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Towards Prognostic Aerosols in COSMO Microphysics Scheme

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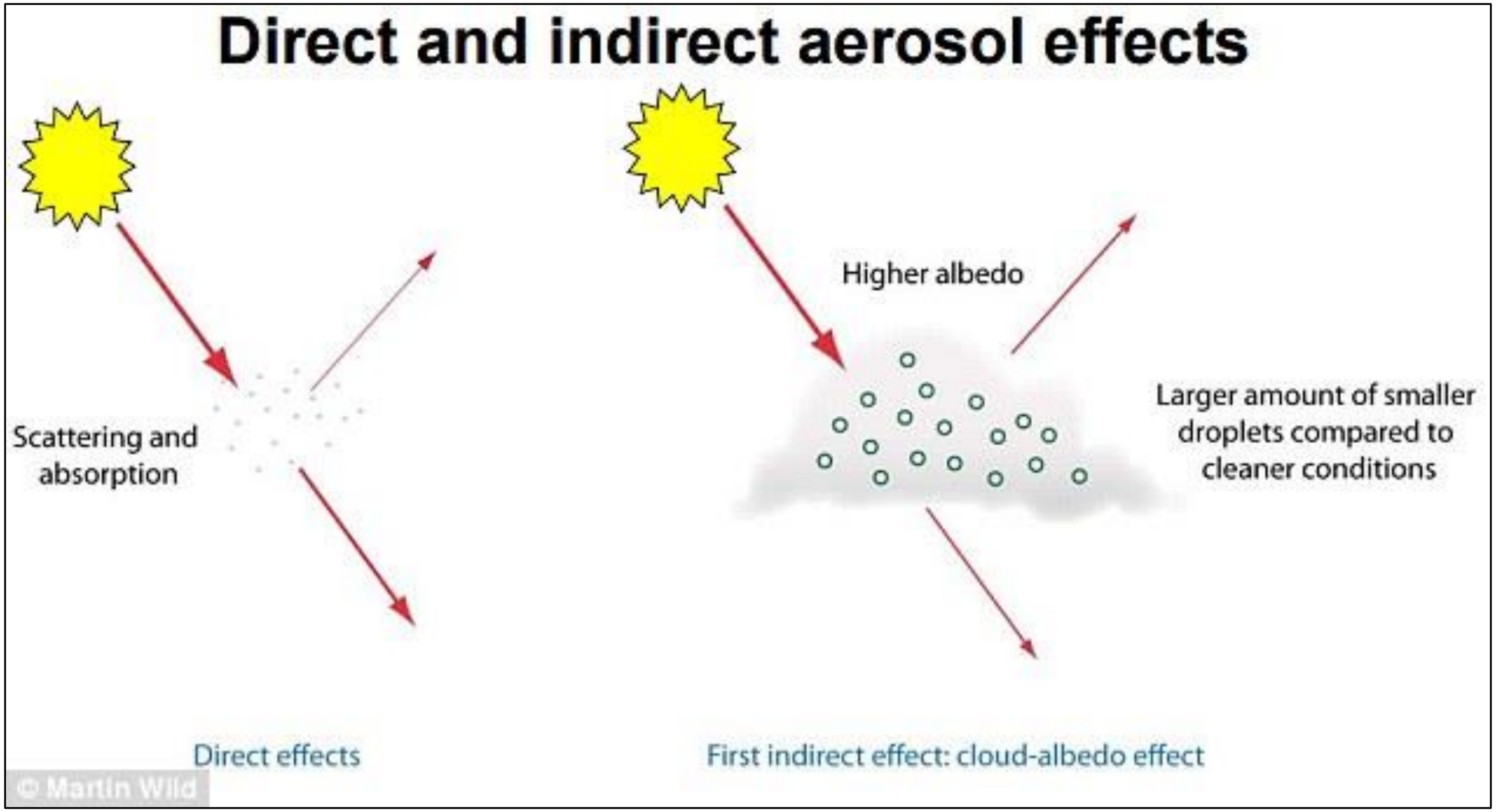
Acknowledgments: Alessio Bozo (ECMWF)

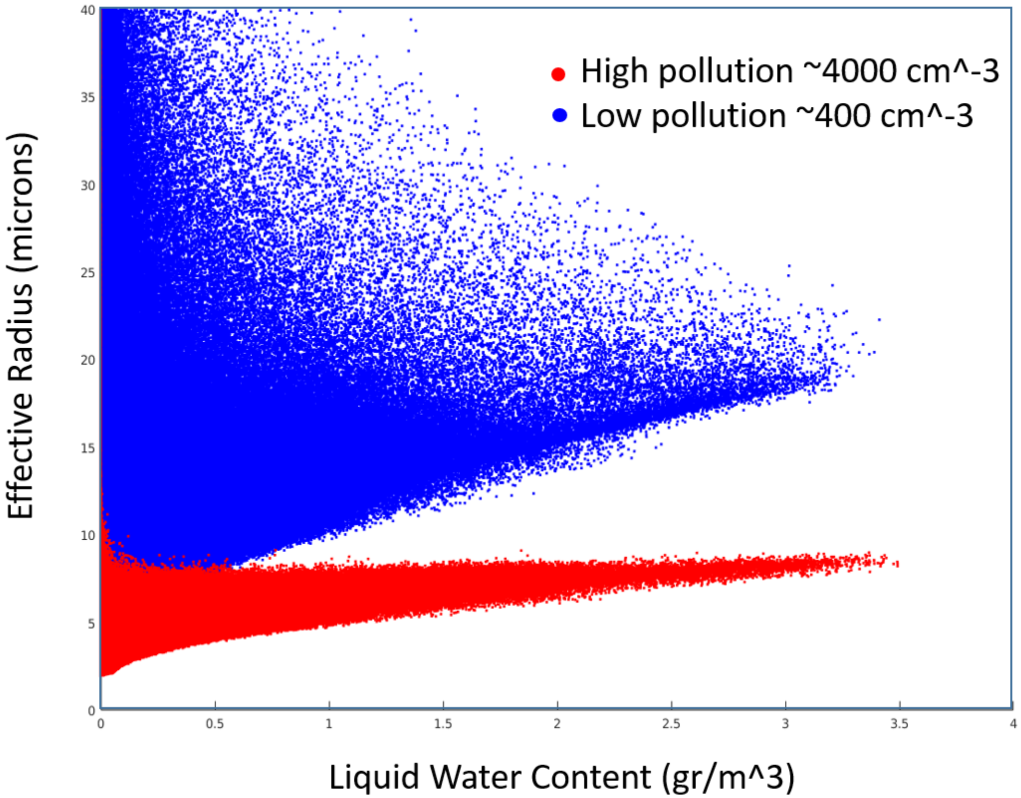
A Part of **$T^2(RC)^2$** COSMO Priority Project

ICCARUS, March 19 2019

Aerosols effects on radiation transfer



Aerosols indirect effects on radiation



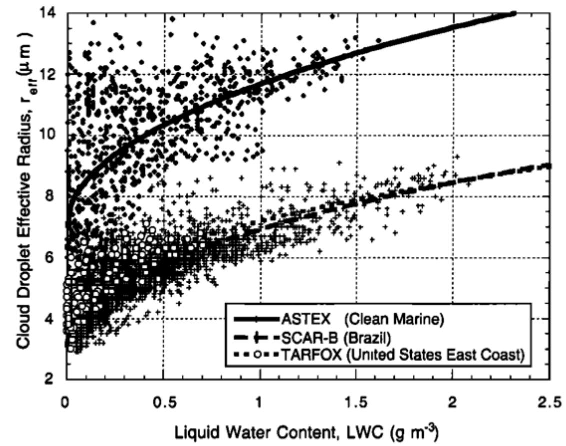
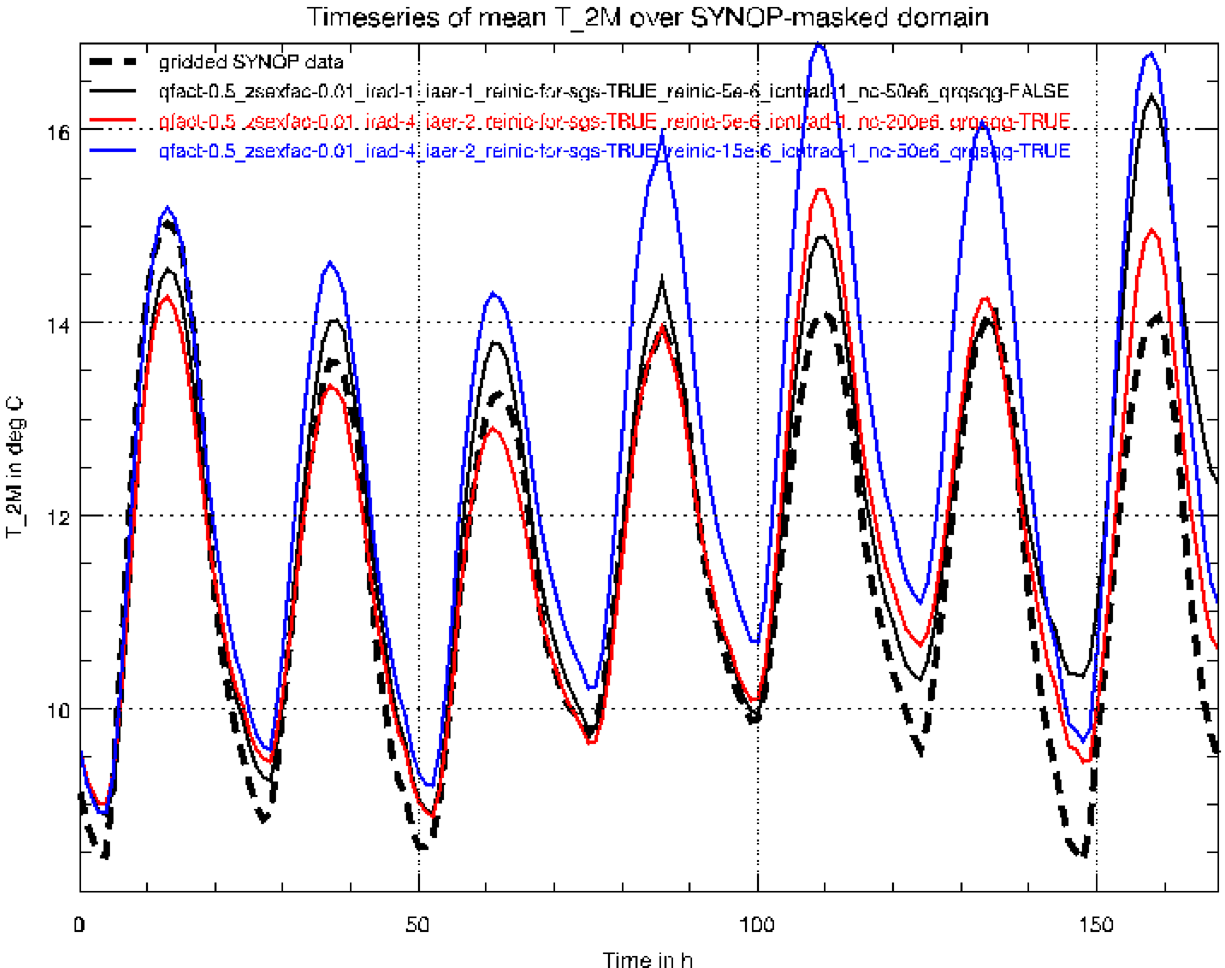


Figure 6. Cloud droplet effective radius (r_{eff}) versus liquid water content (LWC) for cumulus clouds in clean marine air over the northeastern Atlantic Ocean (diamonds, Atlantic Stratocumulus Transition Experiment (ASTEX)), in urban-industrial air off on the U.S. east coast (circles, Tropospheric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

Aerosols indirect effects on radiation

Sensitivity of T_{2M} in 7-day experiment to SGS Reff

COSMO-EU / COSMO-DE setup (1-moment microphysics) /**COSMO-DE results:**

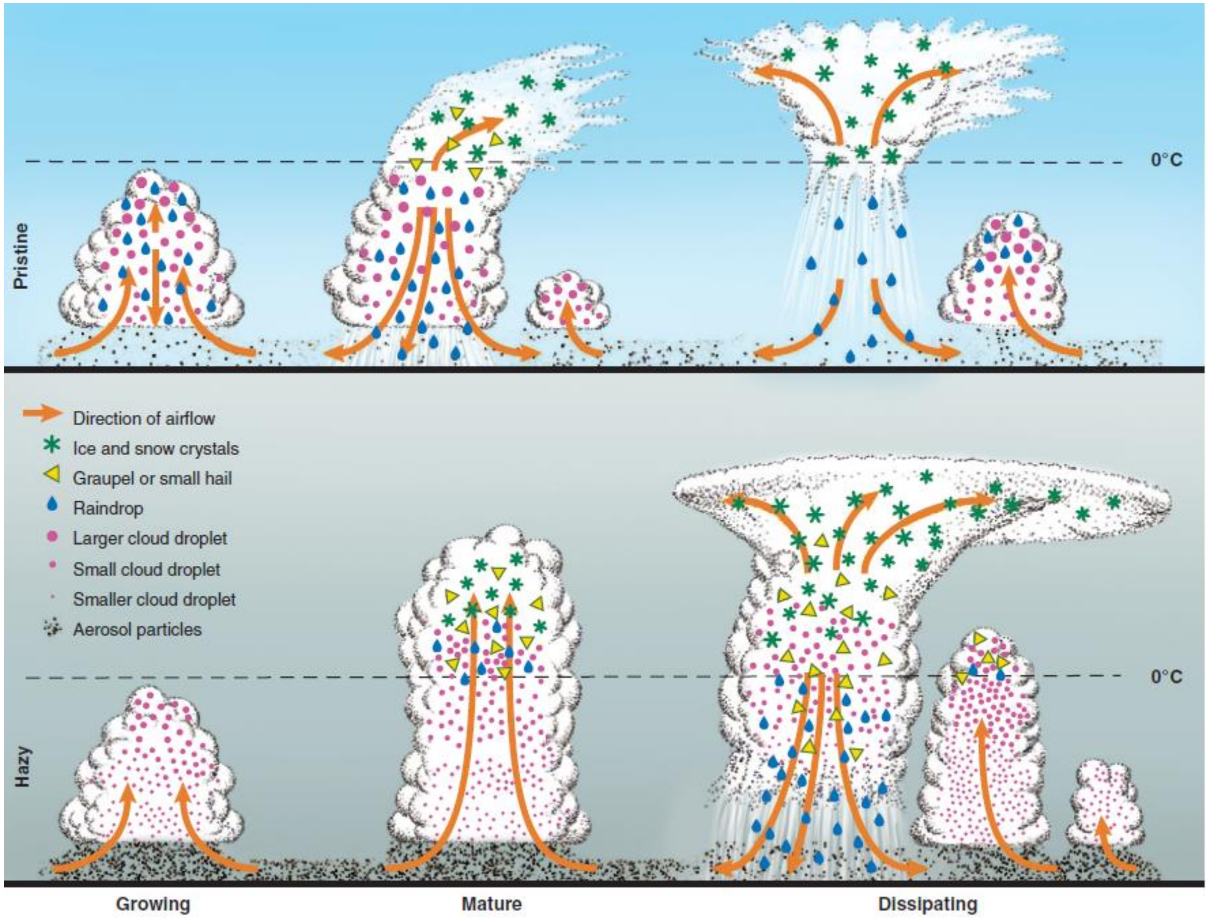


Aerosols effects on clouds formation & precipitation

- Cloud droplets number concentration in the default COSMO 1-mom scheme is fixed to **cloud_num** $(500\ cm^{-3})$. In 2-mom schemes it depends on fixed/climatology aerosols number concentrations
- But variations in the densities of aerosols which act as cloud condensation nuclei CCN can have large impact on cloud formation, dynamics and 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



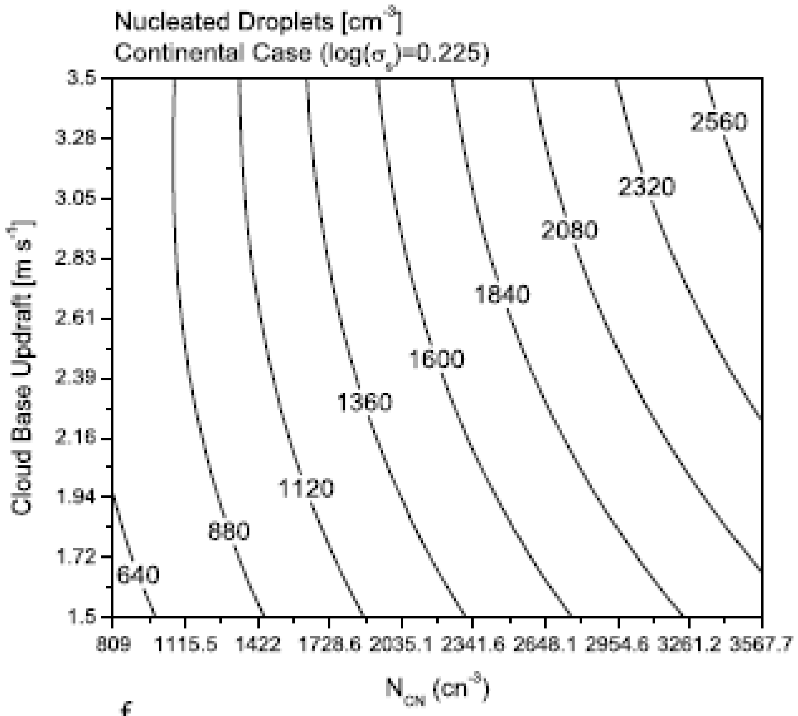
Rosenfeld et al., Science, 321 , 2008

Segal & Khain scheme in COSMO radiation

➔ **icloud_num_type_rad = 2 (Tegen) / 4 (CAMS)**

- 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) parameterization based on the estimated vertical velocity at cloud base
- n_C is assumed equal to n_{CCN}
- 4D look-up table

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



Segal & Khain (2006)

Segal & Khain scheme in COSMO radiation

- 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).
- All other grid points: derive n_c from lookup table based on local n_{CN} and w_{nuc}
- Let $n_{CCN,SK}$ be the lookup table, then:

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

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

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

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

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

→ 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

Segal & Khain scheme in COSMO radiation

R_{eff} in SGS clouds:

- SGS water clouds with a fixed R_{eff}: Tuning parameter **reff_ini_c** (default: 5µm) **luse_reff_ini_c_as_reffc_sgs = .TRUE.**
- Improvment: SGS R_{eff} treated same way as in grid scale clouds - luse_reff_ini_c_as_reffc_sgs = .FALSE.

but using $LWC_{SGS} = QC\_RAD/(CLC * radqcfact)$

QC_RAD = QCI_CON * CLC_CON + QC_SGS * CLC_SGS * (1 – CLC_CON)

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

Segal & Khain scheme in COSMO microphysics

Number concentration of cloud droplets in 1-mom scheme options:

- **icloud_num_type_gscp = 1**
  - Cloud number concentration is a tuning parameter **cloud_num**

    default: $500\ cm^{-3}$

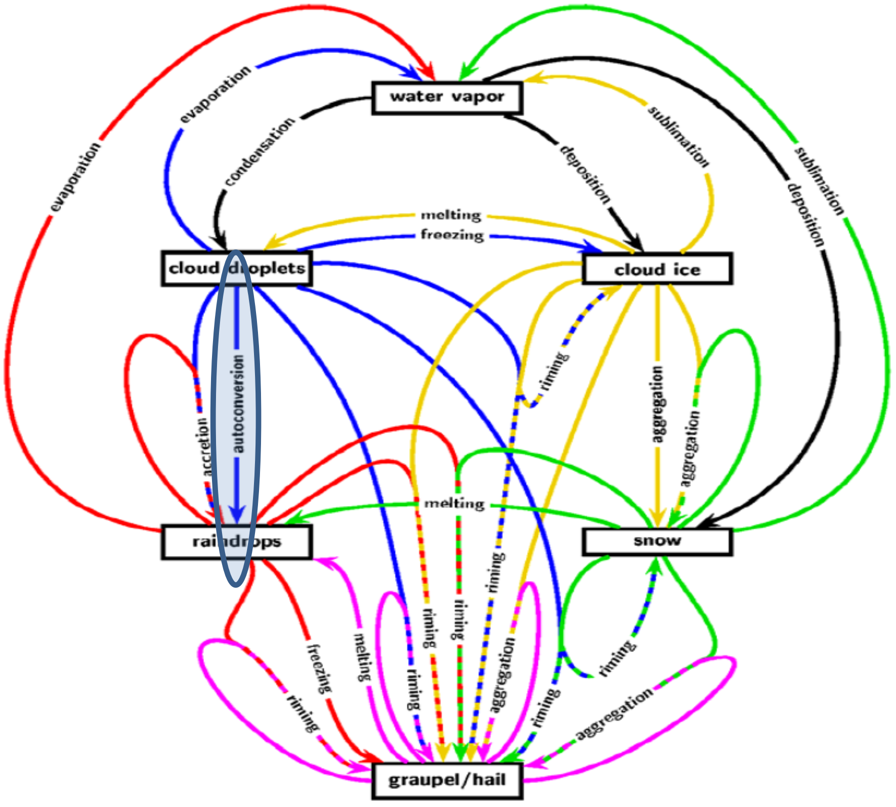
- **icloud_num_type_gscp = 4**

- Cloud number concentration is calculated using CAMS + SK the same way as for itype_num_type_rad = 4

- Effective in the **auto-conversion** parameterization from cloud droplets to raindrops:

$$\frac{d(qc)}{dt} \sim -\frac{qc^4}{qnc^2} = -\frac{qc^2}{xc^2}$$

(xc = mean droplet mass)



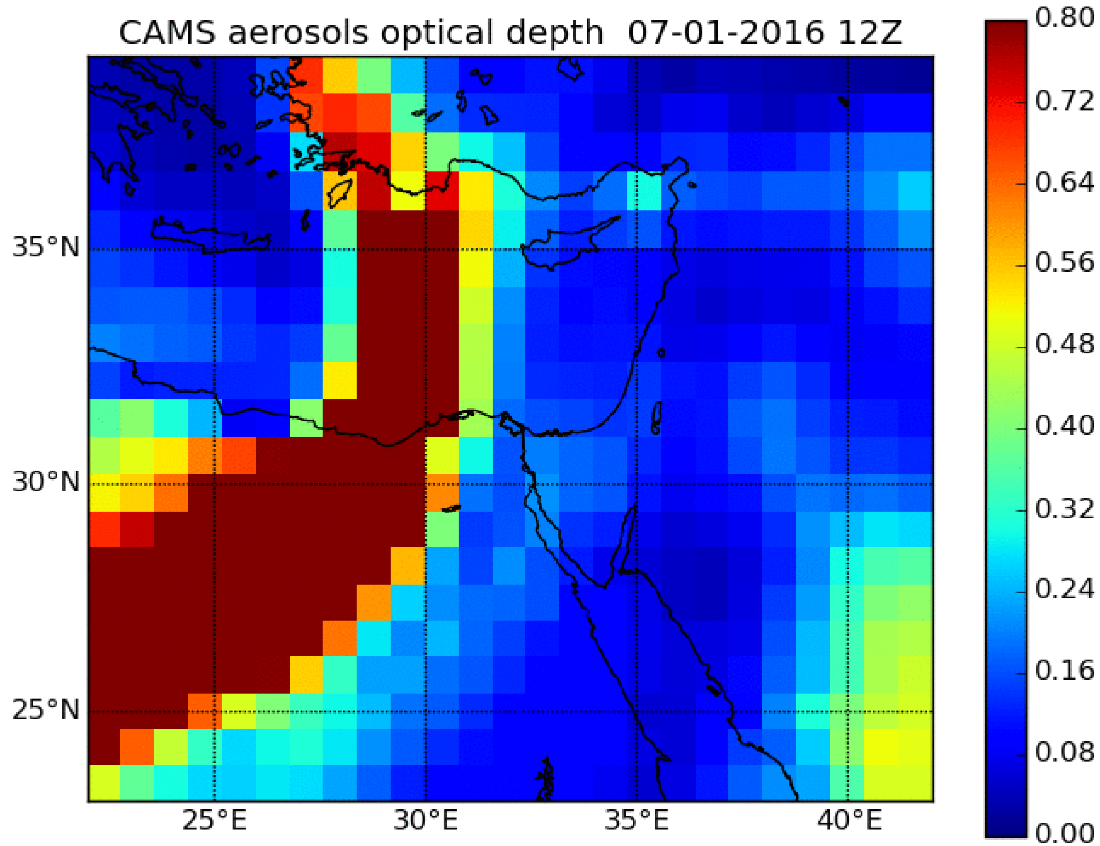
CAMS prognostic aerosols

Atmosphere Monitoring Service

itype_aerosol = 4

- Based on IFS with additional prognostic aerosol variables
- Input aerosols analysis:
  - NASA/MODIS Terra and Aqua Aerosol Optical Depth at 550 nm
  - NASA/CALIOP CALIPSO Aerosol Backscatter
  - AATSR, PMAP, SEVIRI, VIIRS
- Verification based on AERONET

(text adapted from Benedetti CUS2016)



CAMS prognostic aerosols

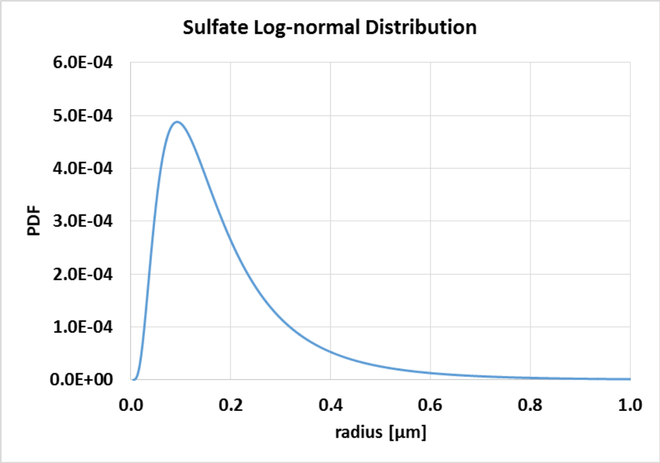
species	r_{mode} [μm]	σ	ρ [$kg \cdot m^{-3}$]	$\bar{m}$ [kg]	Soluble fraction
sea salt [0.03, 0.5]	0.1992, 1.992	1.9, 2.0	1183	7.5023E-17	1
sea salt [0.5, 5]	0.1992, 1.992	1.9, 2.0	1183	3.3269E-15	1
sea salt [5, 20]	0.1992, 1.992	1.9, 2.0	1183	9.3421E-15	1
Dust [0.03,0.55]	0.29	2.00	2610	2.8694E-16	0.1
Dust [0.55,0.9]	0.29	2.00	2610	4.7291E-16	0.1
Dust [0.9,20]	0.29	2.00	2610	1.5570E-15	0.1
OM Hydrophobic [0.005,20]	0.471, 0.0118	2.51, 2.0	1800	1.7860E-18	0
OM Hydrophilic [0.005,20]	0.0212	2.24	1000	1.3411E-18	0.59
BC Hydrophobic [0.005,5]	0.0118	2.00	1000	5.9774E-20	0
BC Hydrophilic [0.005,5]	0.0118	2.00	1000	5.9774E-20	1
Sulfate [0.005,20]	0.0355	2.00	1760	2.8658E-18	1

$$n(x,y,z) = MR(x,y,z) \cdot \rho_{air} / \overline{m_v}$$

$$r_{mode,SK} = [0.02\ \mu m, 0.04\ \mu m]\ \ , \ln(\sigma_g) = [0.1, 0.5]$$

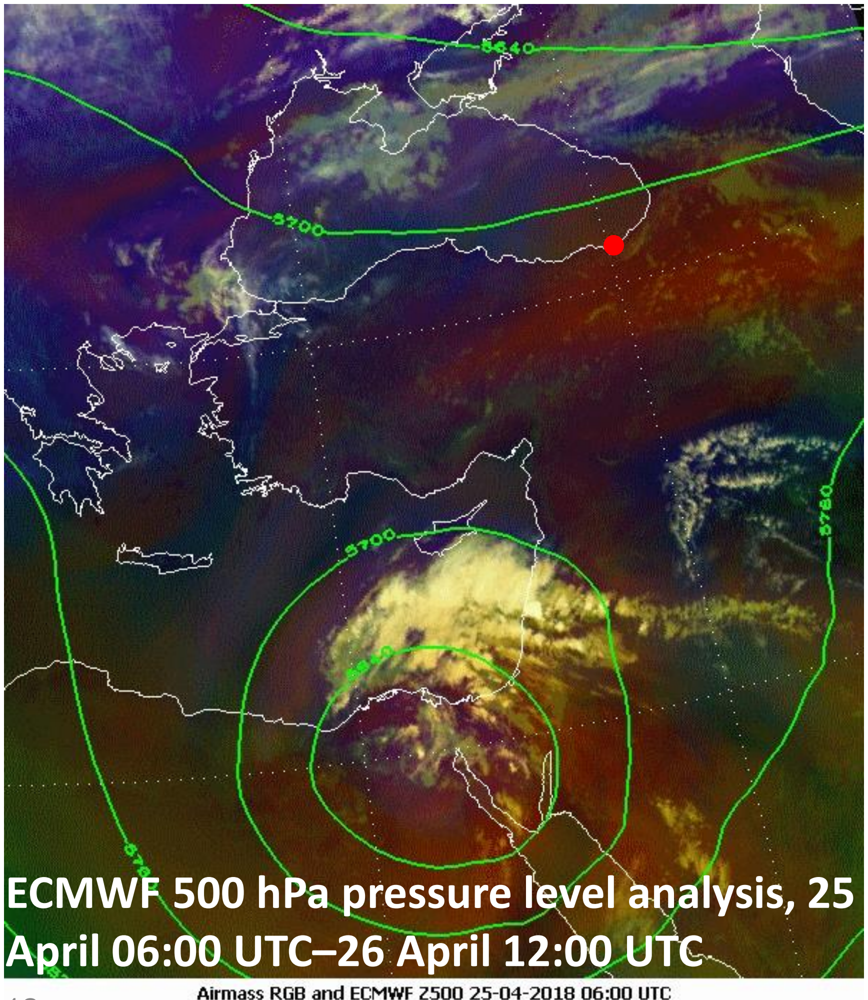
$$\bar{N} = \sum_{aer} N_{aer} \qquad \overline{R_{mode}} = \frac{1}{\bar{N}} \sum_{aer} N_{aer}\, R_{aer}$$

$$\overline{\sigma_g^2} = \frac{1}{\bar{N}} \sum_{aer} N_{aer} \left(\sigma_{g\_aer}^2 + (R_{aer}/\bar{R})^2\right)$$

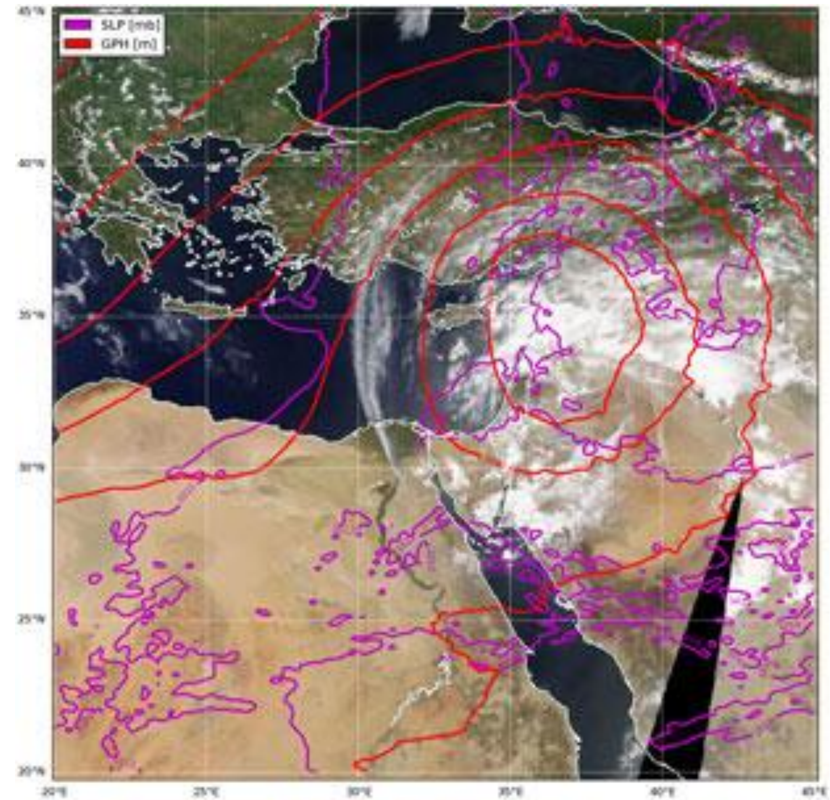


Case study: April 25-27, 2018

- Three days with massive storm cells & flash floods
- 14 deaths. Judean desert and Arava
- Zafit valley disaster: 10 teenager hikers. April 26, 2018 13:15Z.



ECMWF 500 hPa pressure level analysis, 25 April 06:00 UTC–26 April 12:00 UTC

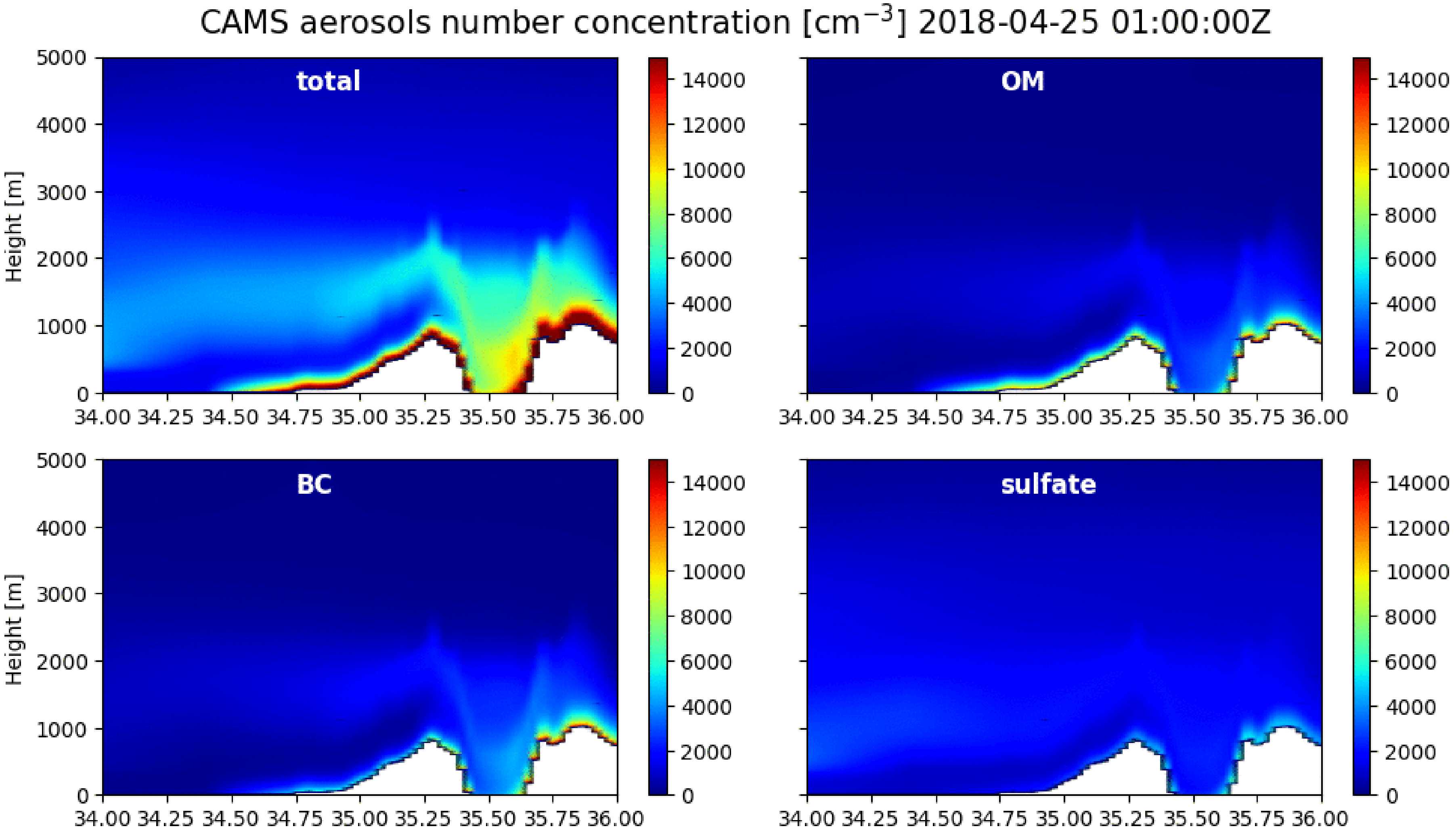


ECMWF synoptic analysis layered over MODIS True Color RGB image, 26 April 12:00 UTC

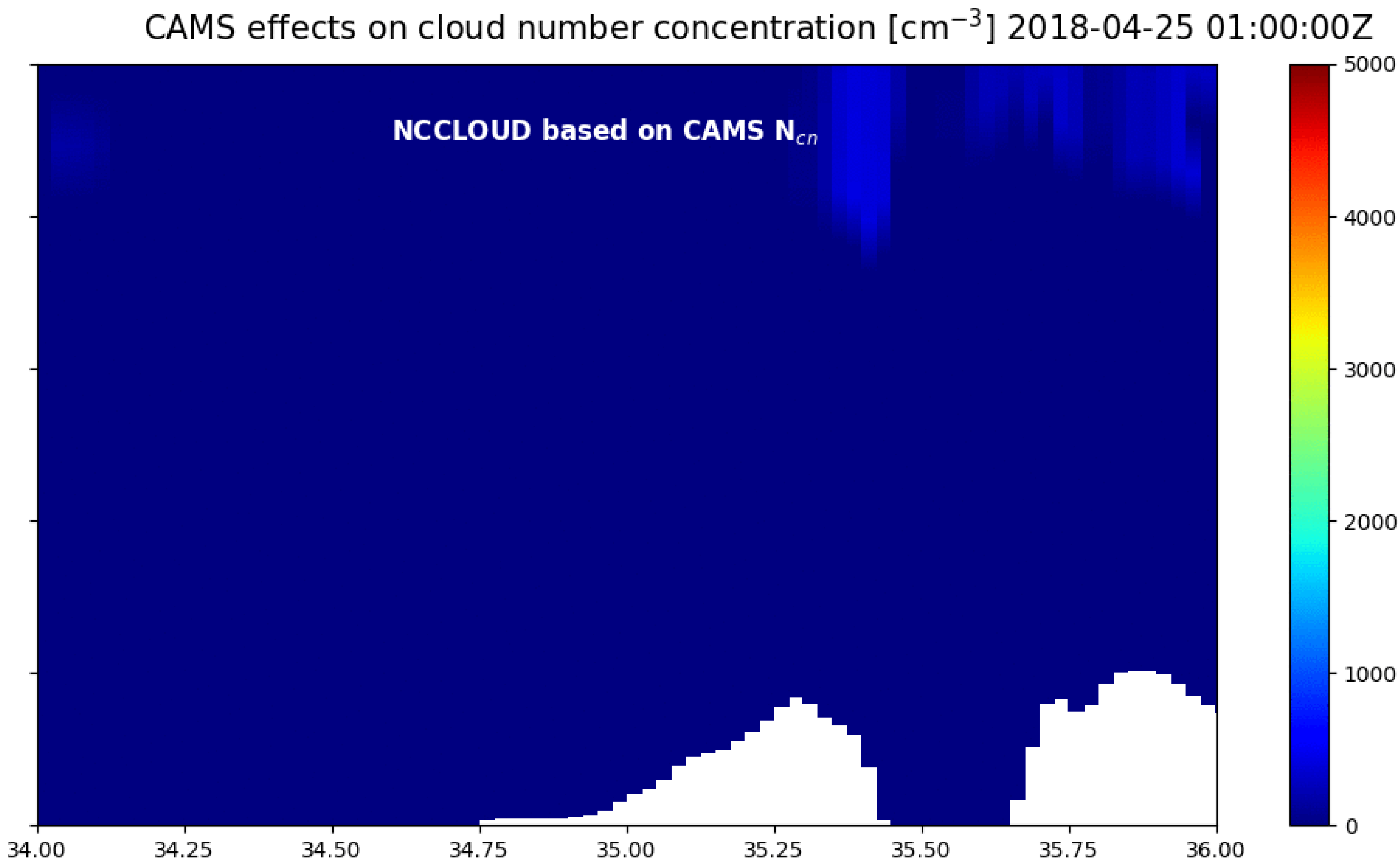
ttps://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_4038669.html

Thanks to Oren Davidoff !

CAMS aerosols number concentration



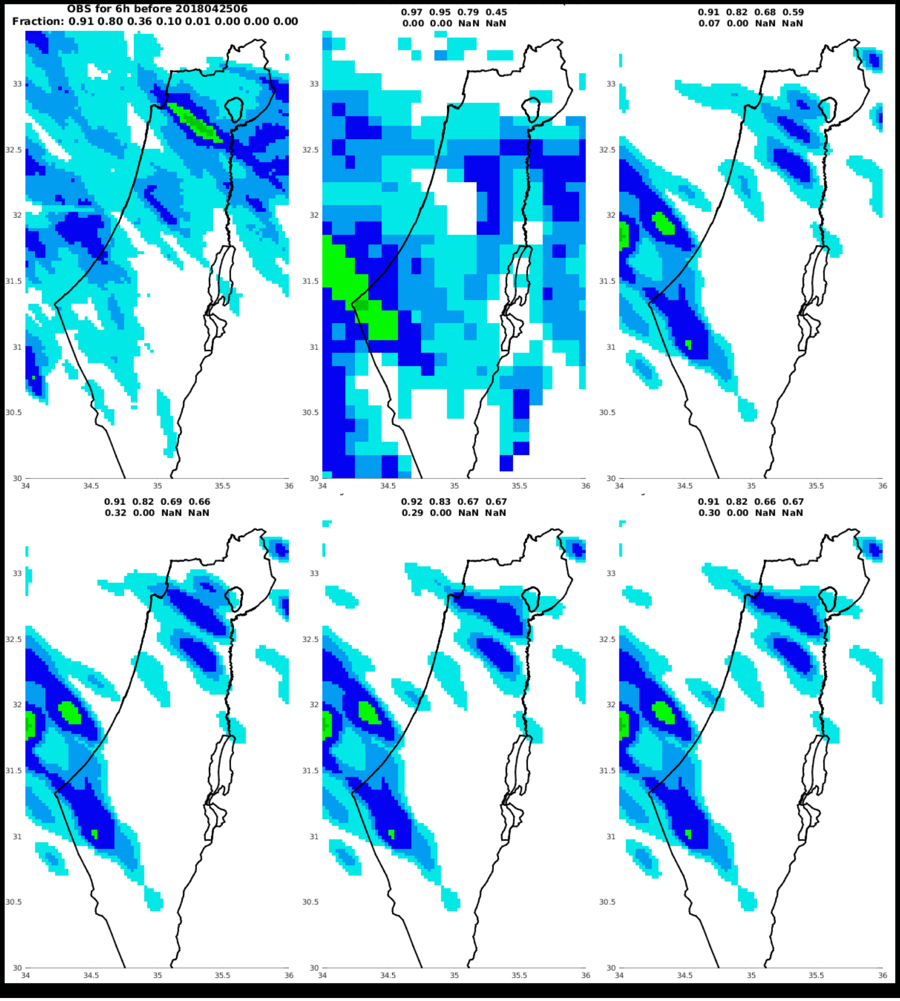
New cloud droplets number concentration



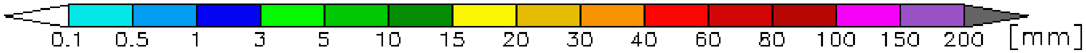
icloud_num_type_gscp/rad = 4

Case study: April 25-27, 2018

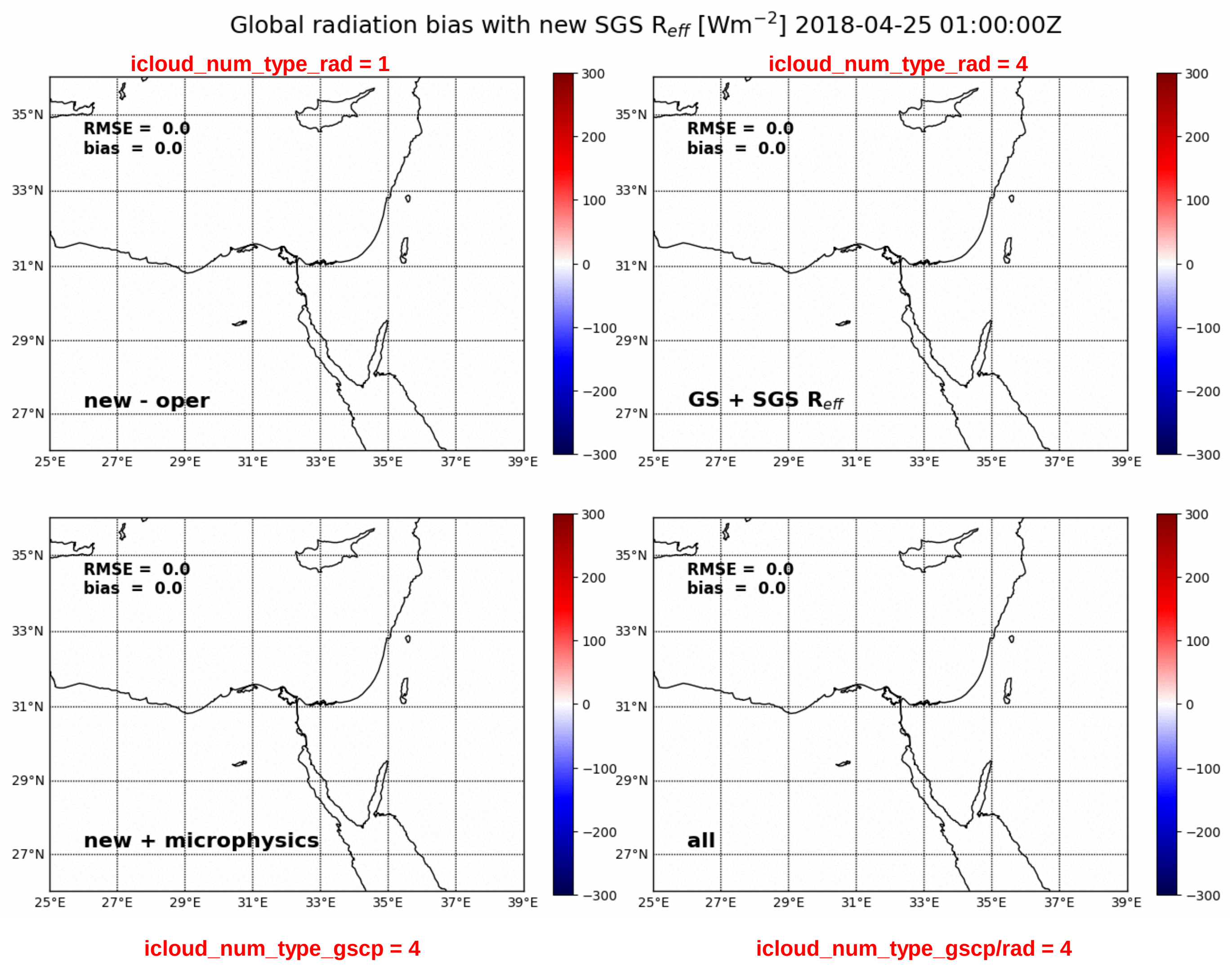
OBS EC COSMO oper



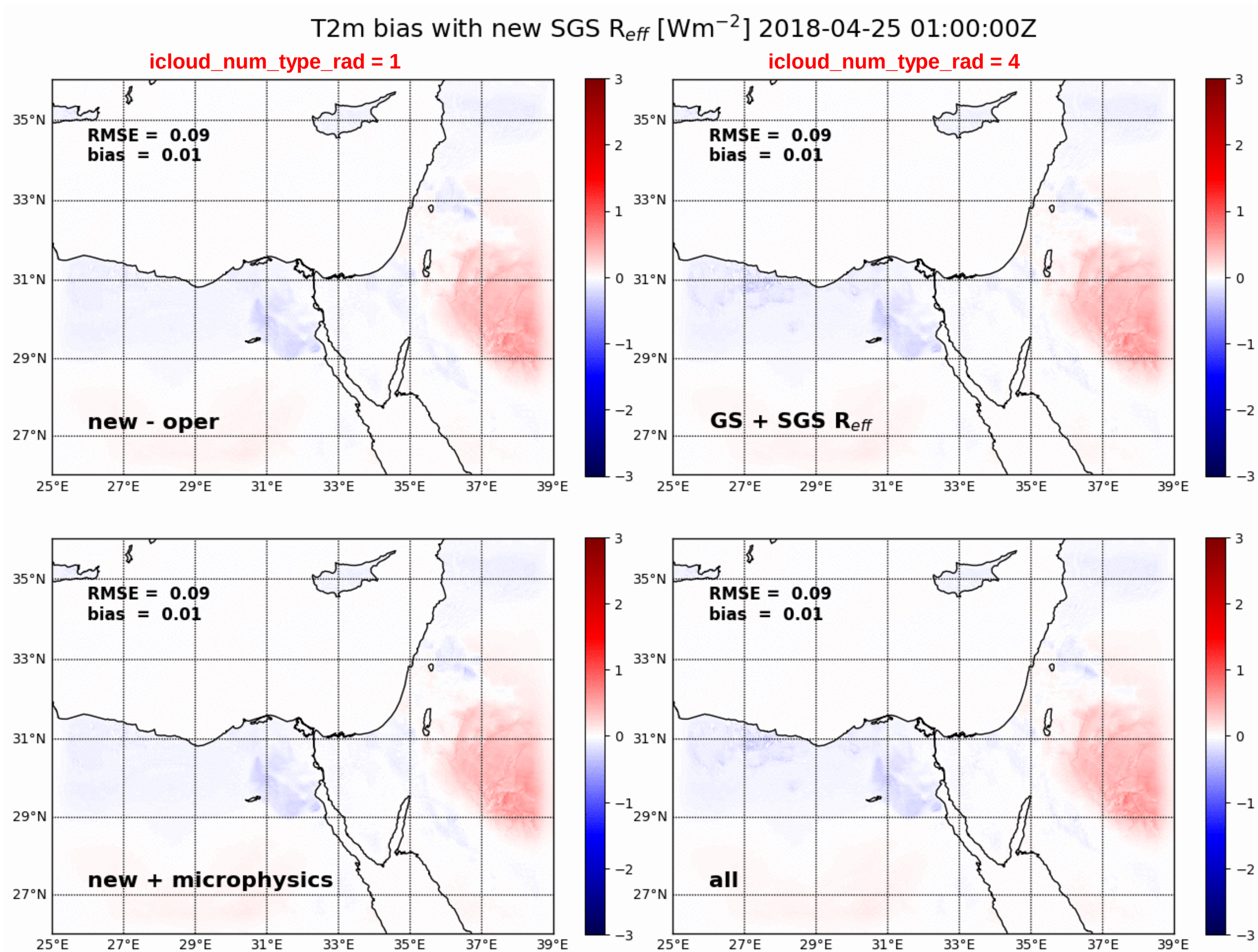
C-CAMS **icloud_num_type_gscp=4** **icloud_num_type_gscp+rad=4**



Impact on radiation



Impact on T2m

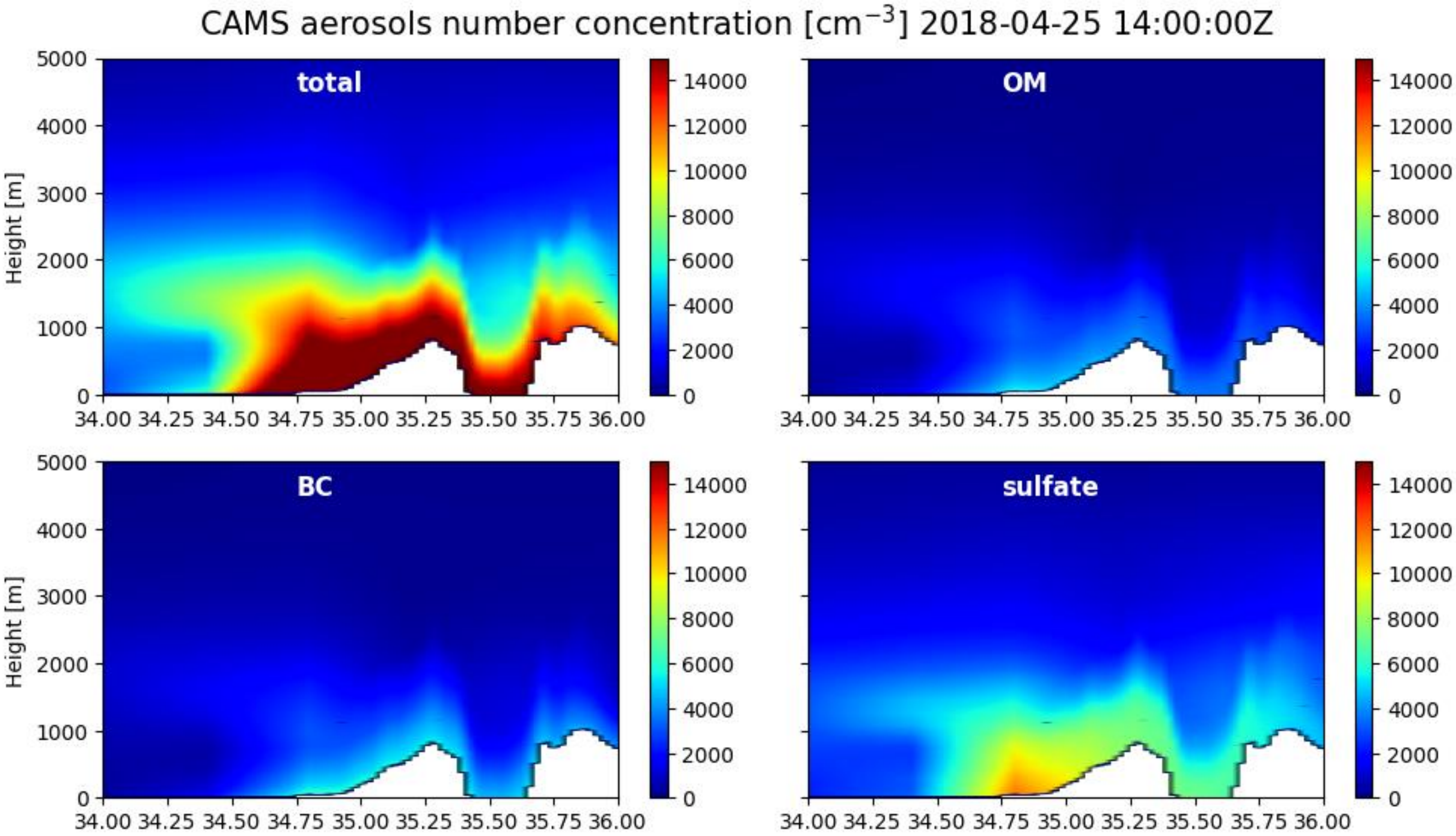


icloud_num_type_gscp = 4

icloud_num_type_gscp/rad = 4

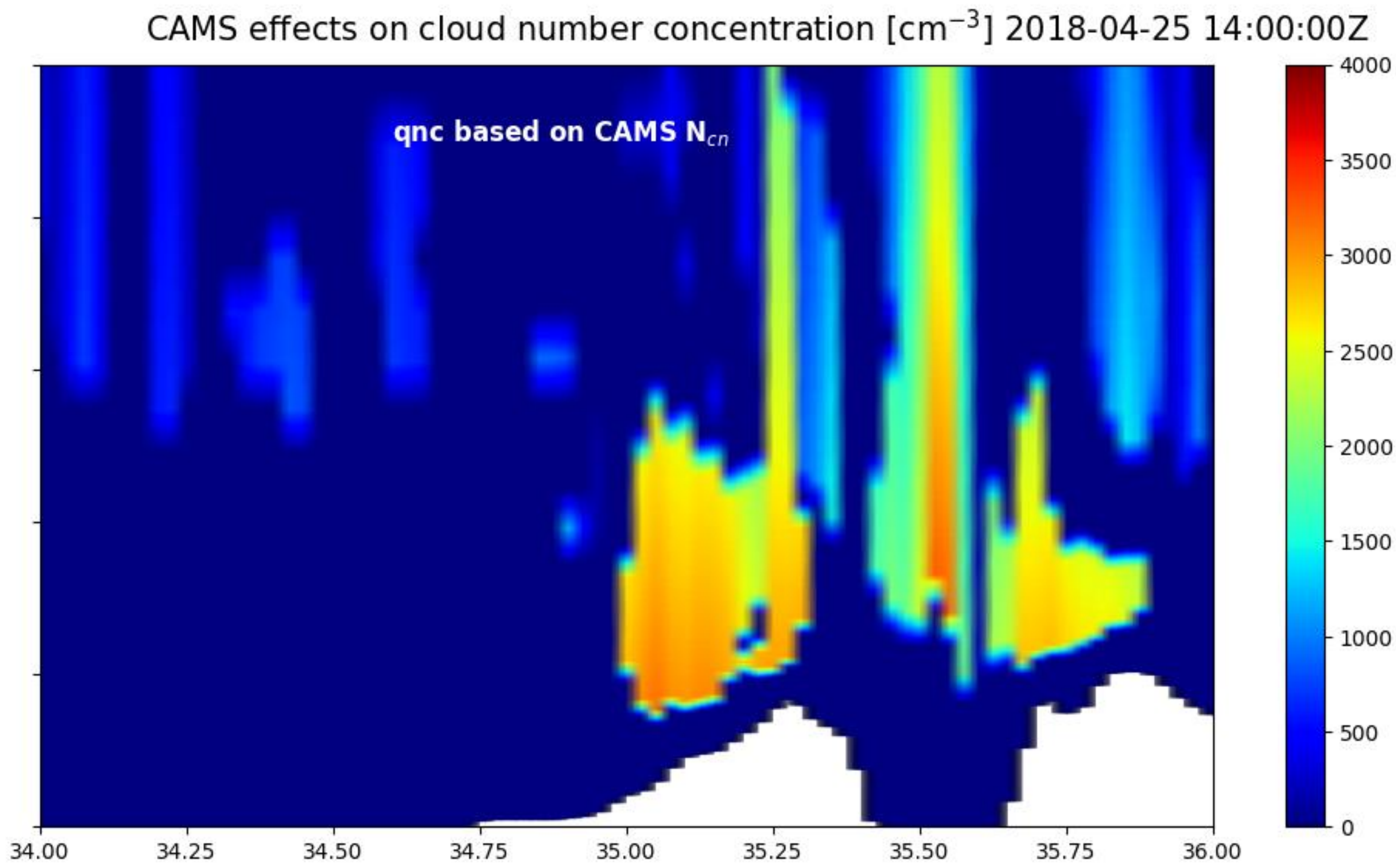
CAMS aerosols number concentration

Peak event April 25 14Z



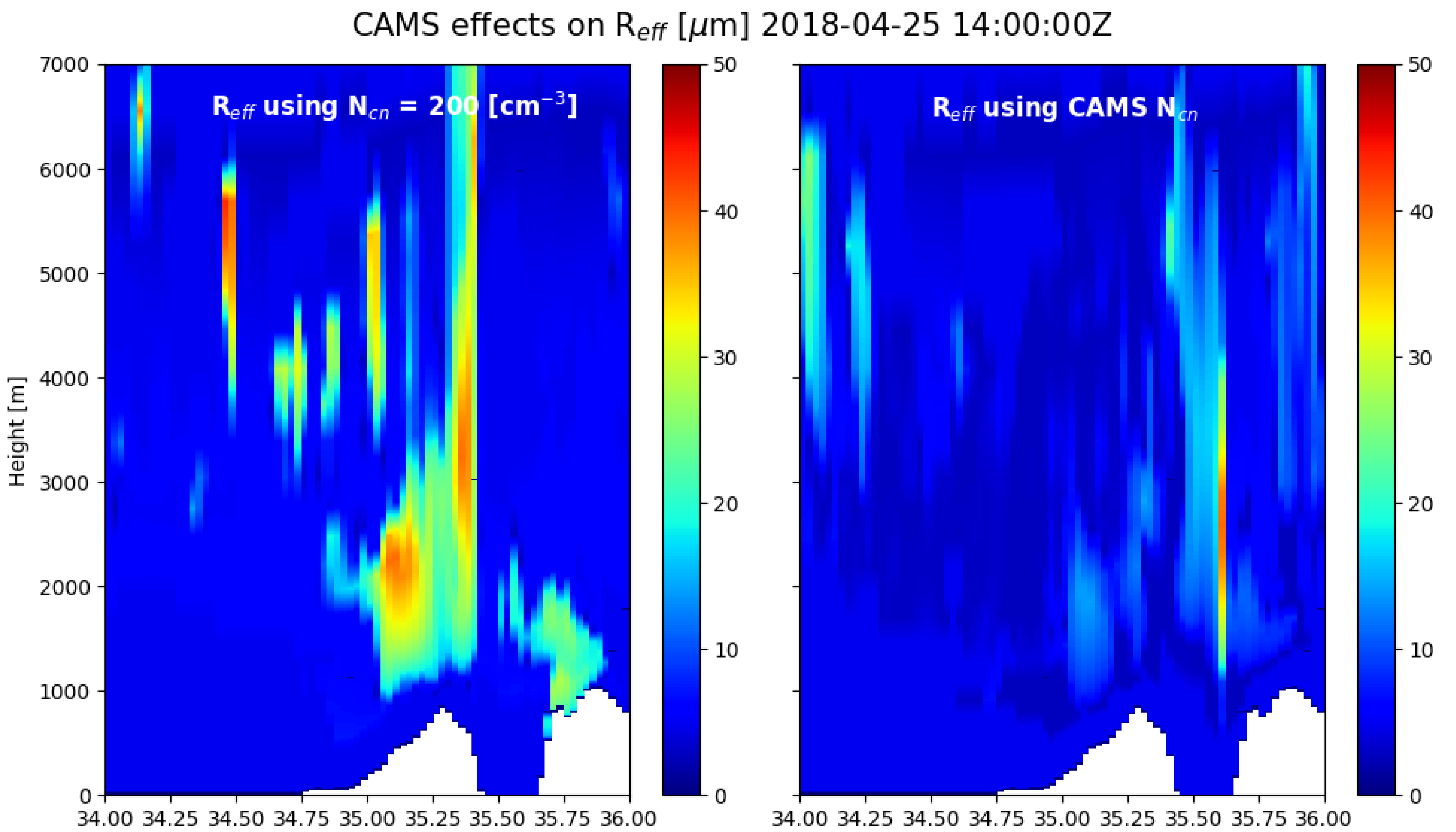
New cloud droplets number concentration

Peak event April 25 14Z



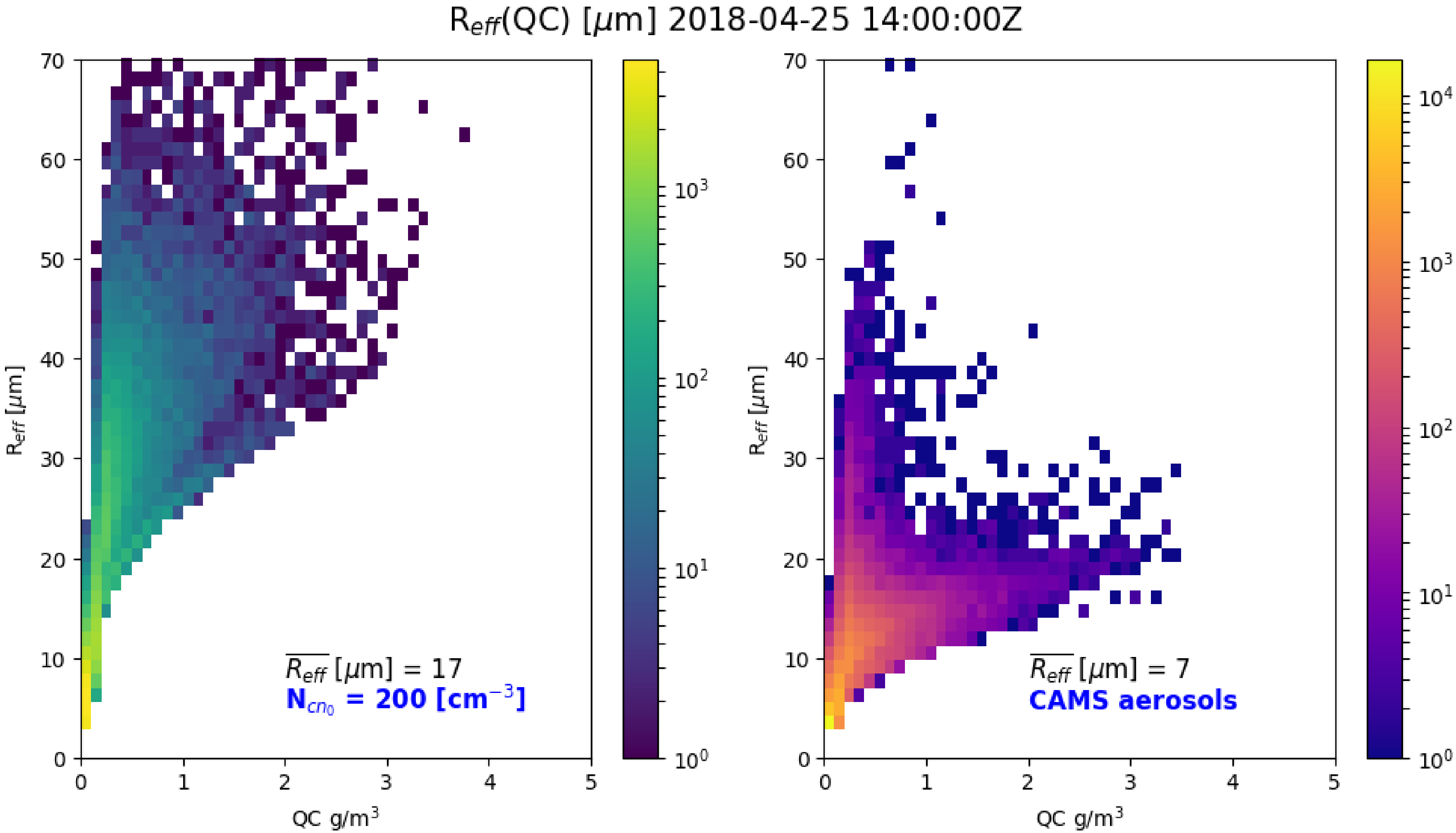
R_{eff} based on CAMS & Segal-Khain

Peak event April 25 14Z



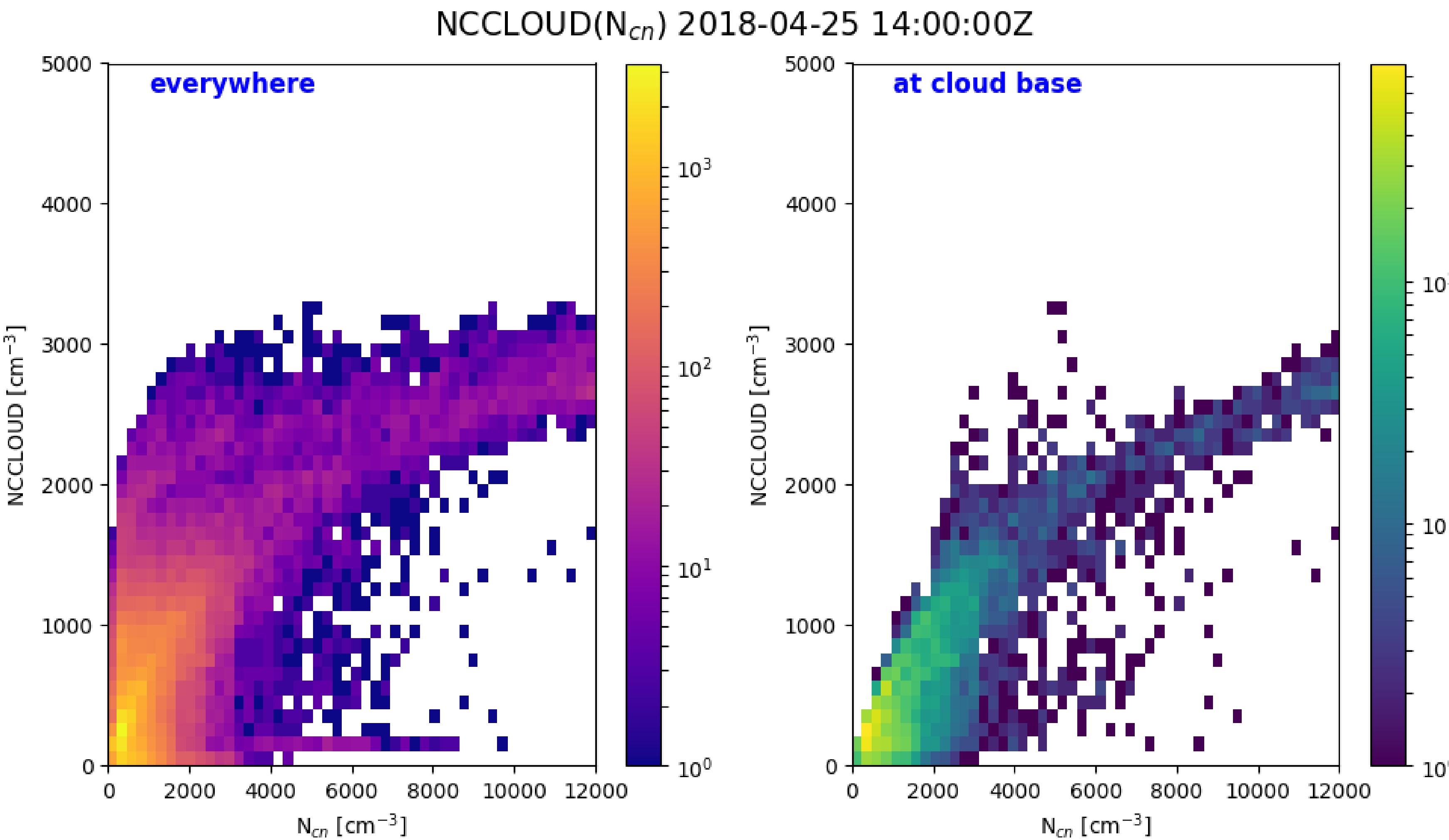
R_{eff} based on CAMS & Segal-Khain

Peak event April 25 14Z



New cloud droplets number concentration

Peak event April 25 14Z



Case study: April 25-27, 2018

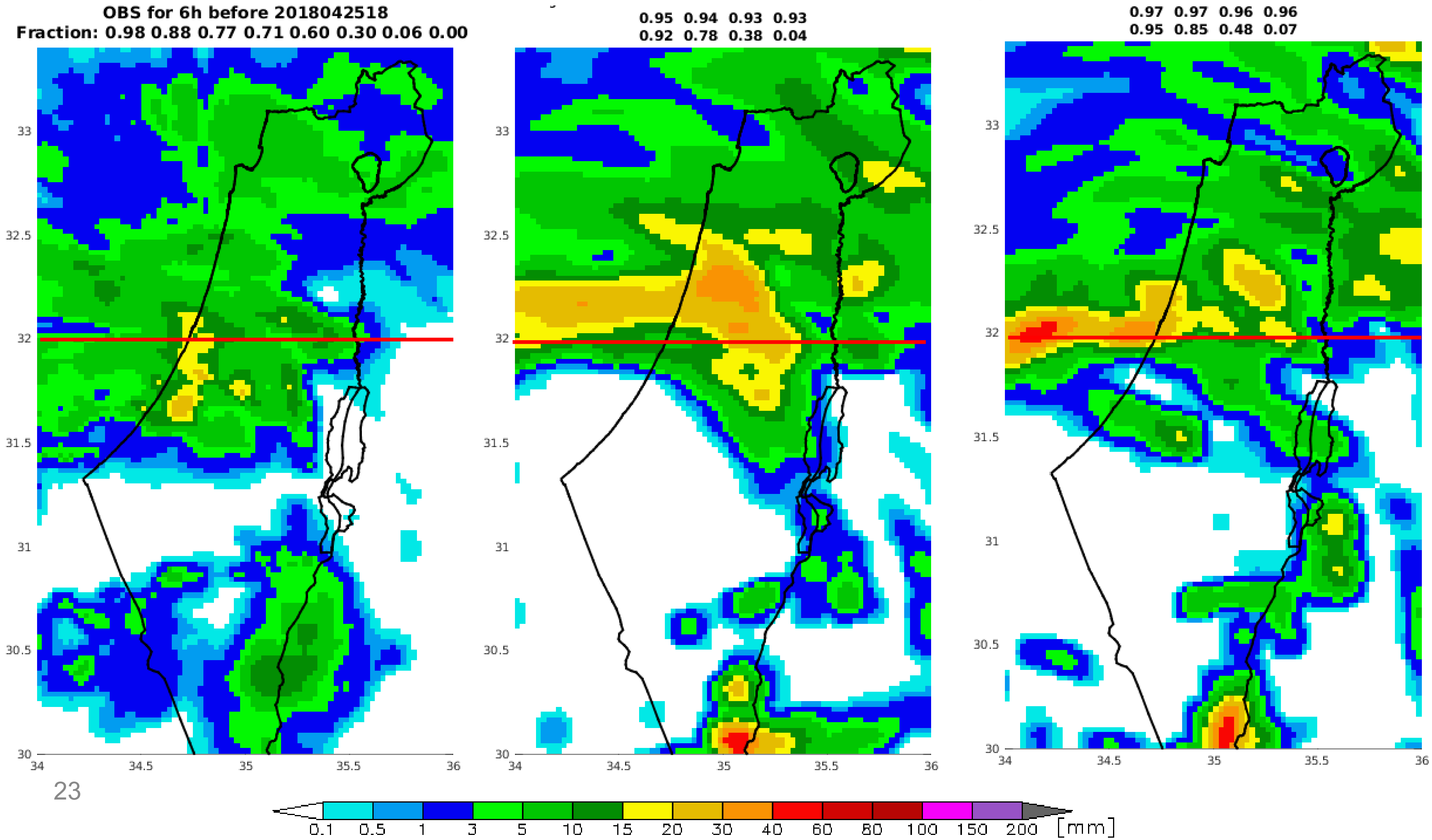
New cloud_rad

CAMS background aerosols

CAMS & SK Ncn → rad + microphysics

OBS

COSMO oper



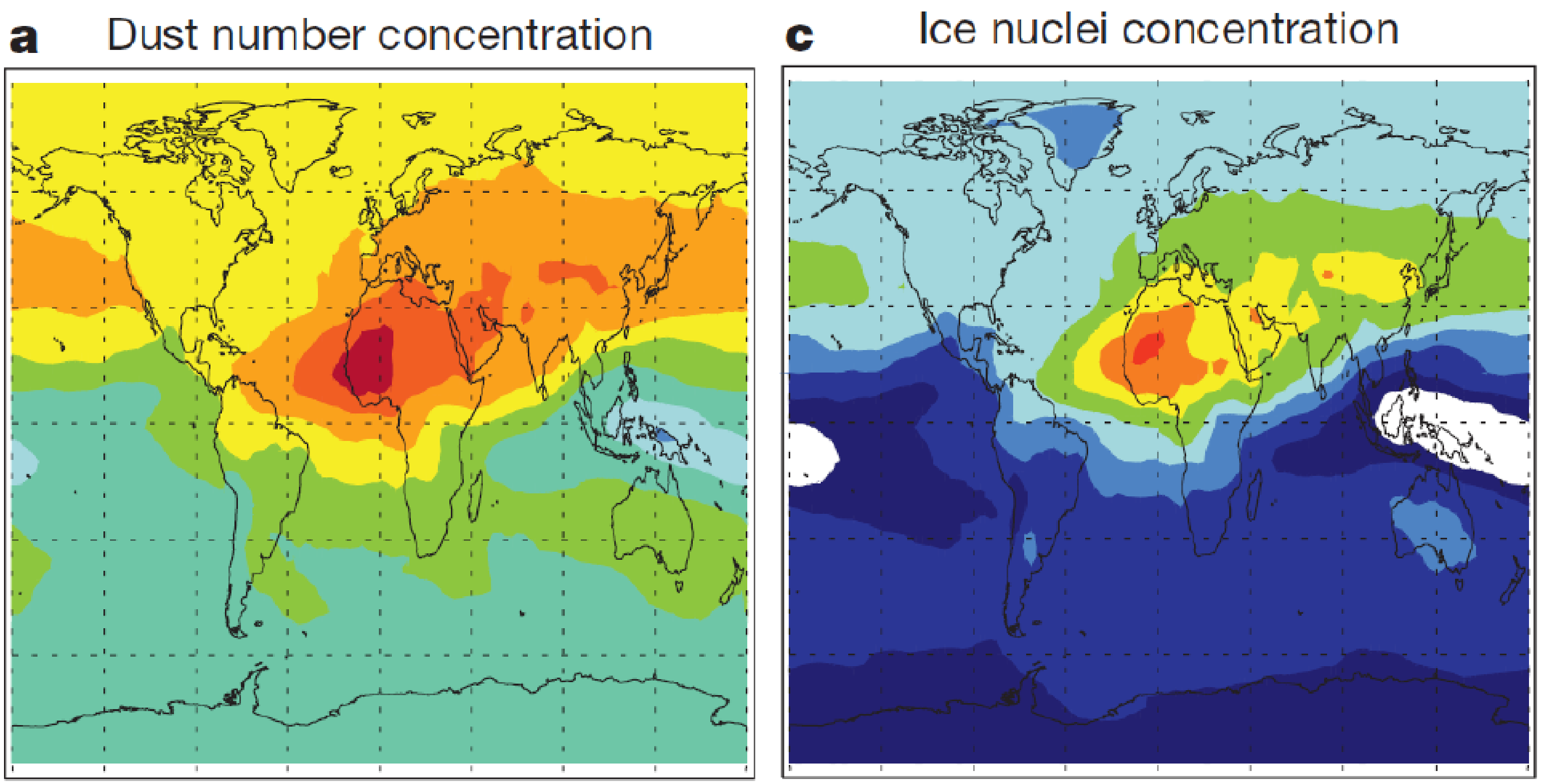
Case study 2 : 06-08/12/2018

	Oper 5.5	Old CAMS 5.1		New CAMS 5.1
Rain 00-06h	0.9	0.97	0.97	0.97
Rain 06-12h	0.89	0.92	0.92	0.91
Rain 12-18h	0.9	0.91	0.91	0.9
Rain 18-24h	0.96	0.97	0.97	0.97
Rain 24-30h	0.91	0.91	0.92	0.92
Rain 30-36h	0.9	0.92	0.9	0.92
Rain 36-42h	0.97	0.95	0.95	0.89
Rain 42-48h	0.87	0.77	0.77	0.87
Rain 48-54h	0.66	0.68	0.72	0.66
Rain 54-60h	0.58	0.33	0.35	0.66
Rain 60-66h	0.55	0.42	0.43	0.55
Rain 66-72h	0.34	0.37	0.21	0.34
Rain 72-78h	0.02	0	0.01	0.69
T AVG	-0.12	-0.14	-0.15	-0.08
RH AVG	-0.38	-0.56	-0.56	-0.34
WS AVG	-0.13	-0.22	-0.19	-0.19
WD AVG	0	0.07	0.08	0.04
Prof AVG	-0.11	-0.13	-0.1	-0.08
Rain AVG	-0.03	-0.15	-0.19	0.22
AVG	-0.1	-0.16	-0.17	0

Prognostic aerosols in ice nucleation

The importance of feldspar for ice nucleation by mineral dust in mixed-phase clouds

James D. Atkinson[1], Benjamin J. Murray[1], Matthew T. Woodhouse[1]†, Thomas F. Whale[1], Kelly J. Baustian[1], Kenneth S. Carslaw[1], Steven Dobbie[1], Daniel O'Sullivan[1] & Tamsin L. Malkin[1]

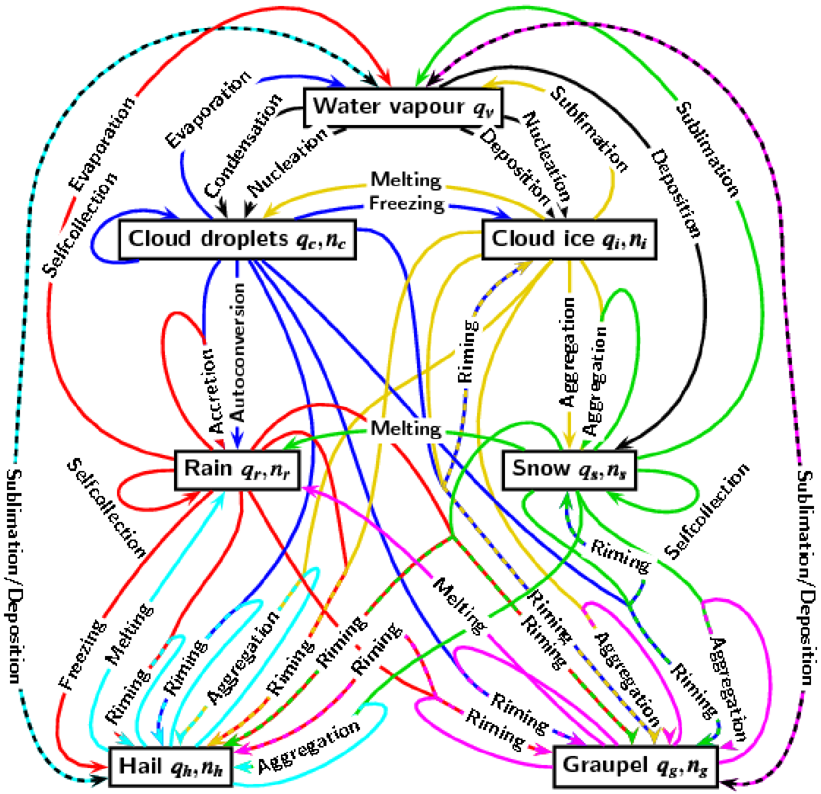


➔ Nature, 498 (7454) 358 – 355 (2013)

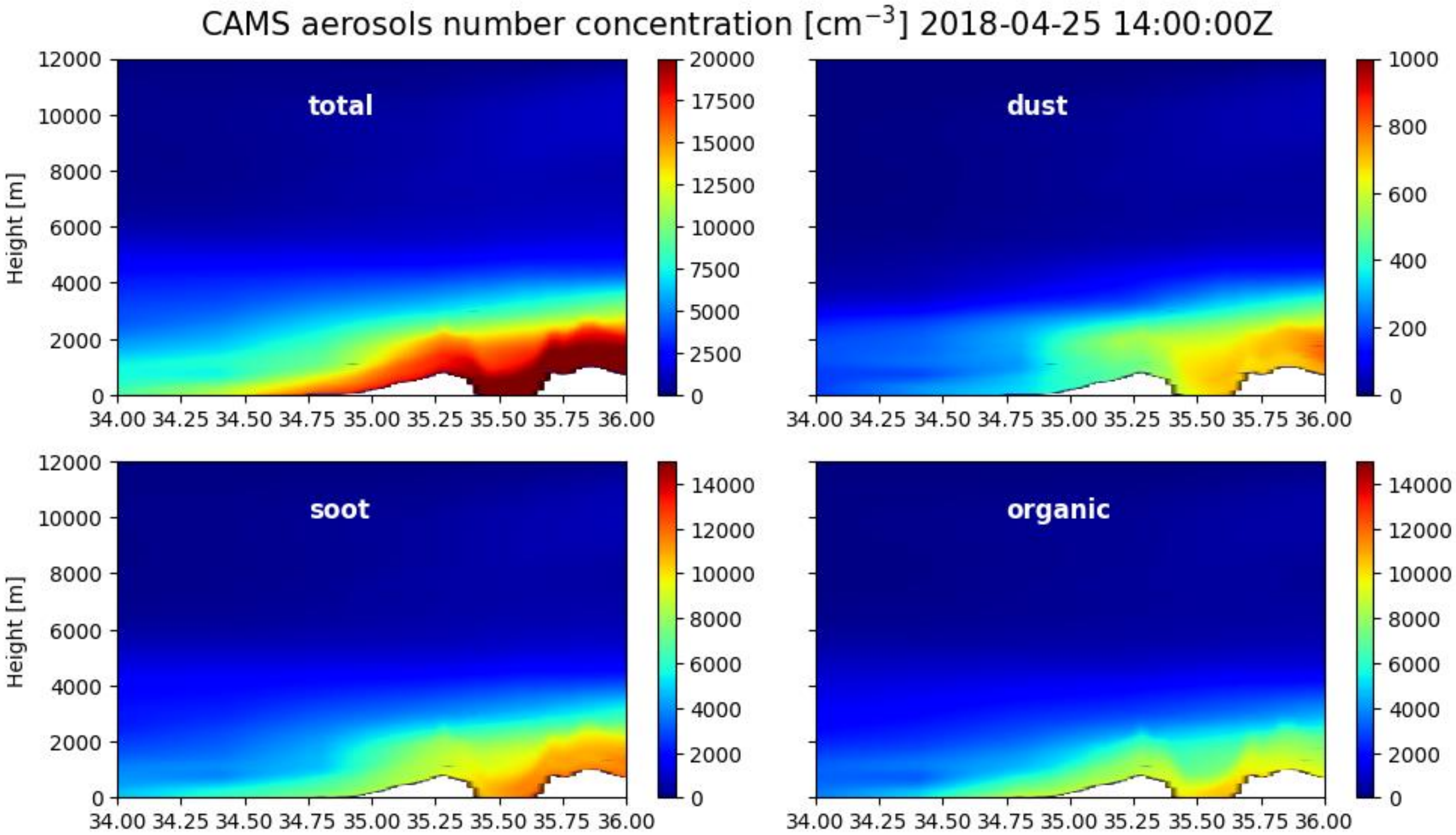
Prognostic aerosols in ice nucleation

- COSMO **2-mom** scheme is using Phillips (2008) heterogeneous ice nucleation scheme
- The homogenous nucleation used is based on Kaercher, Hendricks & Lohmann 2006 (KHL06 scheme) – not treated here
- In the Phillips parametrization ice nuclei (IN) number concentrations are assumed fixed:
  - $\mathrm{nc\_dust} = 0.162\ cm^{-3}$
  - $\mathrm{nc\_soot} = 15\ cm^{-3}$
  - $\mathrm{nc\_organic} = 177\ cm^{-3}$

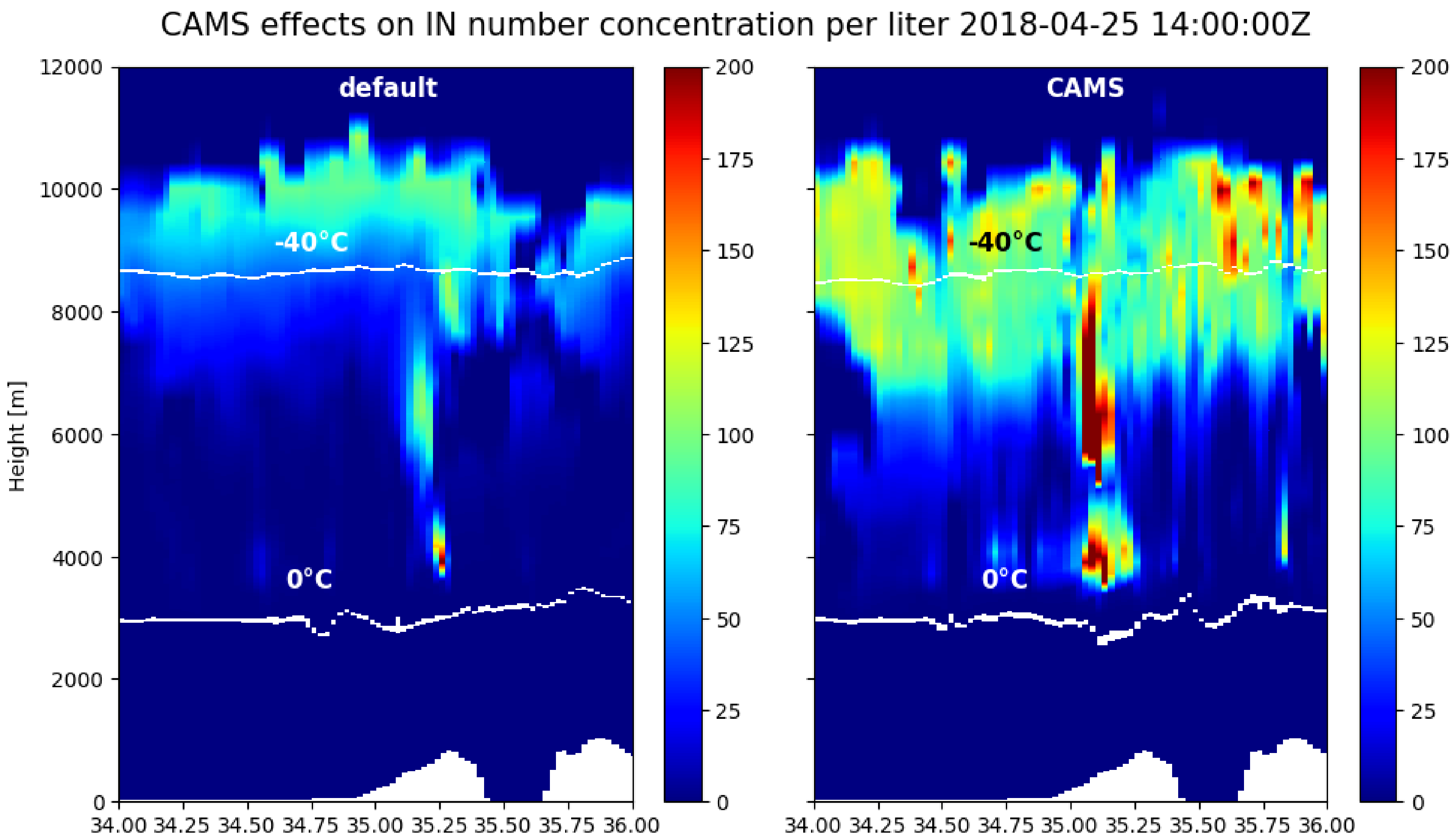
- The fraction of nucleation of each species is calculated from a look-up table based on temperature and super-saturation



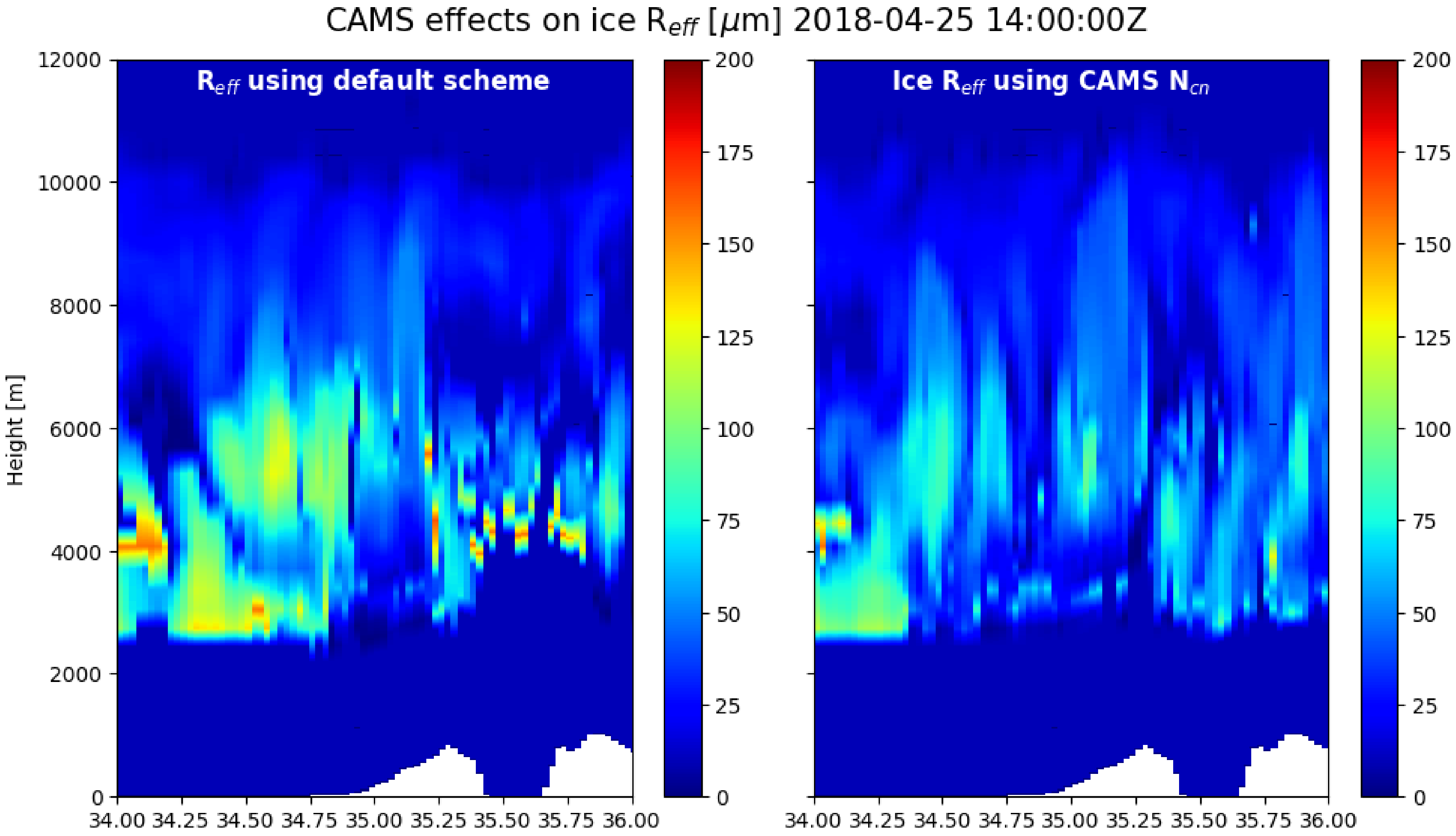
CAMS aerosols number concentration



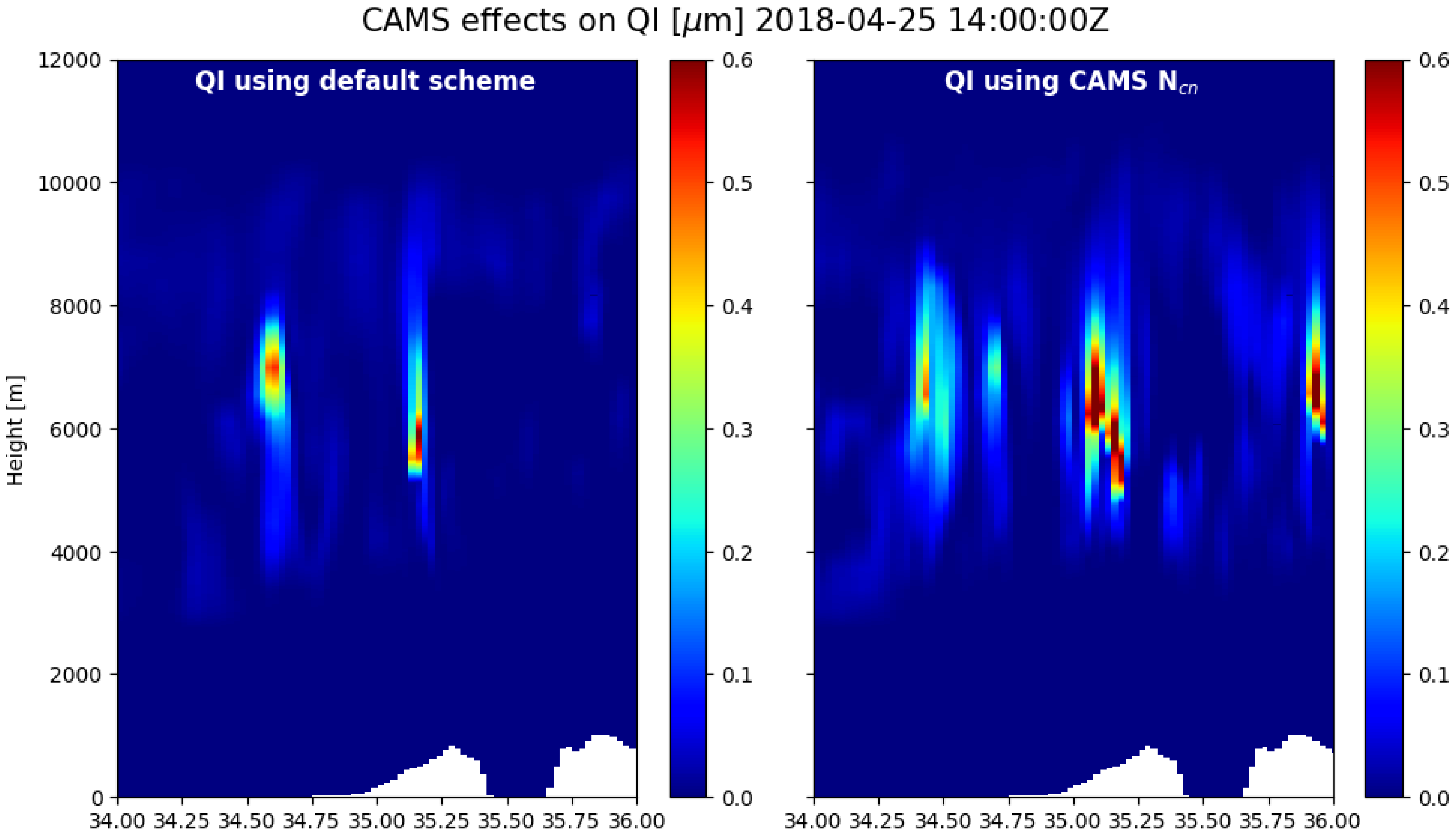
Ice number concentrations based on CAMS



R_{eff} based on CAMS



IWC based on CAMS



Concluding remarks and outlook

- A new cloud droplets number concentration based on CAMS prognostic aerosols concentrations and Segal & Khain nucleation scheme is implemented
- More realistic approach to define cloud droplets densities and effective radii of grid scale and sub-grid scale clouds
- High sensitivities of radiation, T2m, rain, QC etc.
- Prognostic aerosols are now available also in the 2-mom scheme's heterogeneous nucleation process

Outlook:

- Testing against observations
- Test version in IMS
- Same approaches in ICON model

The End