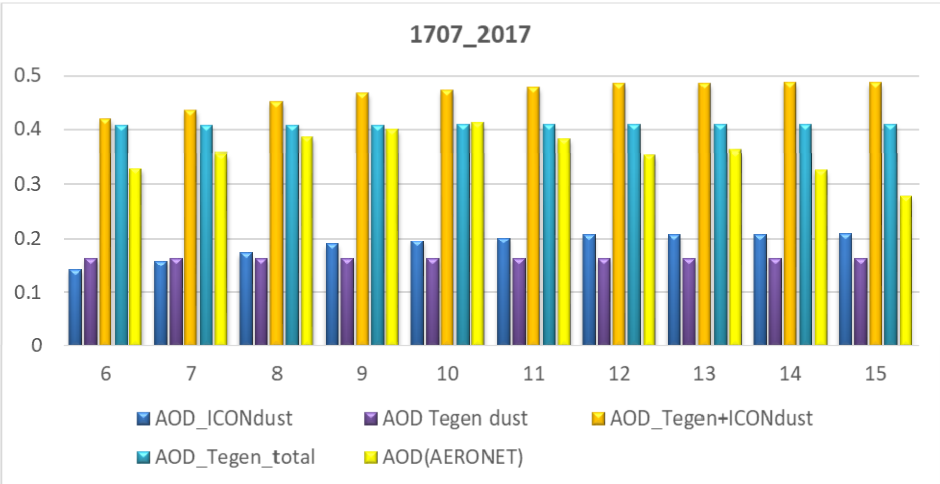
ICON-ART-dust
New Aerosols input for COSMO radiation

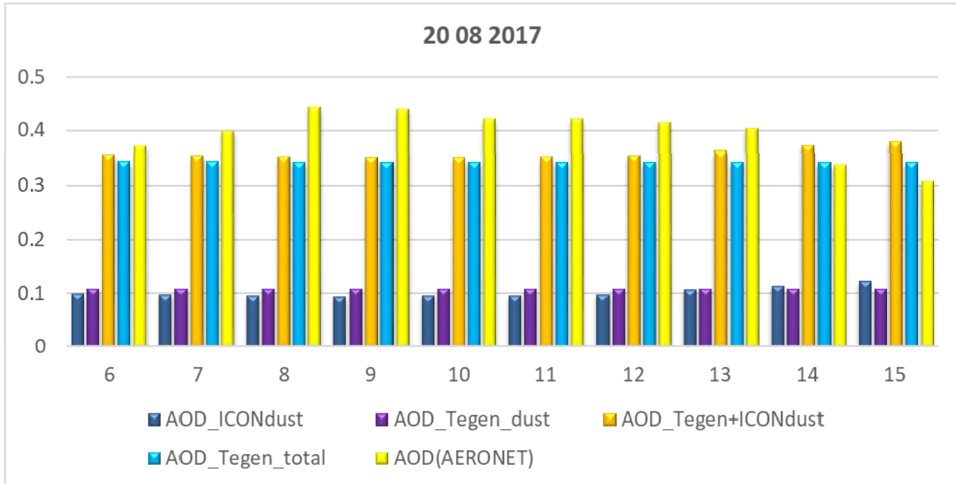
itype_aerosol = 5

Aerosols dust OD: ICON , Tegen
Aerosols AOD: ICONdust+Tegen, Tegen , AERONET
Nes-Tziona. Clear skies



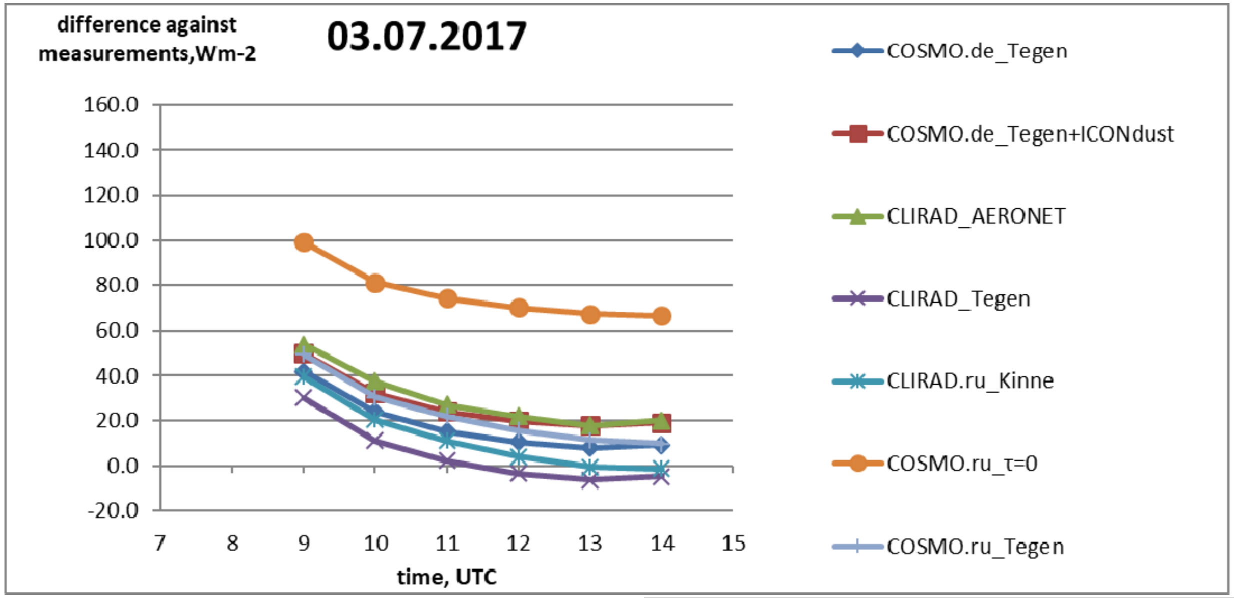


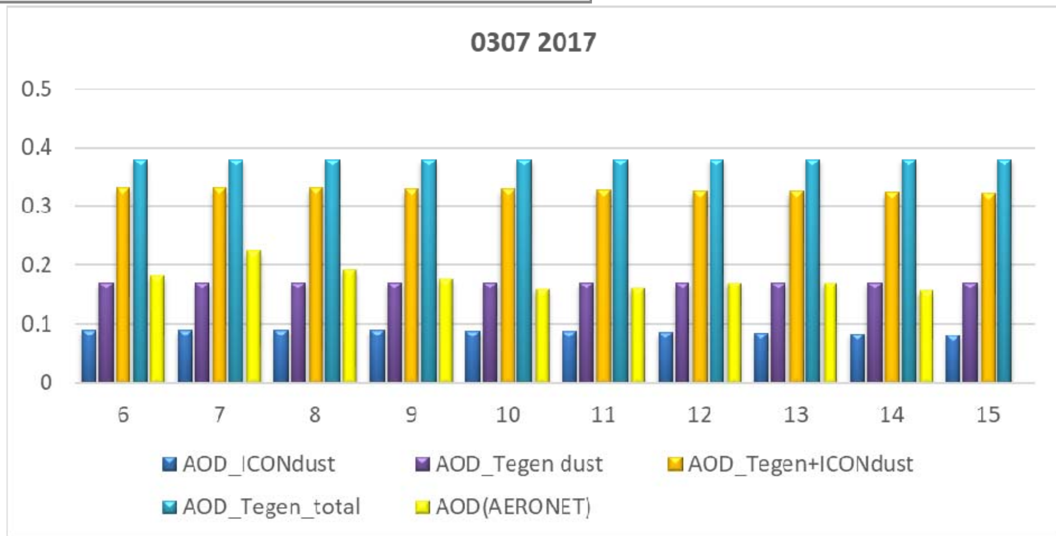




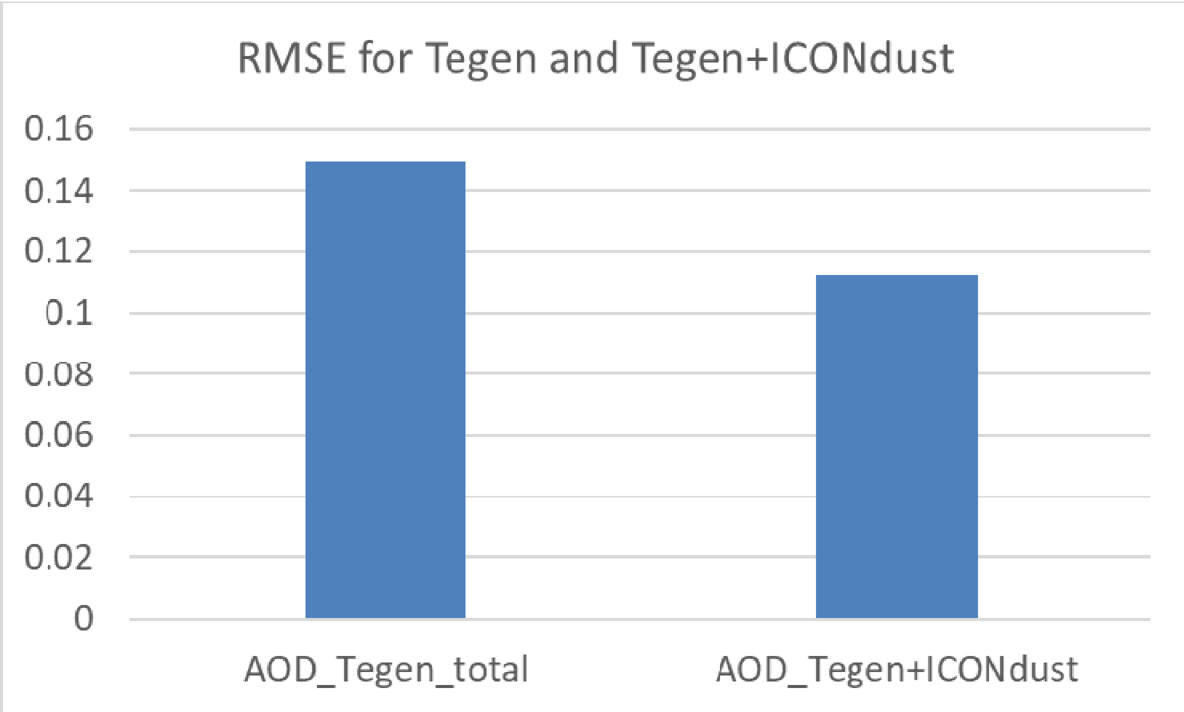
Model global irradiance bias Clear sky conditions

Difference = Q_{model}-$Q_{measurements}$

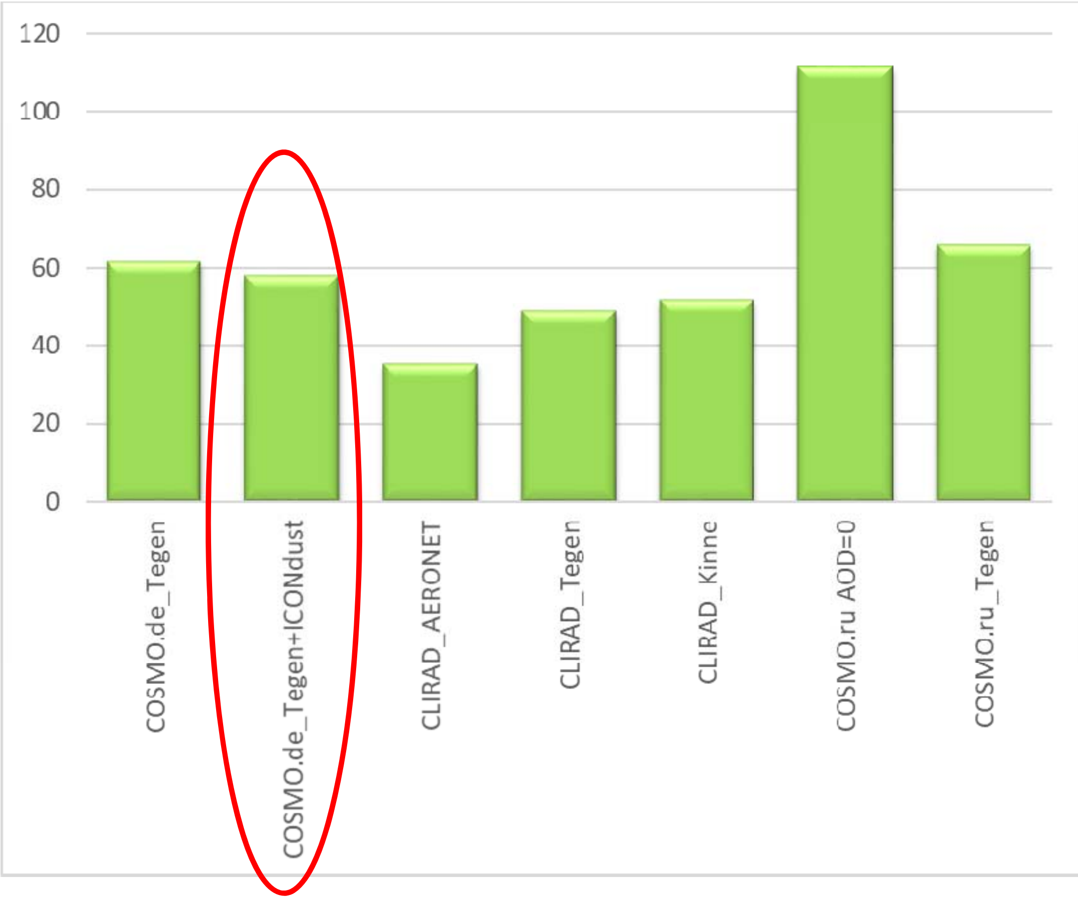




AOD RMSE for Tegen vs. (Tegen+ICON dust) against AERONET measurements

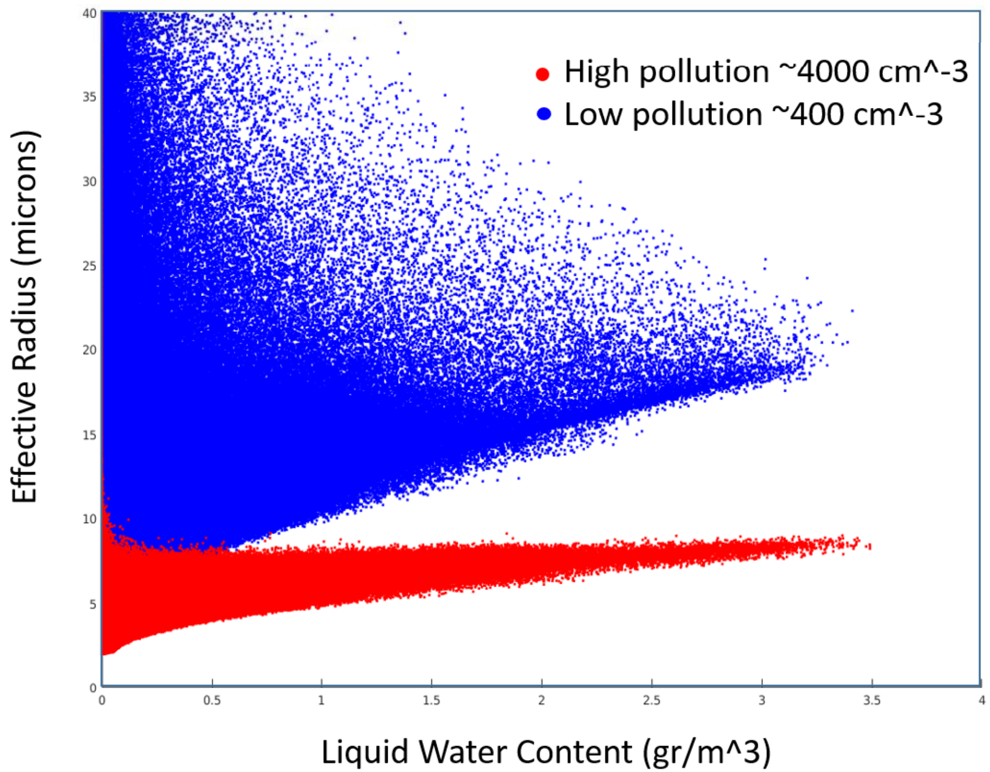


Global radiation RMSE (W/m^2) against meas. in Nes-Tziona



Prognostic Aerosols in COSMO Microphysics

Motivation - radiation



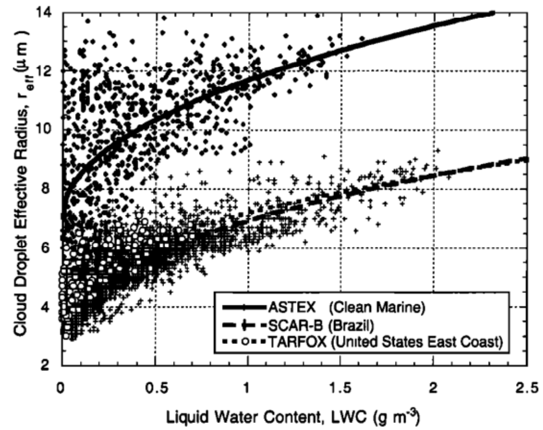


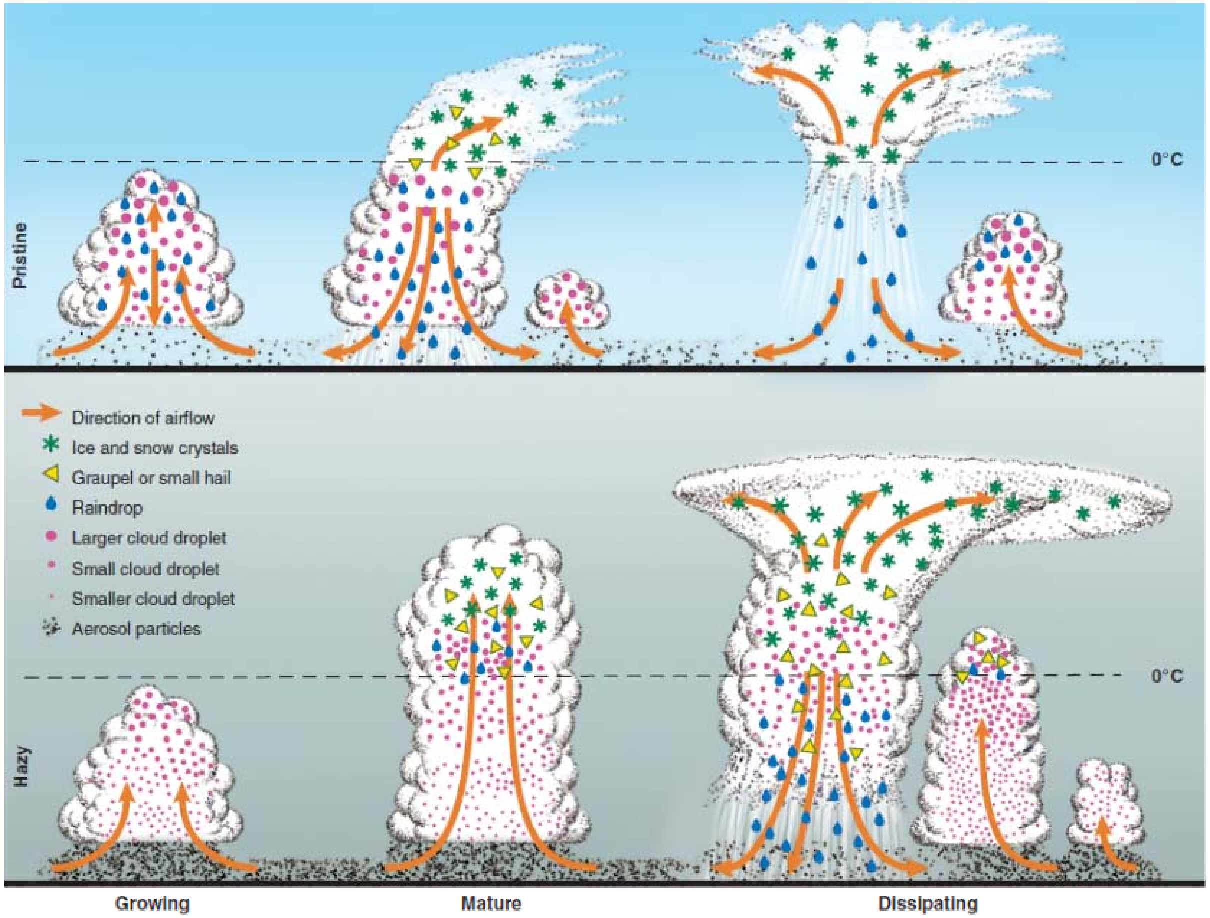
Figure 6. Cloud droplet effective radius (r_{eff}) versus liquid water content (LWC) for cumulus clouds in clean marine air over the northeastern Atlantic Ocean (diamonds, Atlantic Stratocumulus Transition Experiment (ASTEX)), in urban-industrial air off on the U.S. east coast (circles, Tropospheric Radiative Forcing Experiment (TARFOX)), and in air masses dominated by smoke from biomass burning (pluses, Brazil).

- Effective radius in RG92 default version: $R_{eff} = c_7 + c_8\rho^{LW}$

Motivation – clouds formation & precipitation

Pristine tropical clouds with low CCN concentration can rain out too quickly to mature to long lived clouds

Polluted clouds with very high CCN concentrations may evaporate before rain can occur



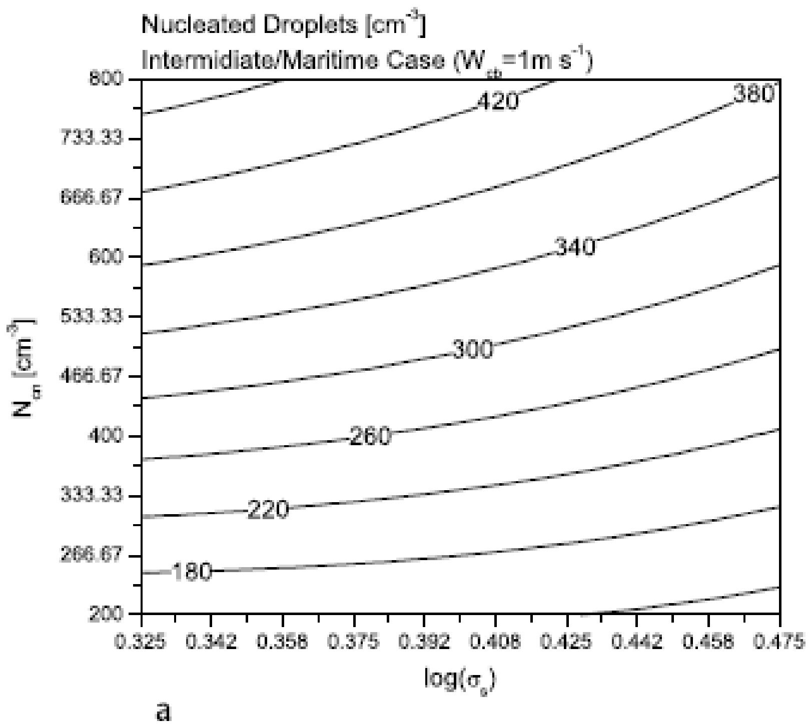
Rosenfeld et al., Science, 321 , 2008

- Cloud droplets number concentration in the default COSMO 1-mom scheme is fixed to **cloud_num** (500 cm^{-3}) effects the auto conversion process

Segal & Khain scheme in COSMO

- Cloud nuclei profile $n_{CN}(z)$ is estimated from Tegen climatology (Uli B.)
- Now also CAMS prognostic aerosols are available
- Activation of n_{CN} to n_{CCN} is estimated from Segal & Khain (2006) 4D look-up table:

$$n_{ccn}^{SK} = f(n_{cn}, log(\sigma), r_{mod}, w_{nuc,CB})$$



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

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

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

(W* - convective velocity scale after Deardorff)

Segal & Khain (2006)

Implications for radiation & microphysics

Radiation: Reff of cloud droplets based on qnc :

- **icloud_num_type_rad = 1**
  $n_C(z)$ has assumed exponentially decreasing vertical profile above z_0
- **icloud_num_type_rad = 4 : CAMS + SK**

$$R_e = c_1 \left(\frac{q_C}{n_C}\right)^{c_2}$$

Number concentration of cloud droplets in 1-mom scheme:

➔ **icloud_num_type_gscp = 1**

- Cloud number concentration is a tuning parameter **cloud_num**

  default: 500 cm^{-3}

➔ **icloud_num_type_gscp = 4 CAMS + SK**

➔ The new cloud_num (qnc) effects the 1-mom via the auto-conversion parameterization (cloud water → rain water):

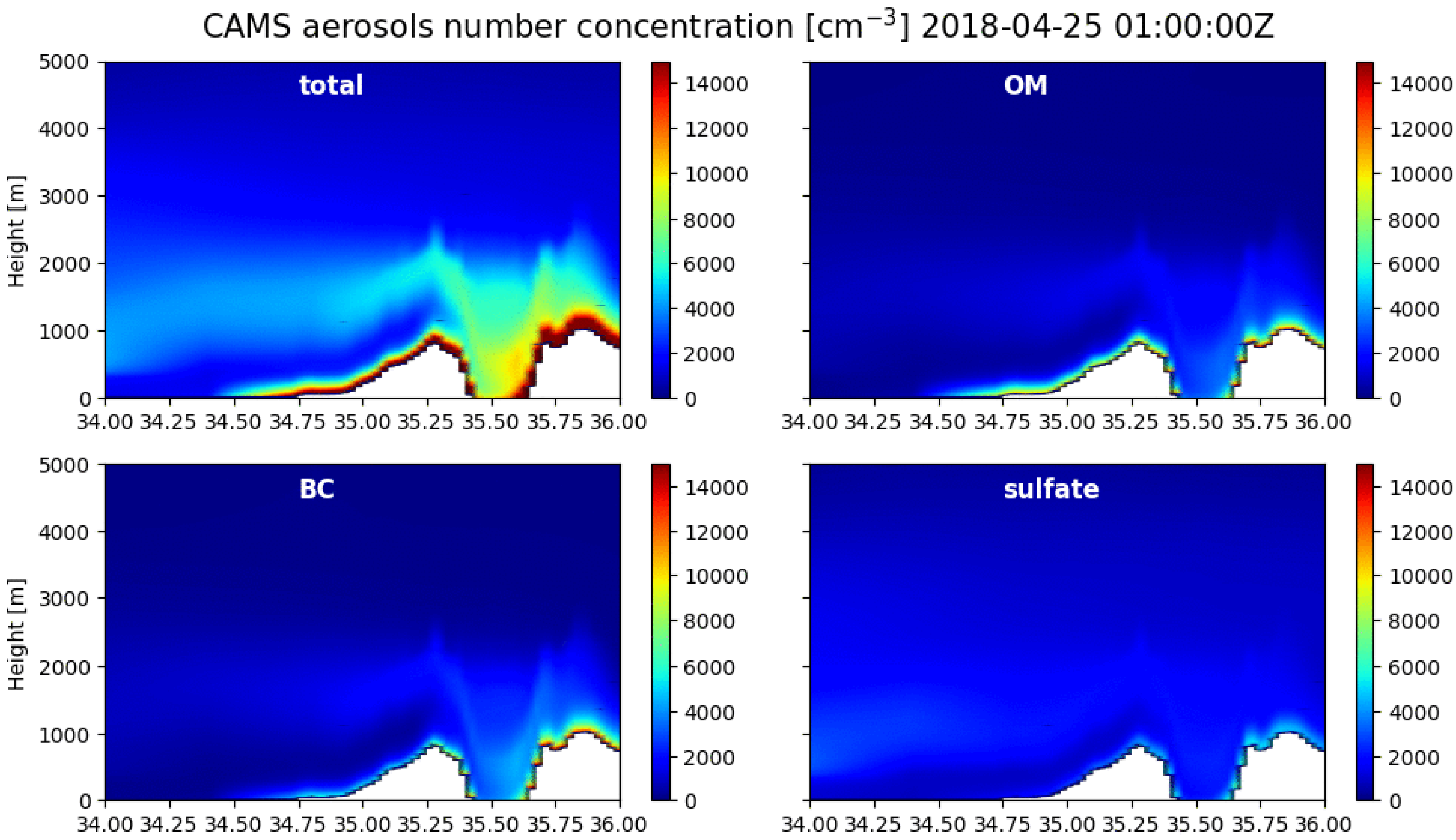
$$\frac{d(qc)}{dt} \sim -\frac{qc^4}{qnc^2} = -\frac{qc^2}{xc^2} \quad (xc = \text{mean droplet mass})$$

CAMS prognostic aerosols

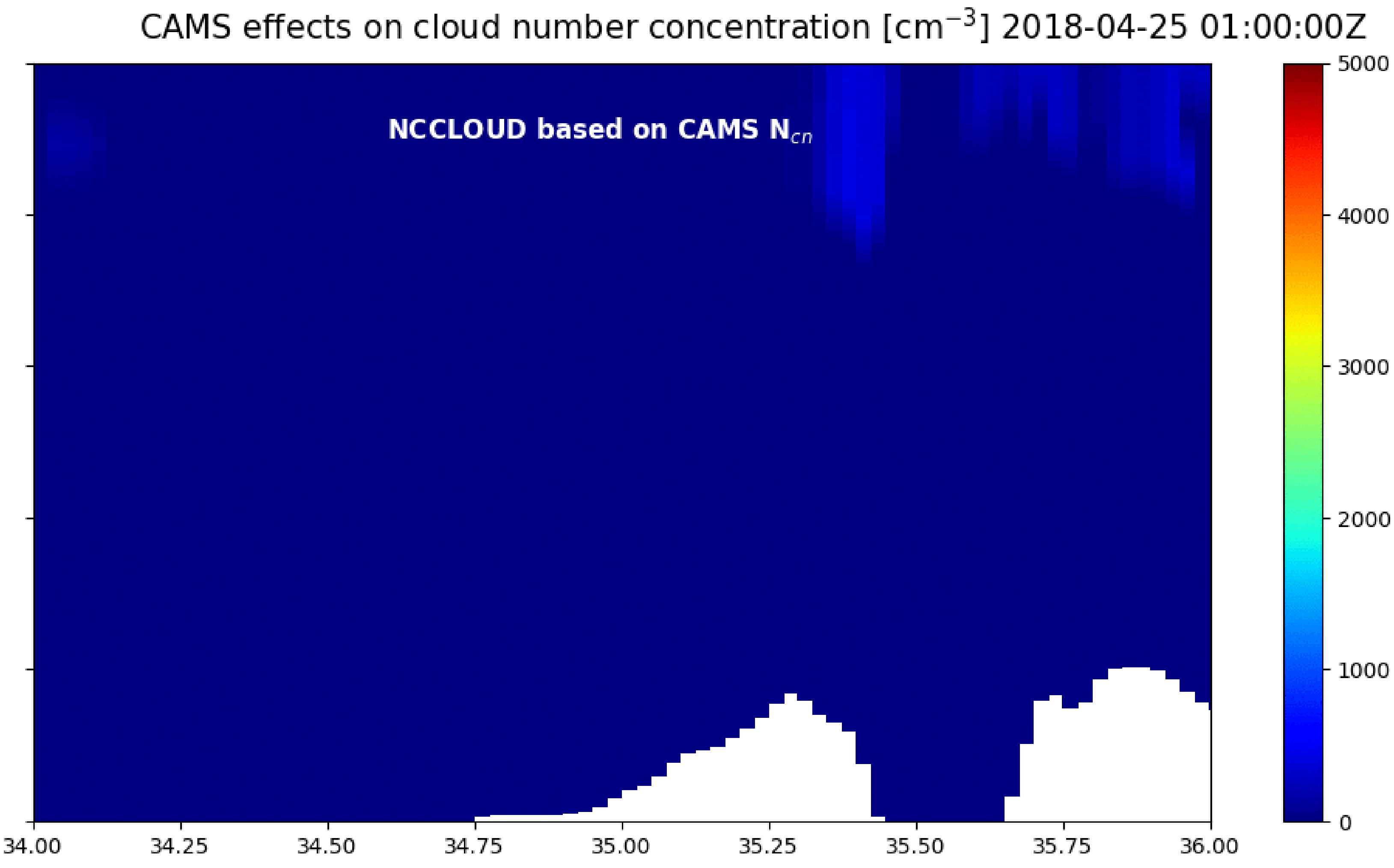
- 3D mixing ratios of 11 aerosols tracers
- 5 days forecast range, 1Hr output resolution based on IFS model with 60 levels
- Data assimilation based on varios data sets
- Using itype_aerosol = 4 effective in radiation

Aerosol type	size bin limits (sphere radius, μm)	Refr. index source	ρ (kg/m^3)	r_{mod} (μm)	σ
Sea Salt* (80% RH)	0.03-0.5 0.5-5.0 5.0-20	OPAC	1.183e3	0.1992,1.992	1.9,2.0
Dust	0.03-0.55 0.55-0.9 0.9-20	Dubovik et al. 2002/ Woodward et al. 2001/ Fouquart et al. 1987	2.61e3	0.29	2.0
Black carbon	0.005-0.5	OPAC (SOOT)	1.0e3	0.0118	2.0
Sulfates	0.005-20	Lacis et al. (GACP)	1.76e3	0.0355	2.0
Organic matter$^+$	0.005-20	WASO+ OPAC INSO+ SOOT	1.8e3 2.0e3 1.0e3	0.0212 0.471 0.0118	2.24 2.51 2.00

CAMS aerosols number concentration

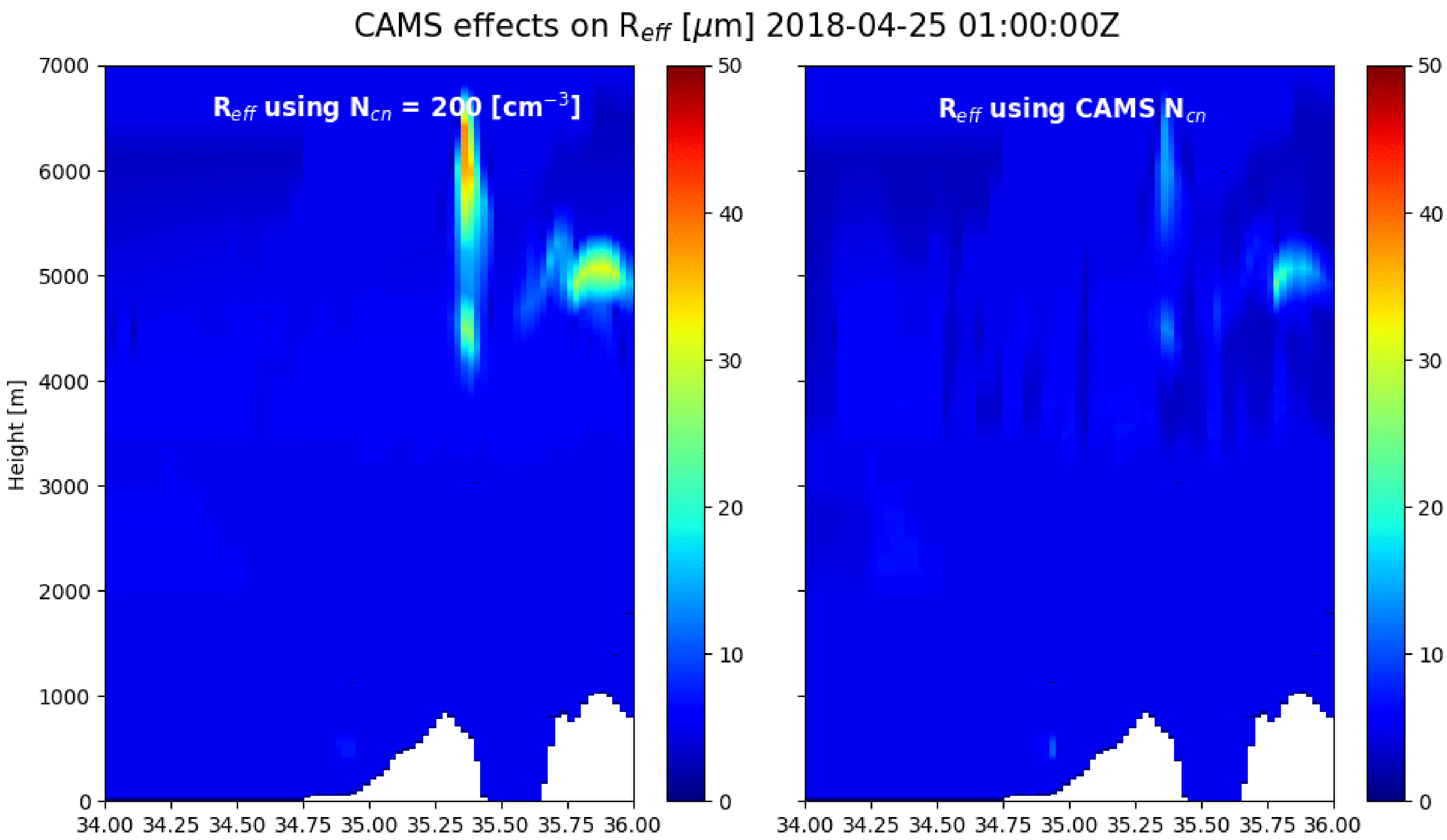


New cloud droplets number concentration



icloud_num_type_gscp/rad = 4

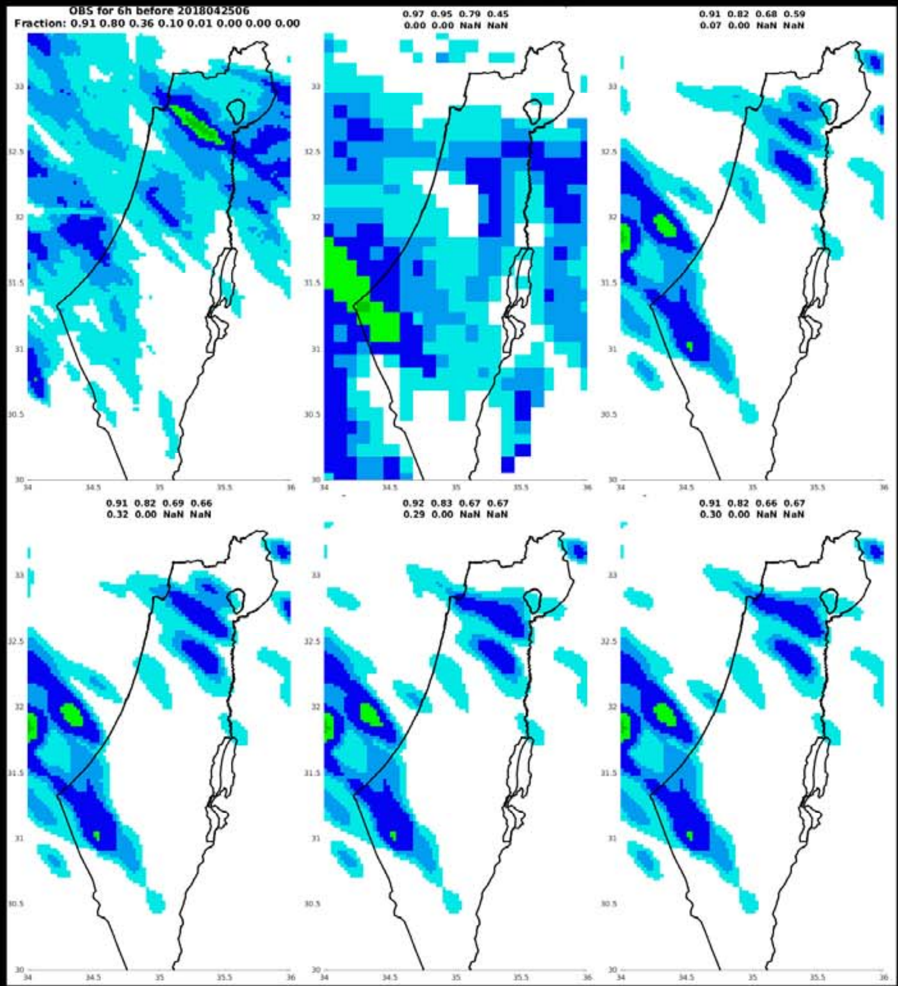
R_{eff} based on CAMS & Segal and Khain



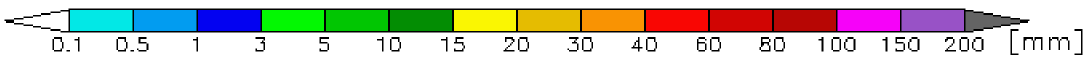
icloud_num_type_rad = 1 **icloud_num_type_rad = 4**

Case study: April 25-27, 2018

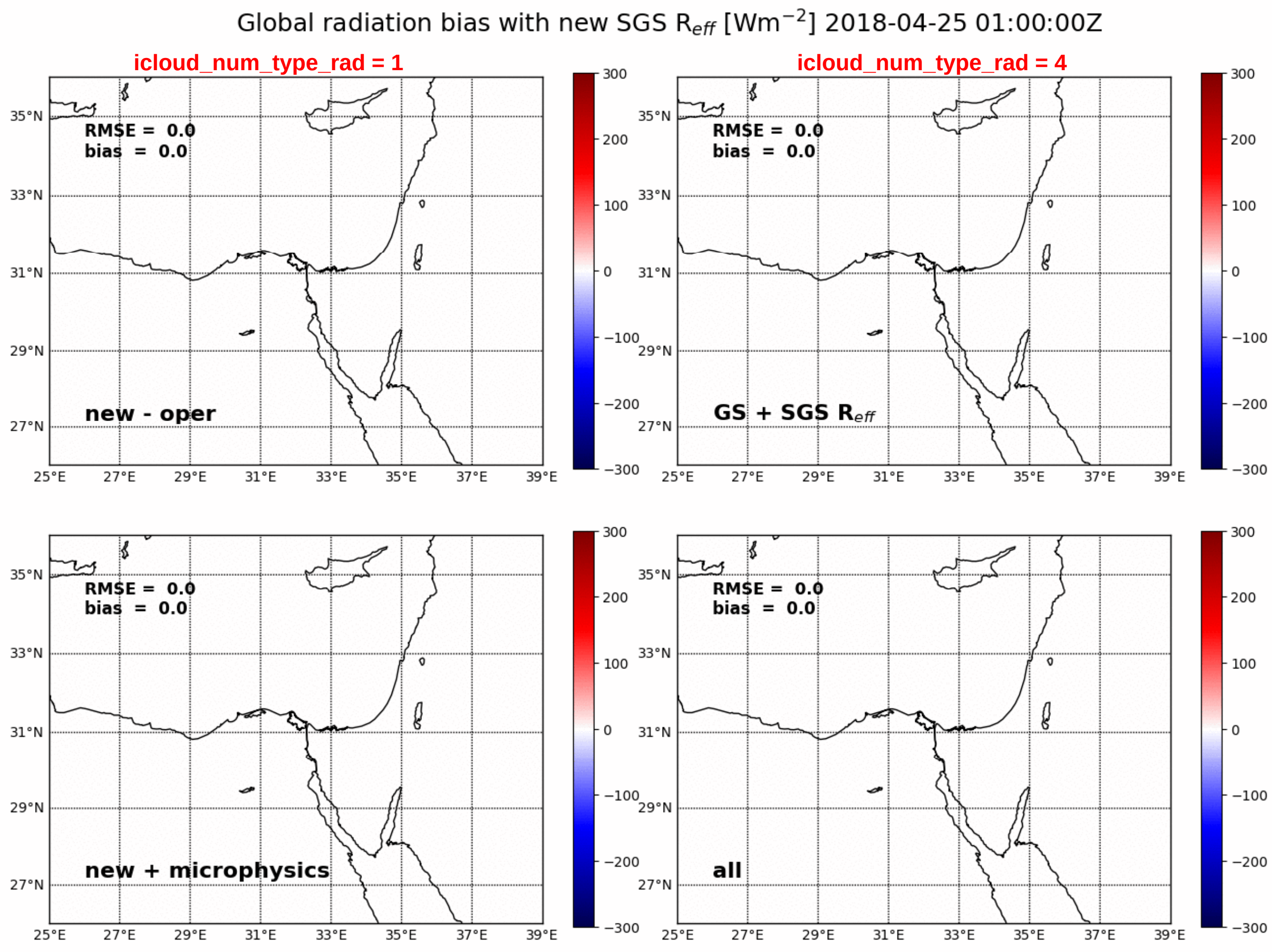
OBS EC COSMO oper



C-CAMS icloud_num_type_gscp=4 icloud_num_type_gscp+rad=4



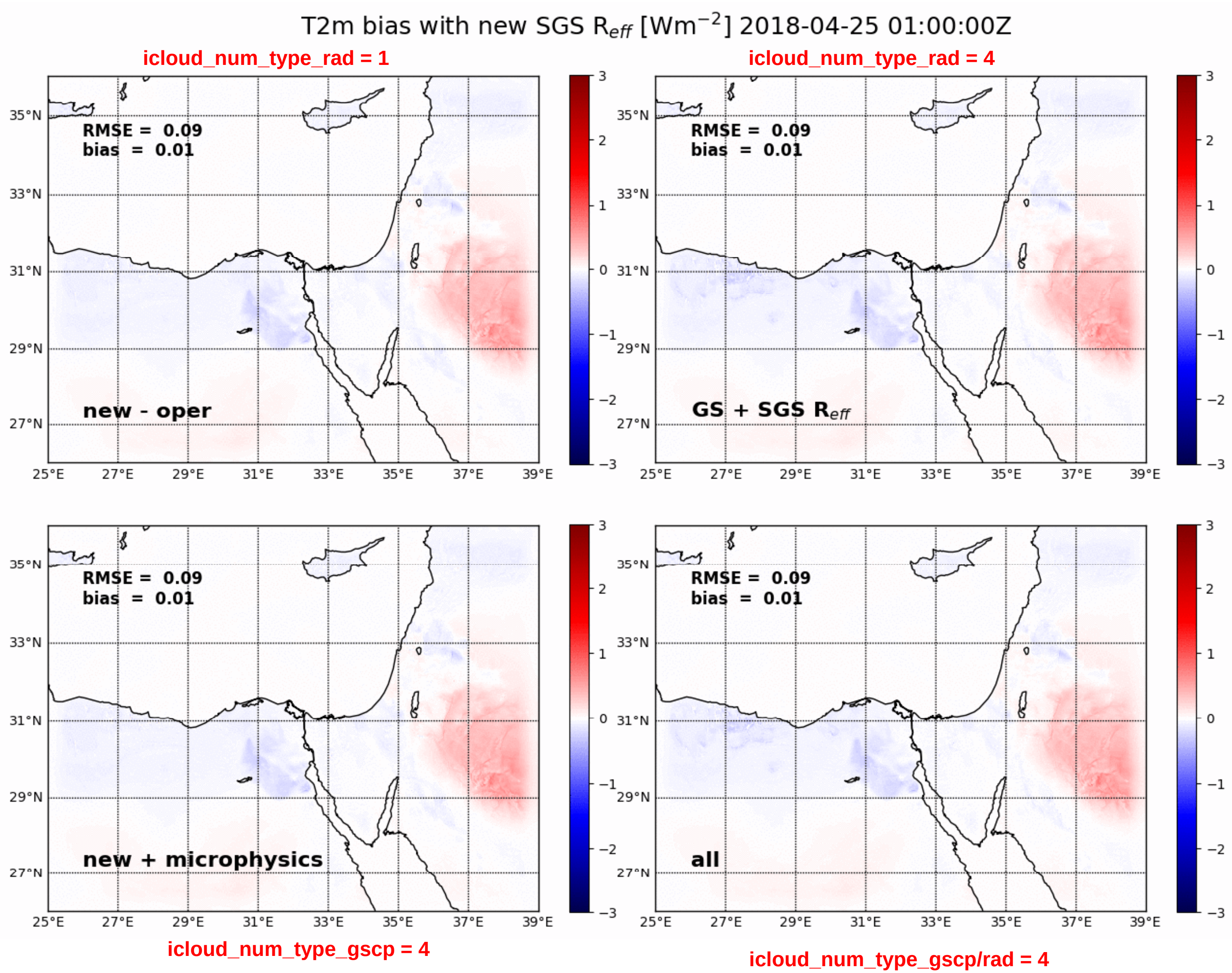
Impact on radiation



icloud_num_type_gscp = 4

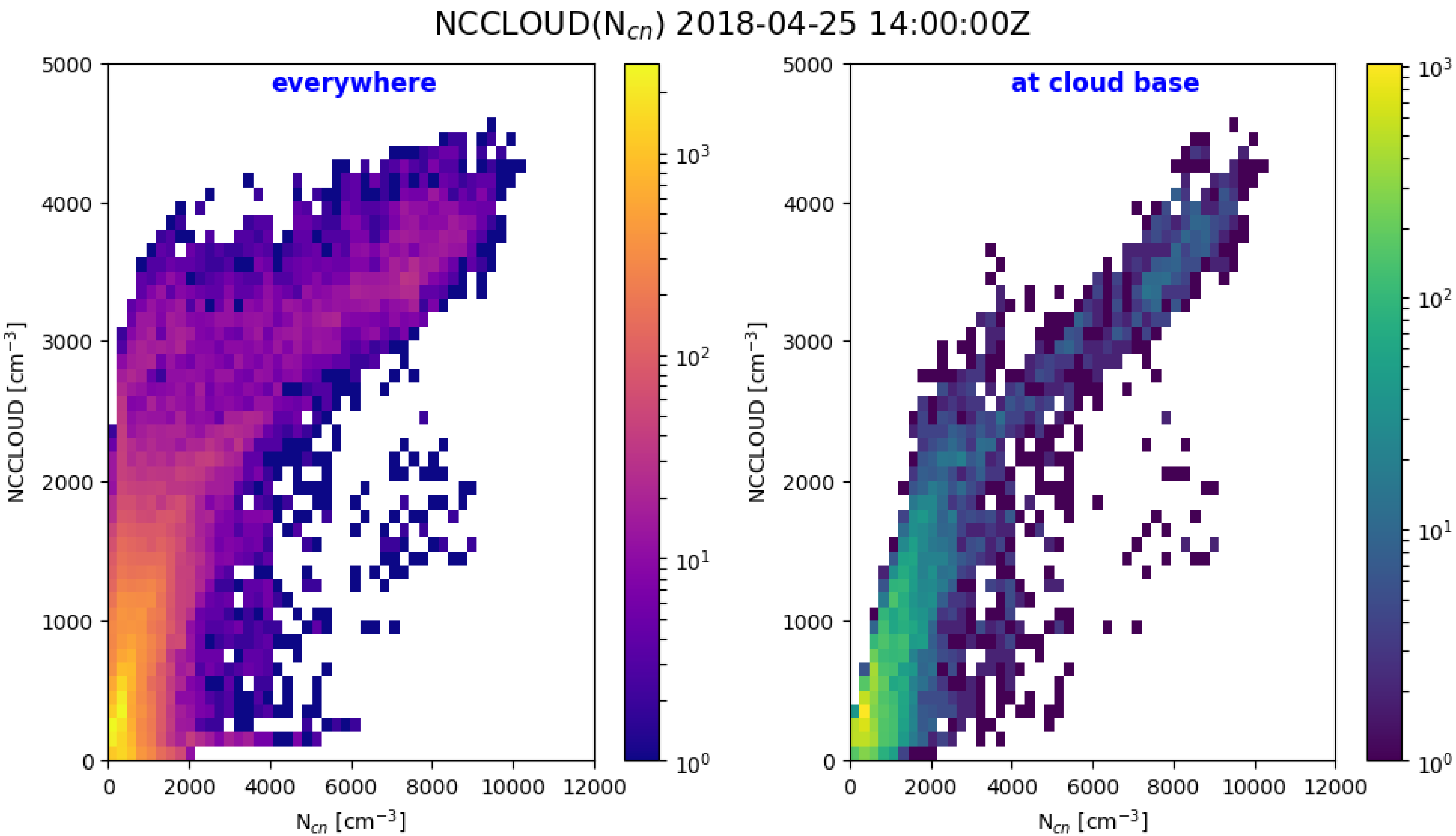
icloud_num_type_gscp/rad = 4

Impact on T2m



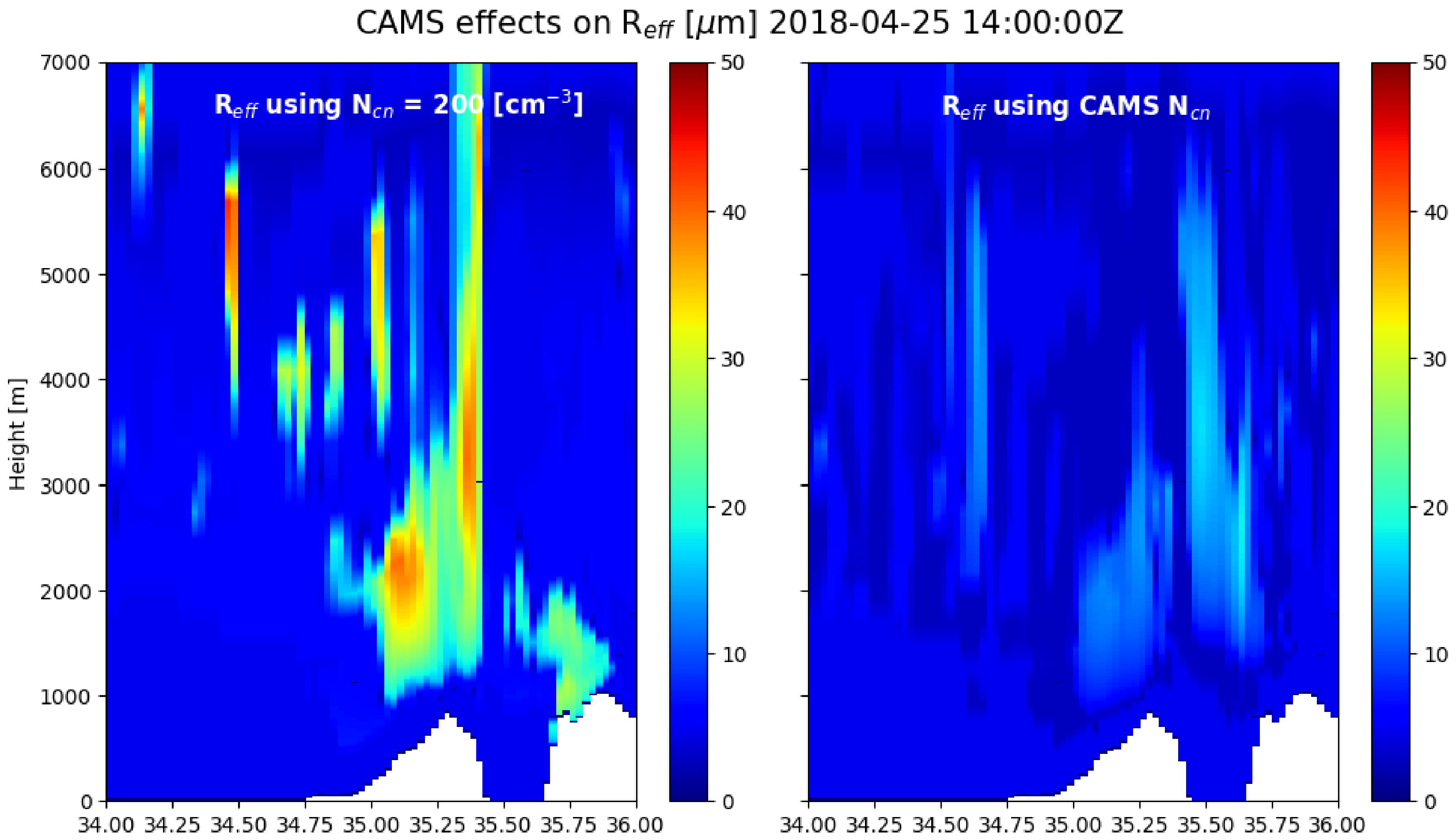
New cloud droplets number concentration

Peak event April 25 14Z



R_{eff} based on CAMS & Segal and Khain

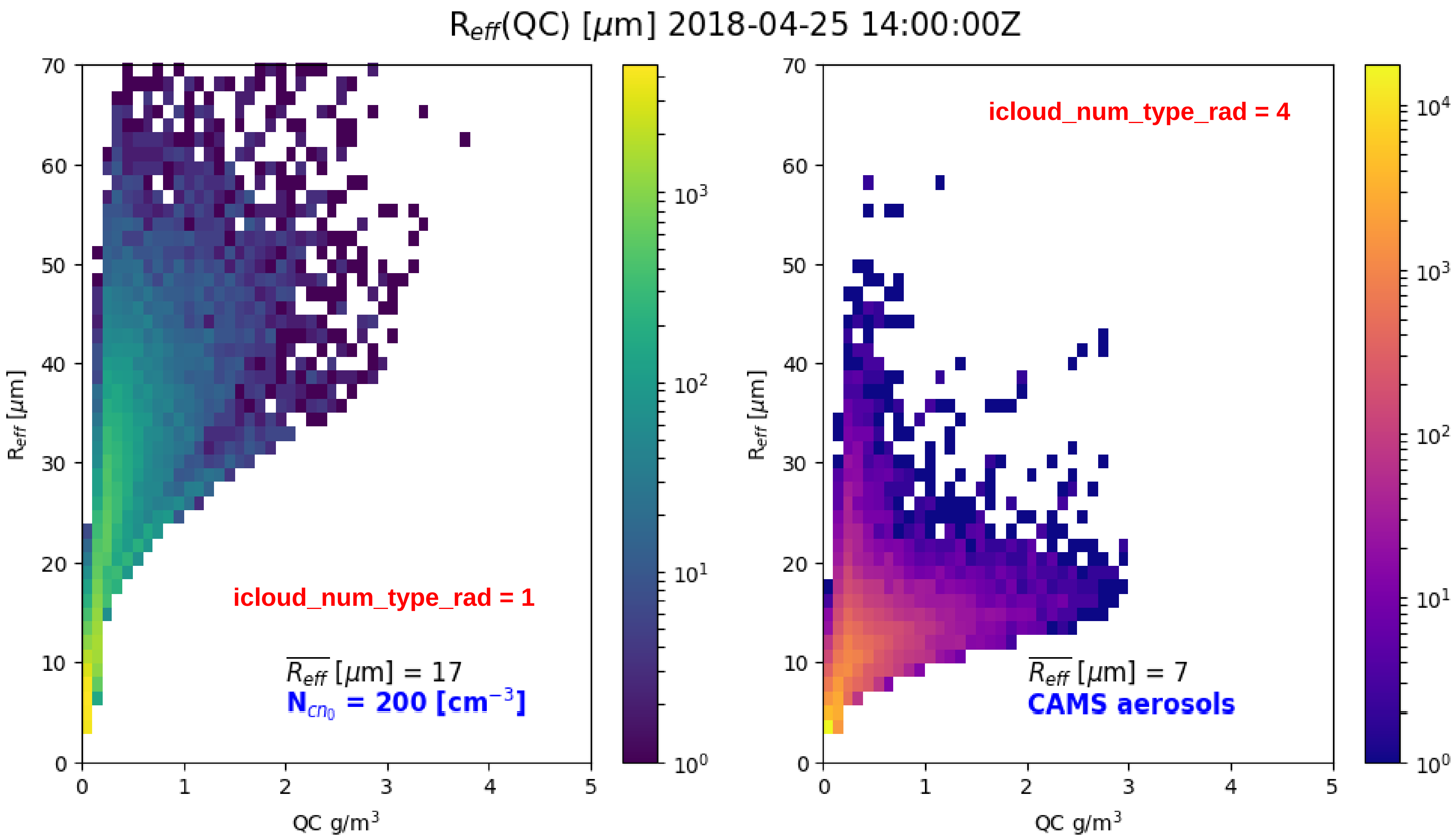
Peak event April 25 14Z



icloud_num_type_rad = 1 **icloud_num_type_rad = 4**

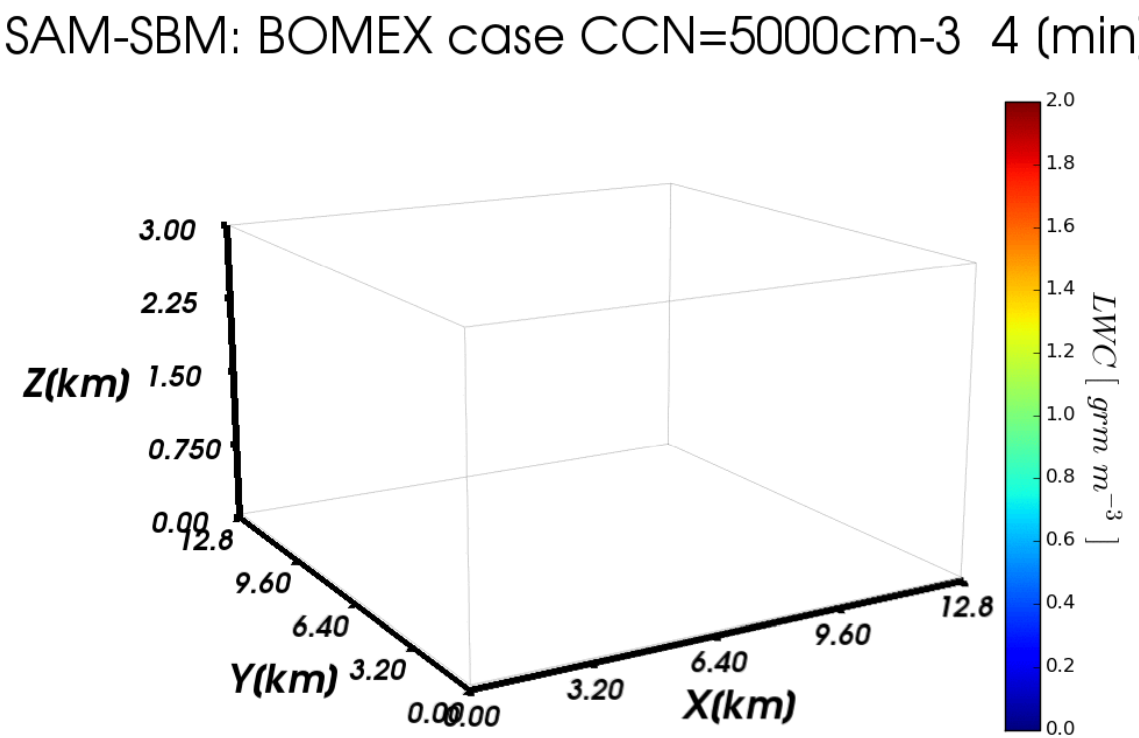
R_{eff} based on CAMS & Segal and Khain

Peak event April 25 14Z



New parametrizations of R_{eff} in SGS Clouds

- icloud_num_type_rad = 1
  - $n_c(z)$ has assumed exponentially decreasing vertical profile above z_o:
  - cloud_num_rad is n_{co} default 200 cm^{-3}
  - dz_oe_cloud_num = $\Delta z_{1/e}$ in [m] (half its value every 8000 m).
  - zref_cloud_num = z_o in [m] (2000 m)
  - $R_{e,c}$ from $n_c(z)$ and $q_c(z)$ resp.

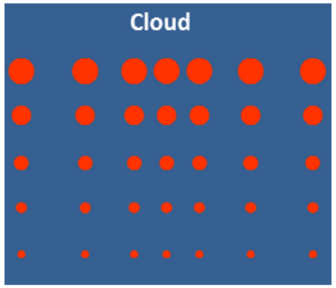


Benchmark test case: Barbados Oceanographic and Meteorological Experiment (BOMEX)

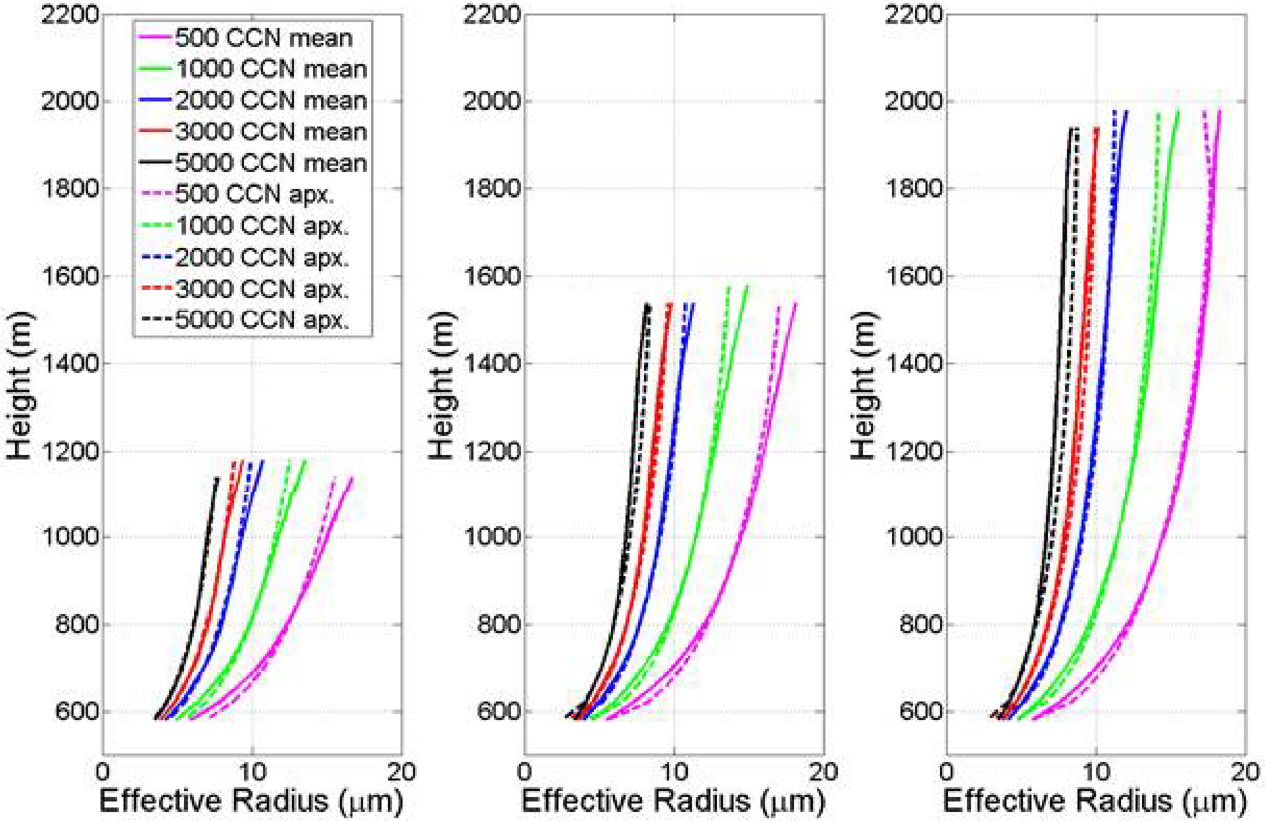
Resolution: horiz. 100m, vertical 40m, time step: 1s, runtime: 8h. Domain: 12.8 X 12.8 X 5.1km

R_{eff} in Sub-Grid Scale Clouds

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



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



Mean R_{eff}

q_c and N_d are highly dispersive but R_e is not! Better get q_c from R_e

~~$\overline{R_e} = c_1 \left(\frac{\overline{q_C}}{\overline{n_C}} \right)^{c_2}$~~

Better calculation

In cloud core below rain formation level and before significant mixing occurs:

$$r_{e\_ad}(z) = 1.15 \cdot r_v = 1.15 \cdot \left(\frac{LWC_{ad}(z)}{\frac{4}{3}\pi \rho_w N_{d\_ad}} \right)^{1/3}$$

Due to rain formation:

$$r_{e_{max}} = \min(22\mu m, r_{e\_ad})$$

From Segal-Khain using CAMS/ART !

The mean eff. radius is slightly smaller:
and deviates with height from the core value due to mixing:

$$\overline{r_e}(z) = \alpha(z) r_{e\max}(z)$$

$$\alpha(z) = 0.95 - 1.2 \cdot 10^{-4}(z - z_{cb})$$

LWC for shallow convection (SGS)

In cloud core: $N_{d\_max}(z) = \begin{cases} N_{d\_ad}, & below\ the\ level\ z_{12}\ , where\ r_{e\_ad} = 12\mu m \\ N_{d\_ad}[1 - \gamma(z - z_{12})], & above\ the\ level\ z_{12} \end{cases}$

Cloud mean: $\overline{N_d}(z) \approx \beta N_{d\_max}(z), \quad \beta = 0.38$

$$\overline{LWC}(z) = \overline{\frac{4}{3}\pi\rho_w N_d(z) r_v{}^3(z)} = \overline{\frac{4}{3}\pi\rho_w N_d(z)\left(\frac{r_e(z)}{1.15}\right)^3}$$

However, since variability of effective radius is low, the last equality can be rewritten as:

$$\overline{LWC}(z) \approx \frac{4}{3}\pi\rho_w \overline{N_d}(z)\left(\frac{\overline{r_e}(z)}{1.15}\right)^3 ,$$

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Optical properties of atmospheric snow in ICON

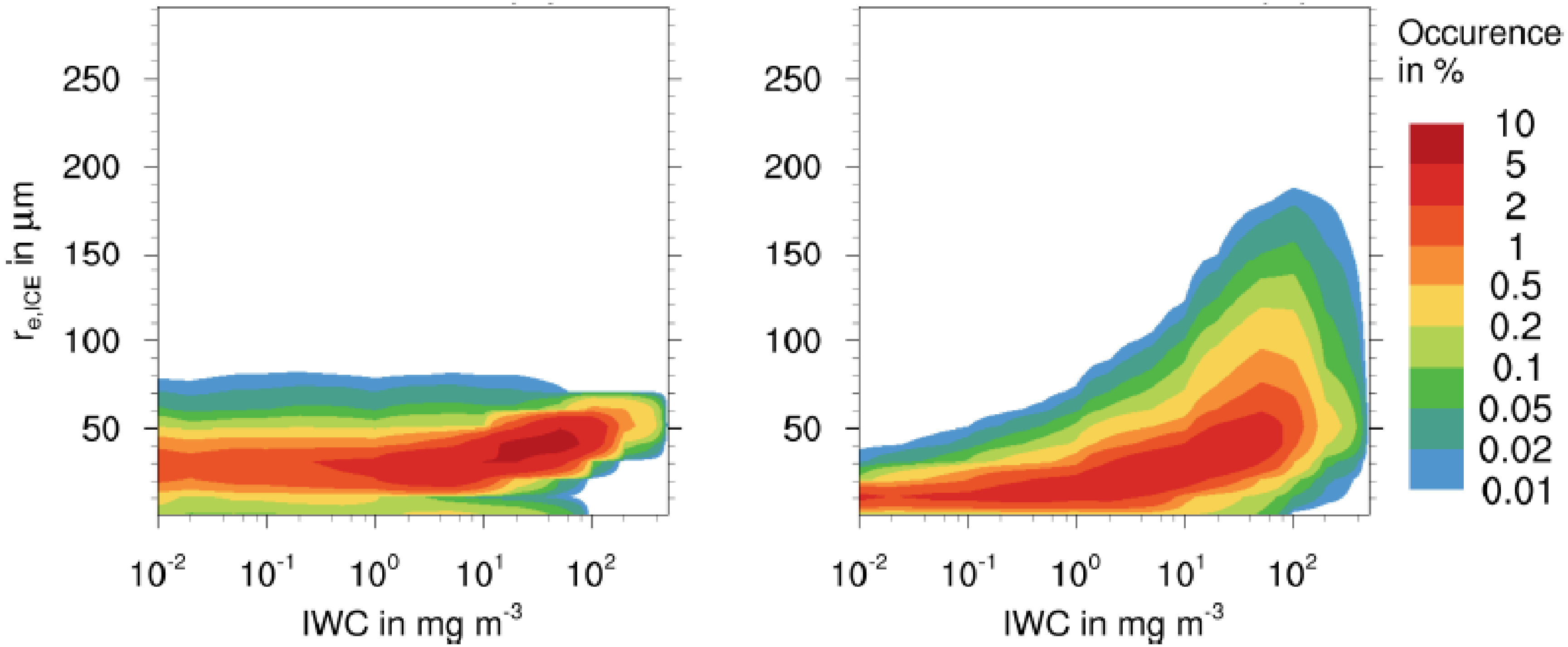
Martin Köhler, Simon Gruber, Uli Blahak, Harel Muskatel, Pavel Khain

DWD, Israel Meteorological Service

Jeff Kubina on Flickr

Optical Properties of Hydrometeors

- old
- new, 2mom

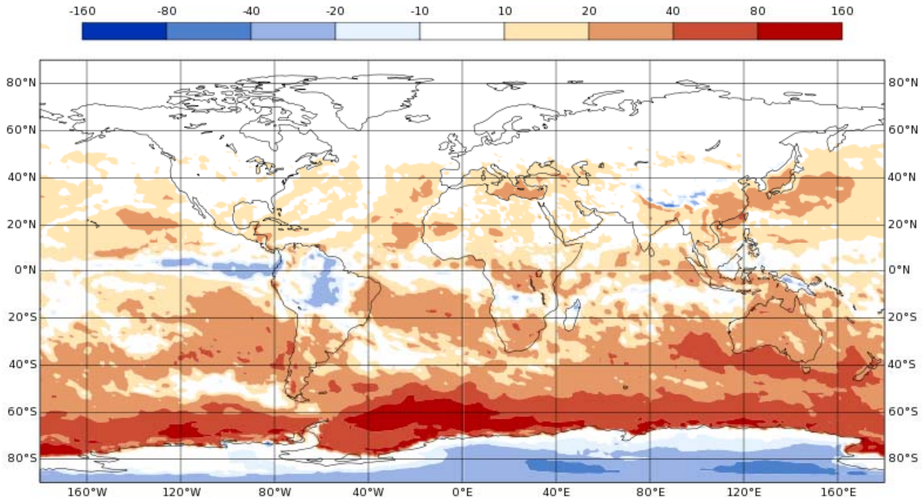


Net top solar Jan2012

default

ICONdefault - CERES

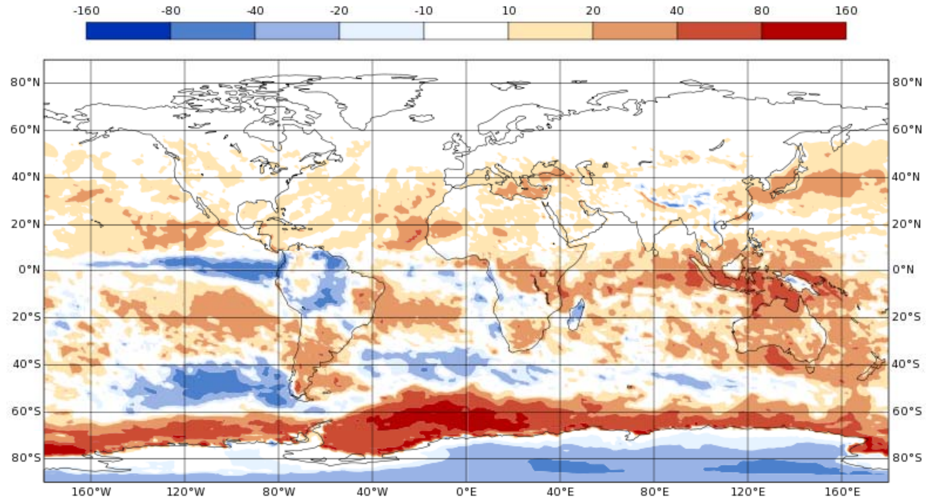
bias: 16.2 W/m^2



New

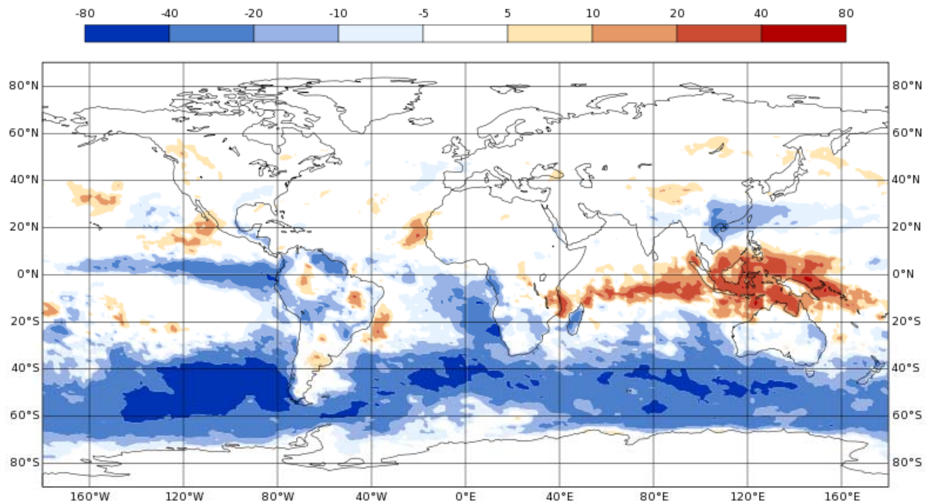
new-optic - CERES

bias: 9.9 W/m^2



new-optic - ICONdefault

diff: - 6.3 W/m^2

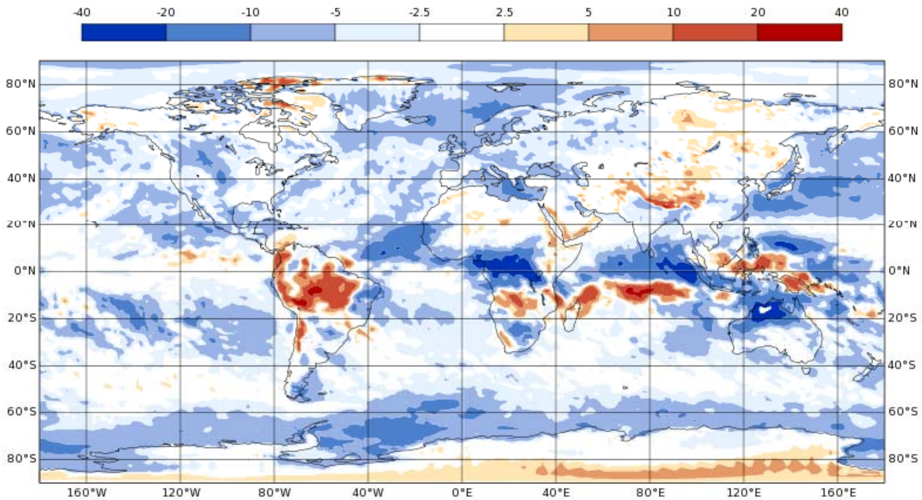


Outgoing long-wave Jan2012

default

ICONdefault - CERES

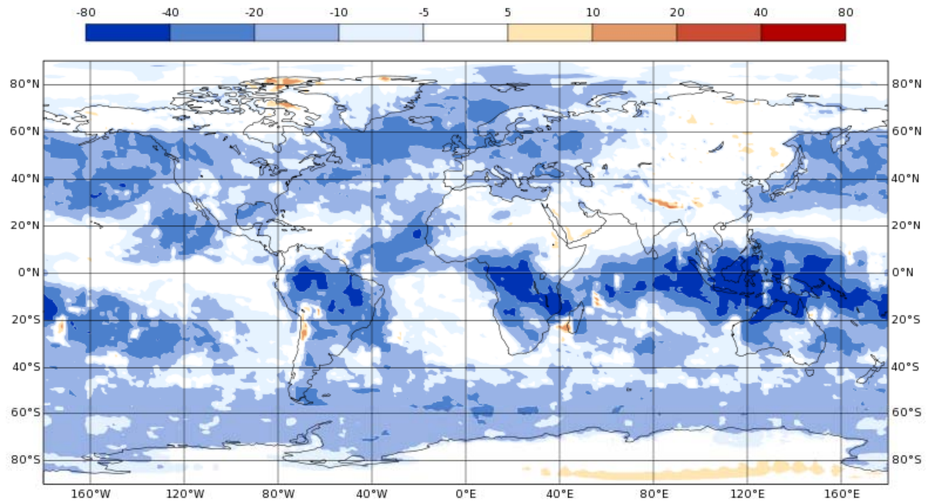
bias:
- 3.7 W/m²



New

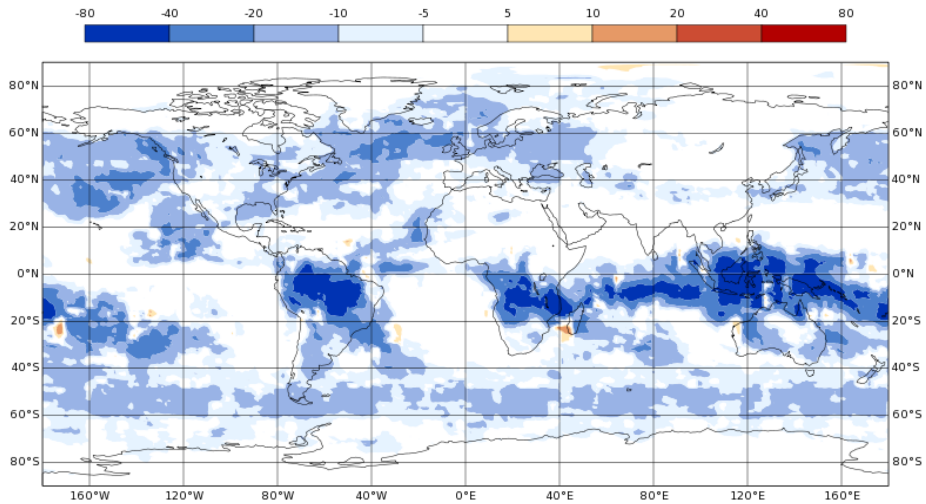
new-optic - CERES

bias:
- 13.8 W/m²



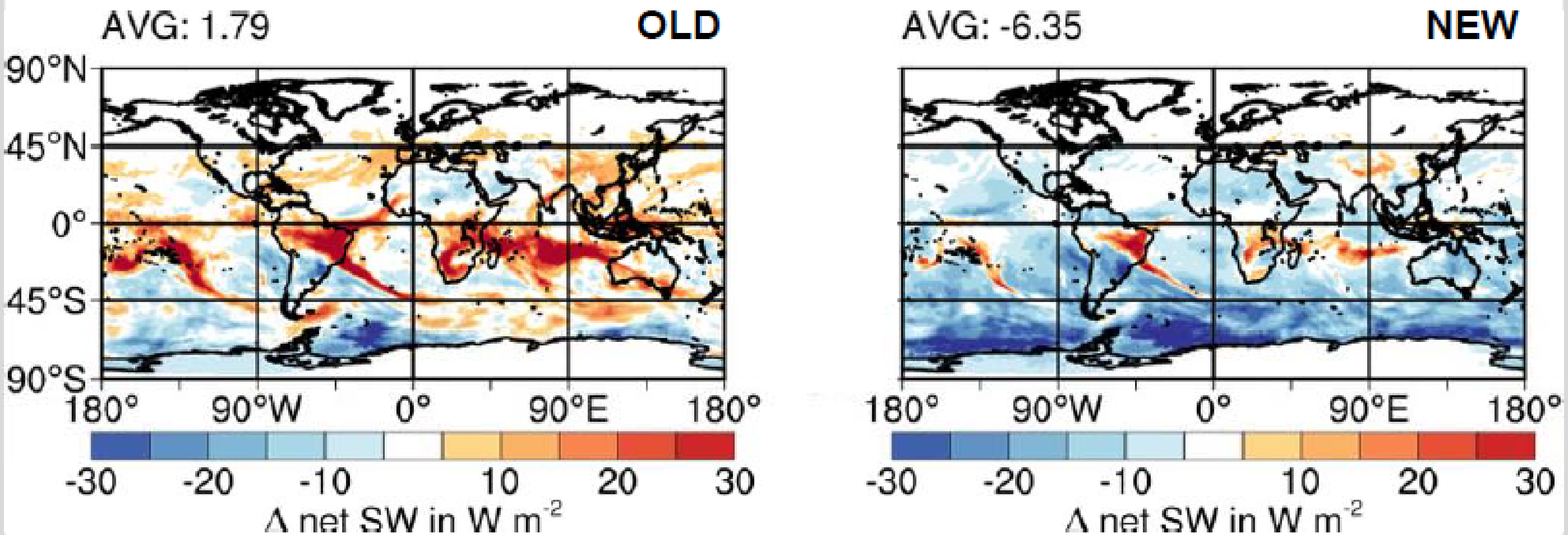
new-optic - ICONdefault

diff:
-10.1 W/m²



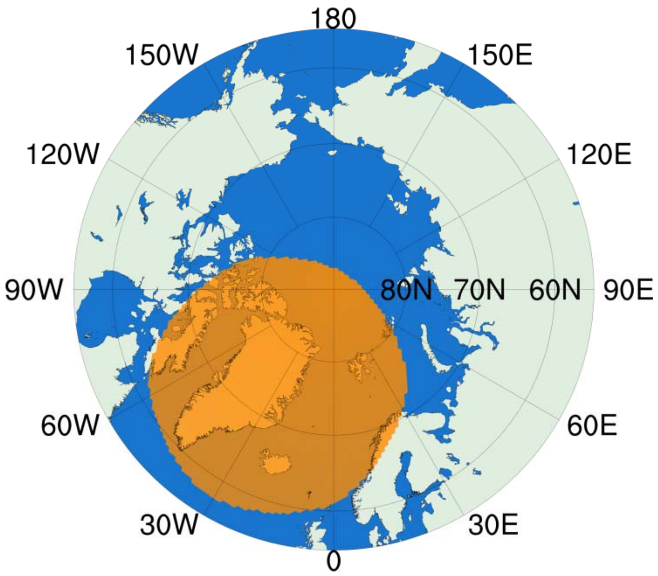
ICON vs CERES, January 2016

- net SW

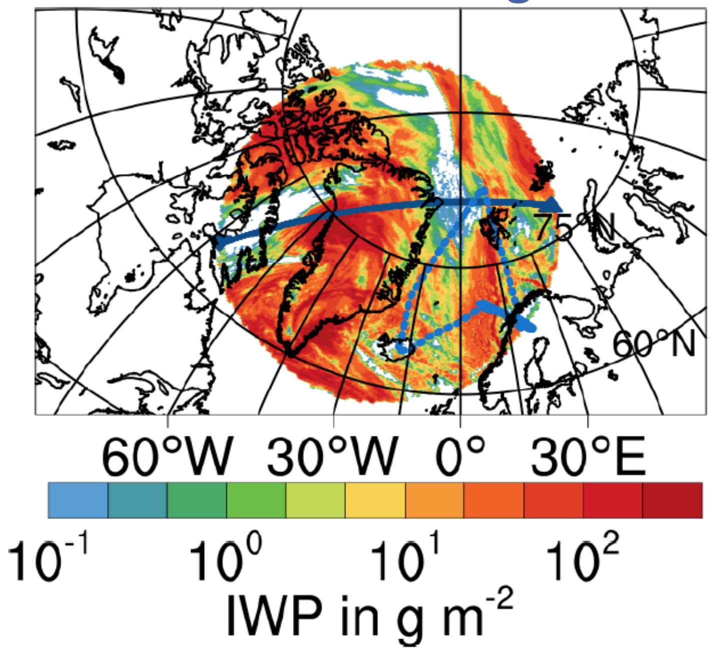


Model setup: ICON-ART LAM

- R2B09 (~5 km)
- two-moment microphysics: Seifert and Beheng (2006)
- cloud optical properties: Fu et al. (1998), Fu (2007), Hu and Stamnes (1993)
- nucleation: Barahona and Nenes (2009)
- heterogeneous nucleation: Phillips,et al. (2013)
- activation of CCN: Bangert et al. (2012)



CALIPSO and HALO flight tracks



Gruber et al., 2018

Validation: CALIPSO

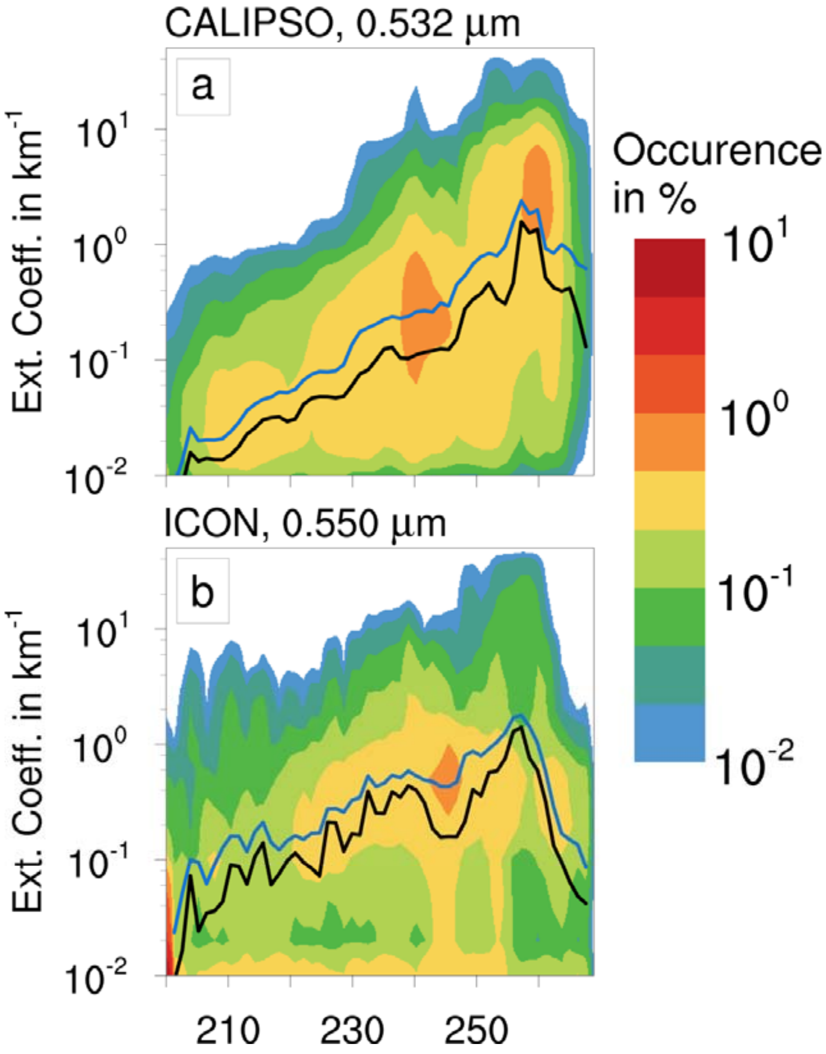


Figure 5. Two-dimensional probability distribution of the extinction coefficient with respect to temperature sampled along all tracks of CALIPSO crossing the simulation domain during the entire integration time for CALIPSO (a) and reference simulation (b). Black (blue) lines indicate average (median) extinction coefficient in each temperature bin.

Concluding remarks and outlook

- Project duration: September 2015 - August 2019

  FTEs (plan/used): 2.60/2.51 in COSMO year 2015-2016
  2.70/2.33 in COSMO year 2016-2017
  2.30/2.35 in COSMO year 2017-2018
  2.35/0.00 in COSMO year 2018-2019

  Total FTEs planned: **9.95**

  Total FTEs used: **7.19**

- Comments and plans for next year:
  - Using the new list of recommended tuning parameters in test version
  - Continue the testing campaign clear & cloudy conditions
  - Aerosols-radiation coupling: ICON-ART-dust more tests ahead
  - New cloud nucleation based on CAMS + Segal & Khain: 2-mom
  - Ice nucleation based on CAMS
  - Implementing the new Reff and LWC parametrizations for SGS clouds
  - ICON: new cloud optical properties – more testing needed (droplets)
  - Port new cloud_rad to newest COSMO