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# Testing & Tuning of Revised Cloud Radiation Coupling: $T^2(RC)^2$ and the new CLOUDRAD scheme

Harel Muskatel (IMS)

21th COSMO General Meeting, Rome, September 11, 2019

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

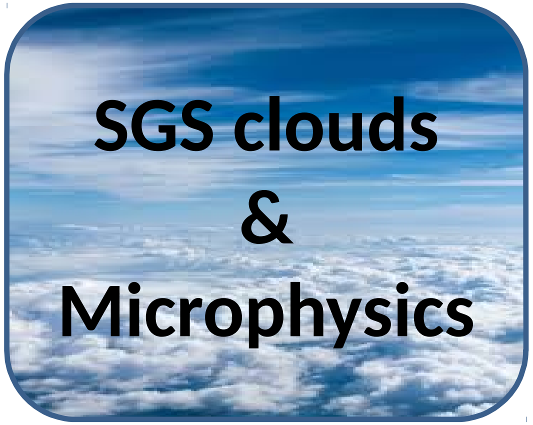
- **Project duration: September 2015 - February 2020**
- **Total FTEs : 11.1**

Participants:

- Harel Muskatel (IMS)
- Pavel Khain (IMS)
- Alon Shtivelman (IMS)
- Gdaly Rivin (RHM)
- Natalia Chubarova (RHM)
- Marina Shatunova (RHM)
- Alexey Poliukhov (RHM)
- Alexander Kirsanov (RHM)
- Ulrich Blahak (DWD)
- Matthias Raschendorfer (DWD)
- Martin Kohler (DWD)
- Daniel Rieger (DWD)
- Oliver Fuhrer (MCH)
- Xavier Lapillonne (MCH)
- Simon Gruber (KIT)

# Main achievements







New Cloud
Optics

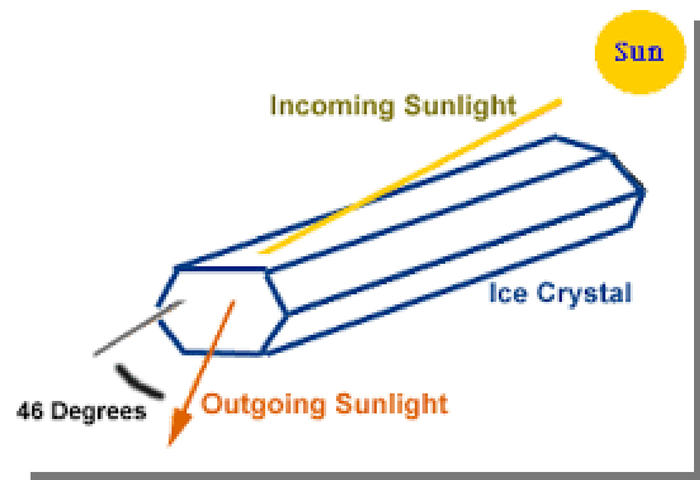
# New optical properties parametrizations

- Optical properties:
- Optical properties: $\beta_{ext} = \int_0^\infty \sigma_{ext}(D)N(D)dD$ ,

$$\varpi = \beta_{sca}/\beta_{ext}$$

$$g = \frac{\int_0^\infty g_p(D)\sigma_{sca}(D)N(D)dD}{\int_0^\infty \sigma_{sca}(D)N(D)dD}$$

- Default RG92 scheme:
- New CLOUDRAD scheme:
- Default RG92 scheme: $opt\_prop = f(q_x, \lambda)$
- Implemented in both COSMO and ICON
- New CLOUDRAD scheme: $opt\_prop = f(q_x, \lambda,\ R_{eff})$
- Implemented in both COSMO and ICON



# Liquid hydrometeors

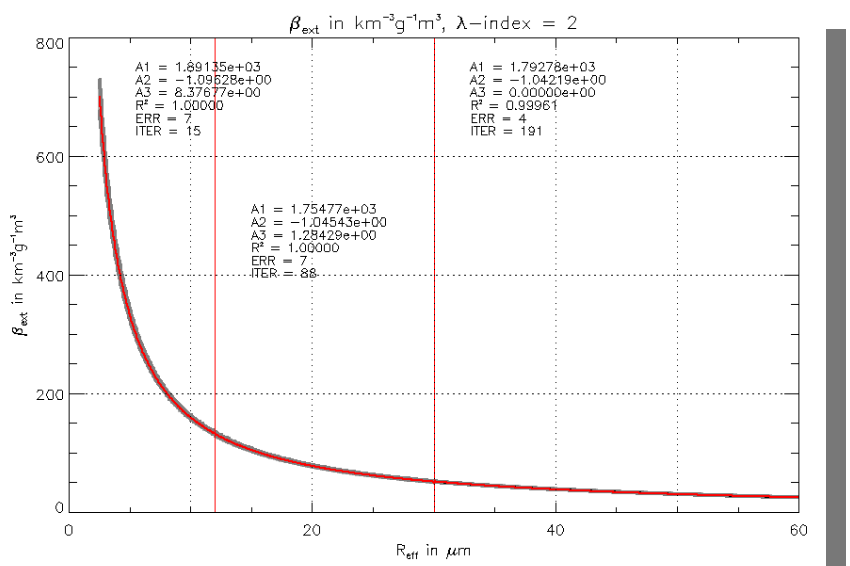
- COSMO - new optical properties after Hu and Stamnes (1993)
  **iradpar_cloud > 1**
- Special spectral ramping to the COSMO-8-band scheme
- Expending the validity range from original RG92 – include rain
- Large size approximation used

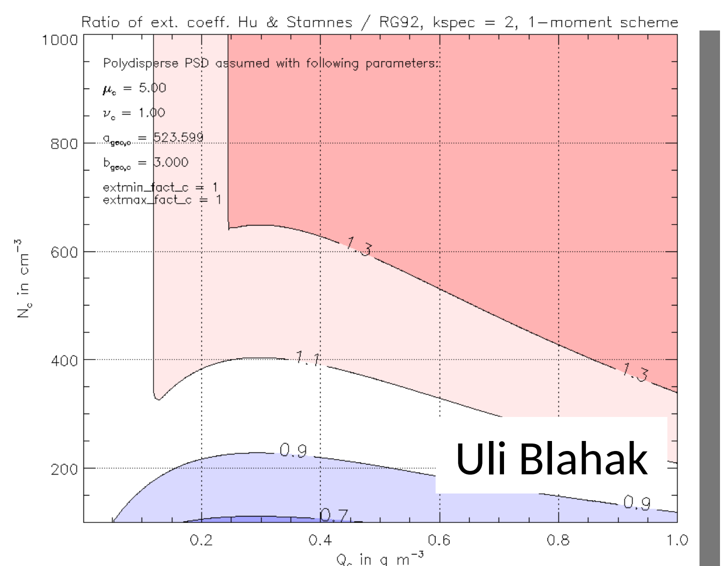

- COSMO - new optical properties after Hu and Stamnes (1993)


- $f(R_e) = a_1 R_e^{a_2} + a_3 \rightarrow R_e = \frac{1}{2}\frac{\int_0^\infty D^3 N(D)dD}{\int_0^\infty D^2 N(D)dD} = \frac{1}{2}\frac{M_3}{M_2} = c_1\left(\frac{LWC}{n_w}\right)^{c_2}$
- $n_w$ can calculated in three different ways (to be discussed later)


- Special spectral ramping to the COSMO-8-band scheme
- Expending the validity range from original RG92 – include rain

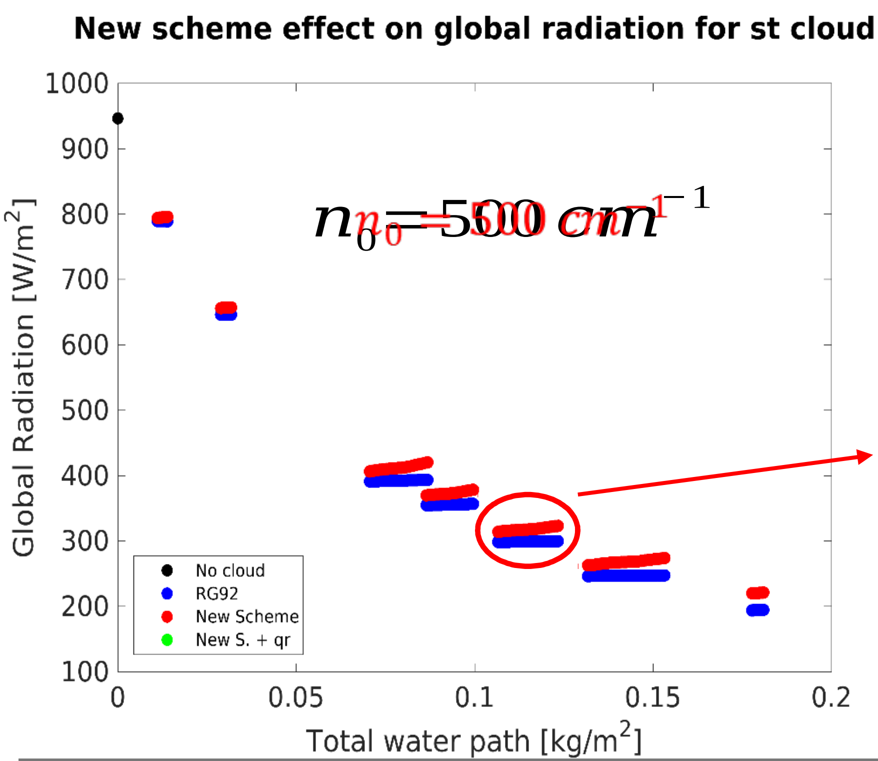

- Large size approximation used $\lim_{R/\lambda \to \infty} \sigma_{ext} = 2A_{geo};\ A_{geo} = \pi R^2$

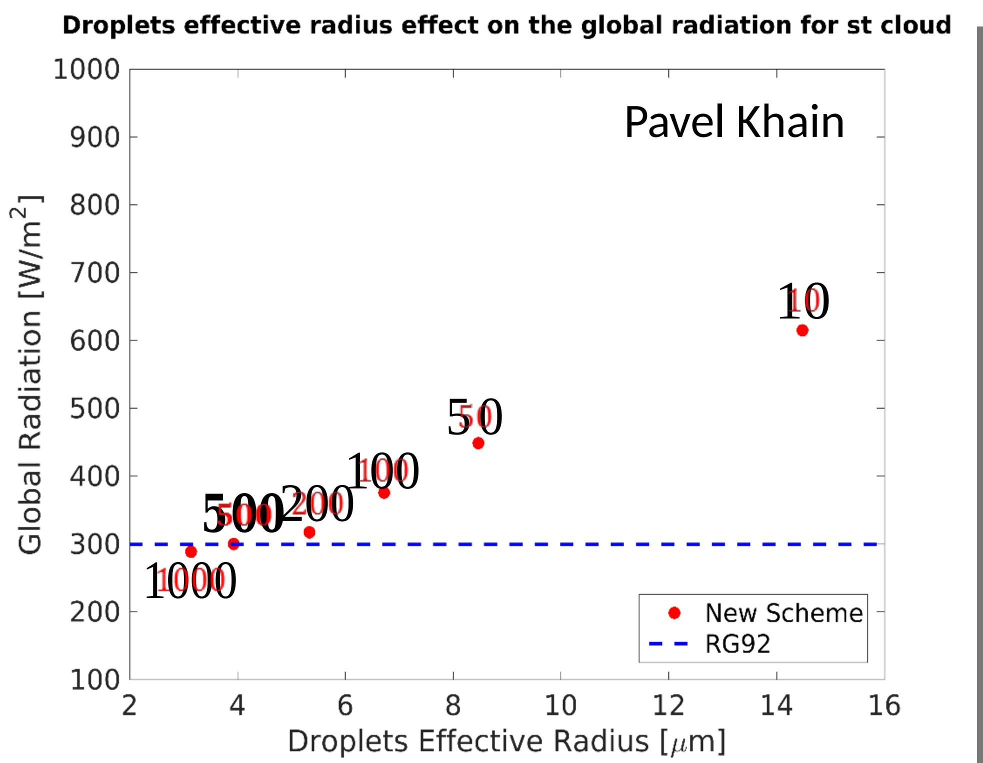


# Liquid hydrometeors

- Idealized COSMO runs with tailored 7 stratus clouds cases
- 6 hours run with fixed SZA almost stable and homogeneous clouds
- Each case with different cloud thickness

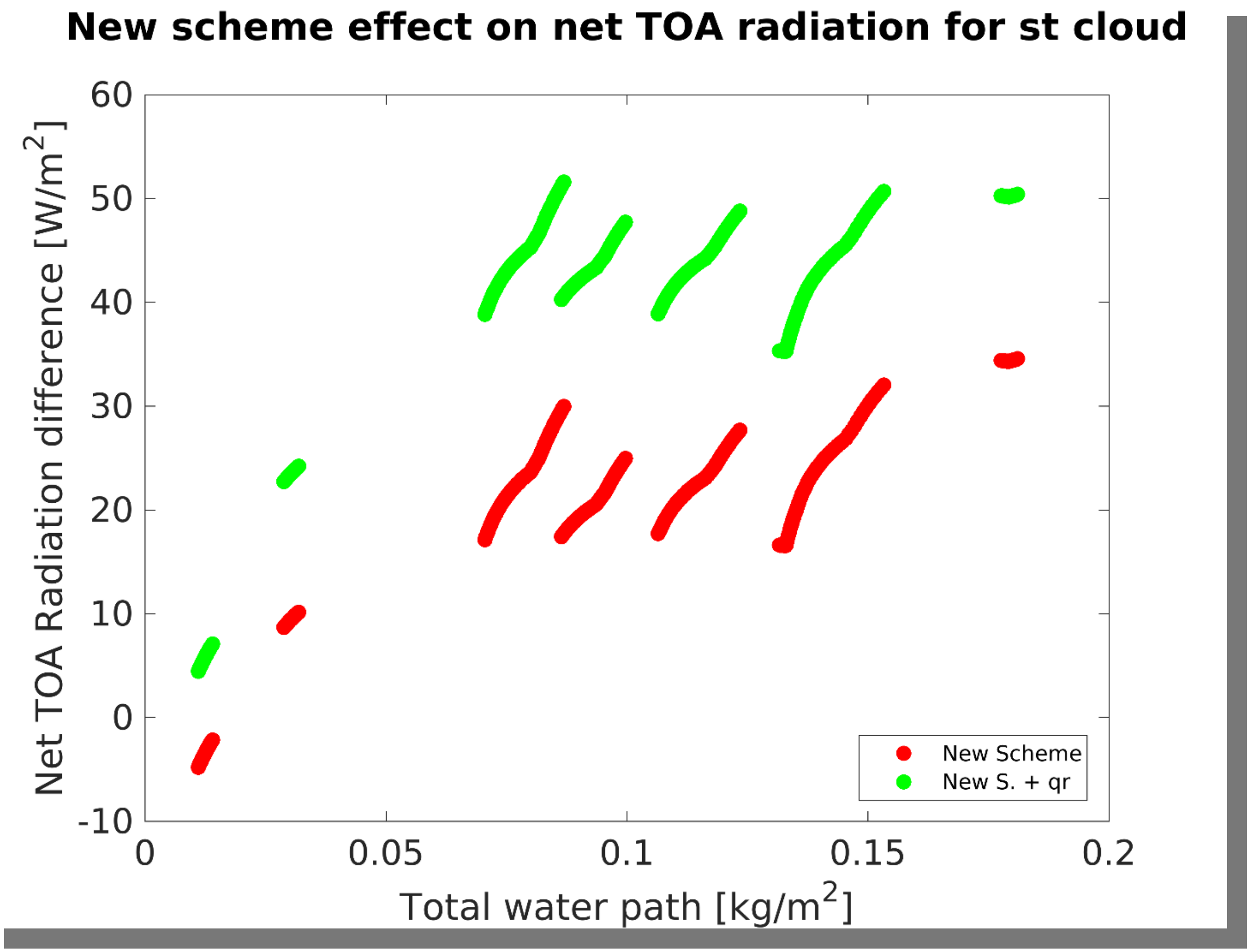



$$N_{CLOUDRAD} = n_0 \exp\left(-\frac{z - z_{CB}}{\lambda}\right), z_{CB} = 2000\ m, \lambda = 2000\ m$$

$$if\ z < z_{CB}\ \ N_{CLOUDRAD} = n_0$$

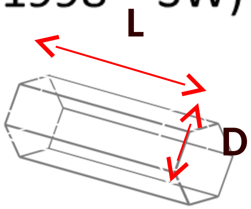
# Liquid hydrometeors




**Warming** effect of the new scheme compared with RG92!

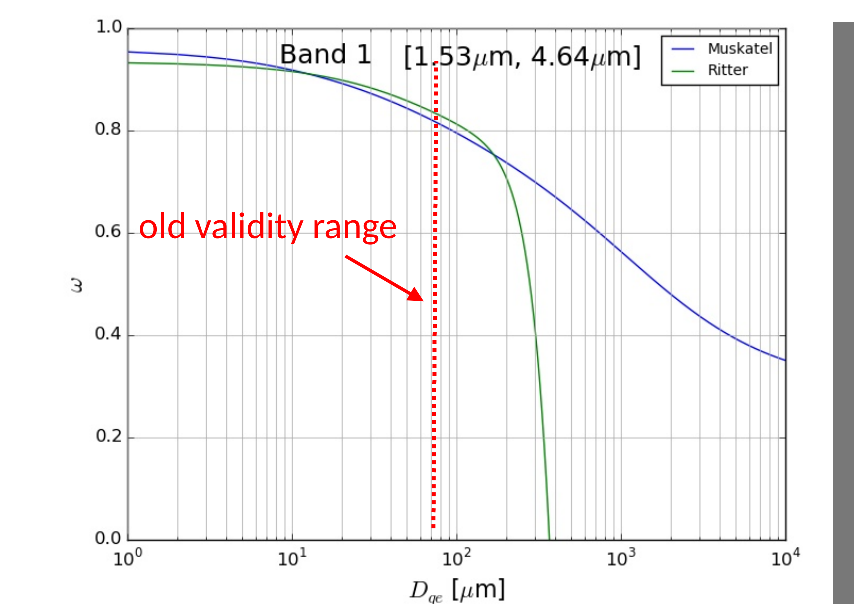
# Ice hydrometeors

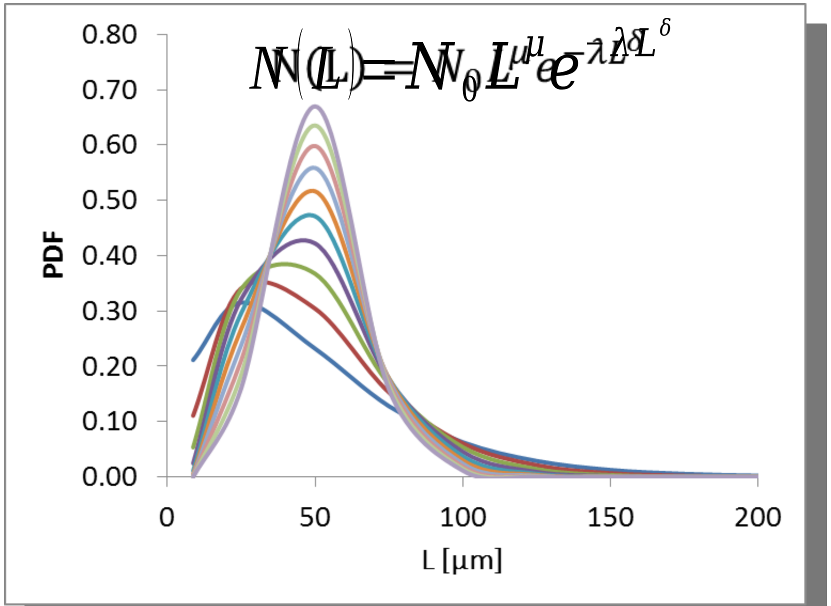
- Single particle optical properties after Fu (1996 – LW, 1998 – SW)
- Assuming randomly oriented hexagonal particles
- Using AR and $D_{ge}$ as the bulk parameters:




$$\beta, g, \bar{\omega} = \sum_{i=0}^{i=n} a_i \mathrm{Re}^i \quad AR = \frac{\int_{L_{min}}^{L_{max}} \left(\frac{D}{L}\right) A_c N(L)\, dL}{\int_{L_{min}}^{L_{max}} A_c N(L)\, dL} \quad \beta_{ext}, \bar{\omega}(D_{ge}) = \frac{\sum_{i=0}^{n} a_i D_{ge}^i}{\sum_{i=0}^{m} b_i D_{ge}^i} \quad g(AR) = \frac{\sum_{i=0}^{n} a_i AR^i}{\sum_{i=0}^{m} b_i AR^i}$$

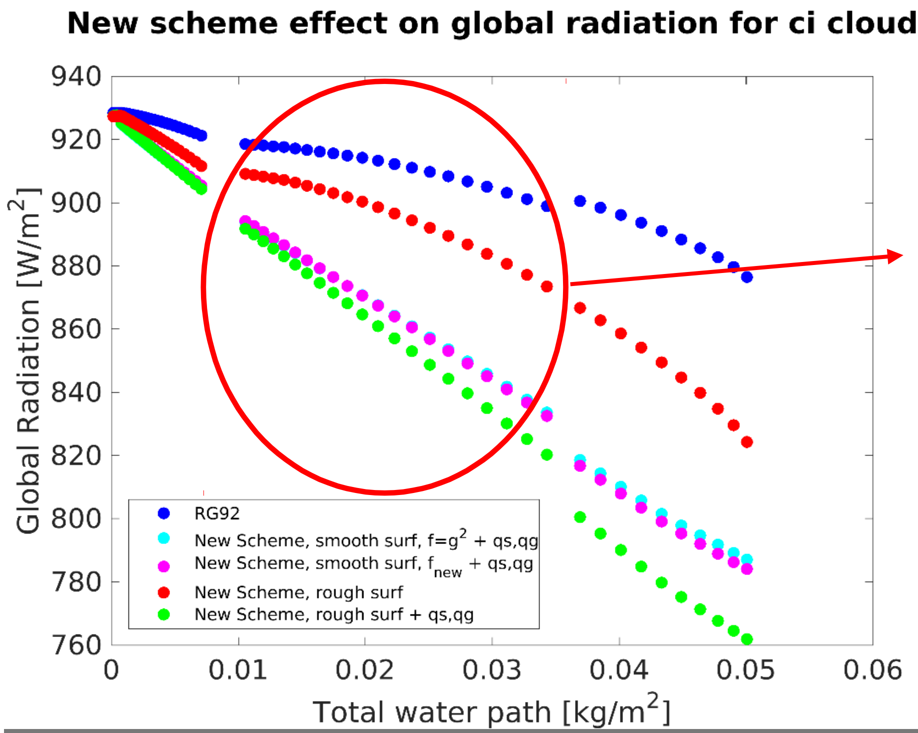
- The size range was expended by using 7000 generalized gamma distributions
- Large size approximation to include snow and graupel
- Including rough or smooth particles (rough is recommended)

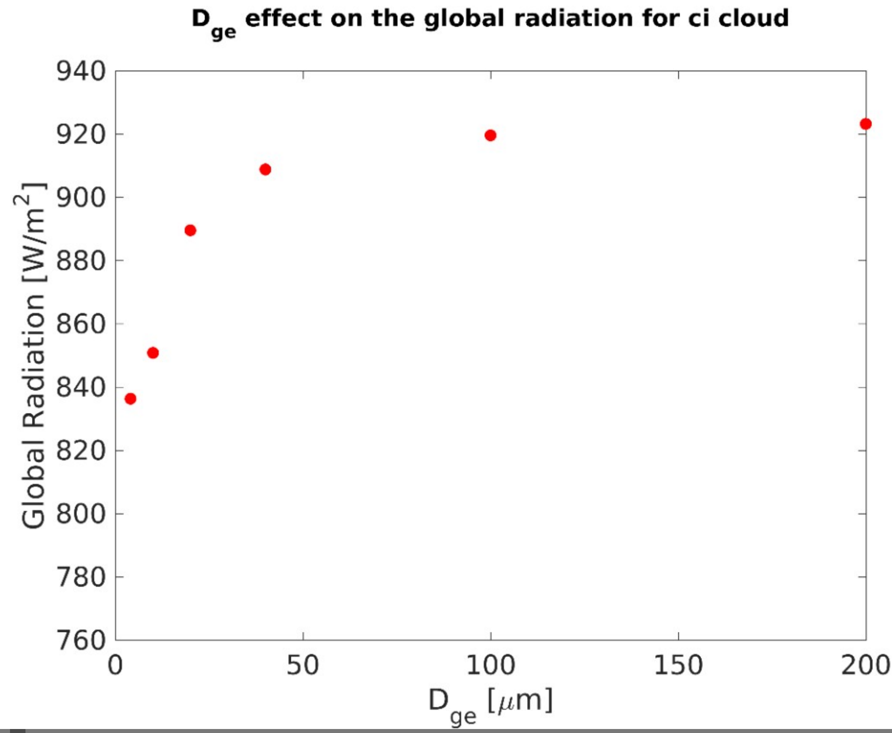


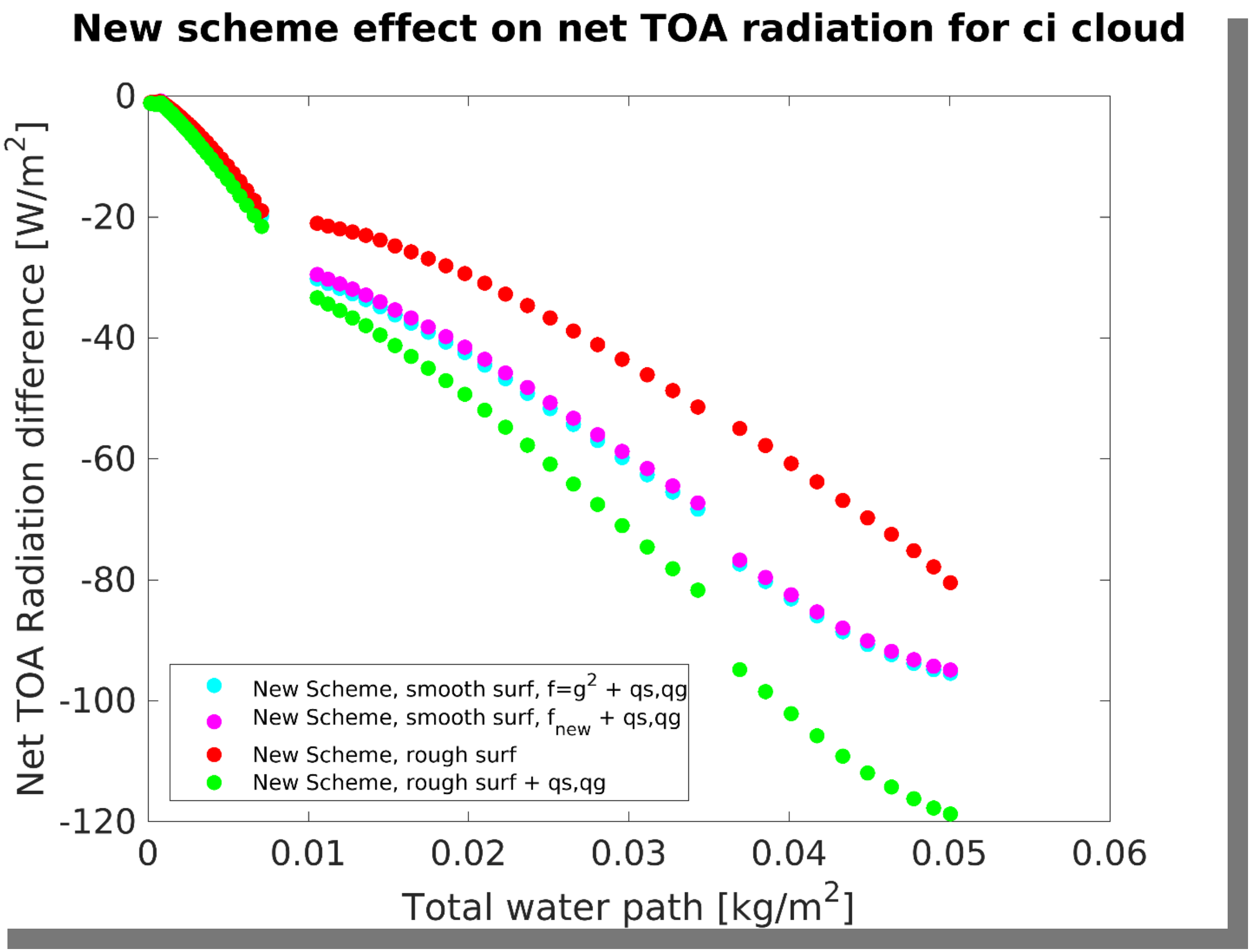
# Ice hydrometeors

Idealized COSMO runs with tailored 3 cirrus clouds cases



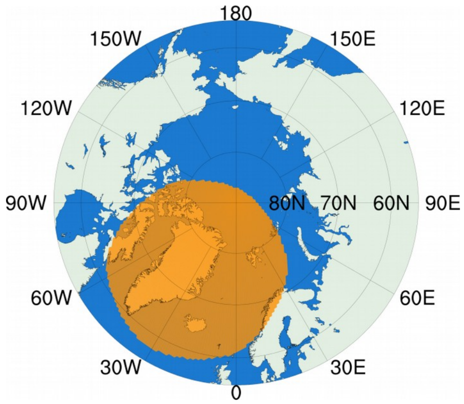



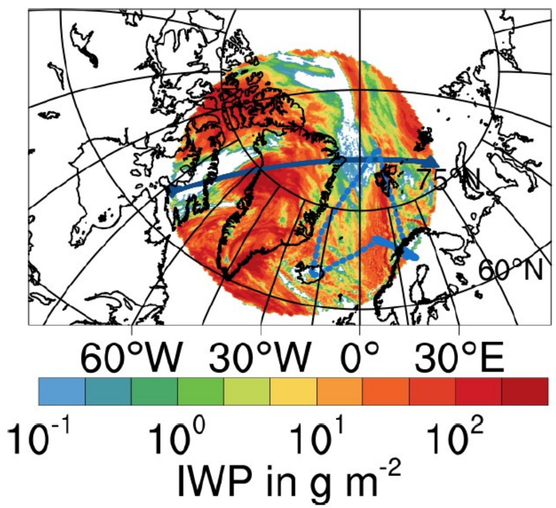
# Ice hydrometeors




**Cooling** effect of the new scheme compared with RG92!

# Validation: CALIPSO : Simon Gruber’s work



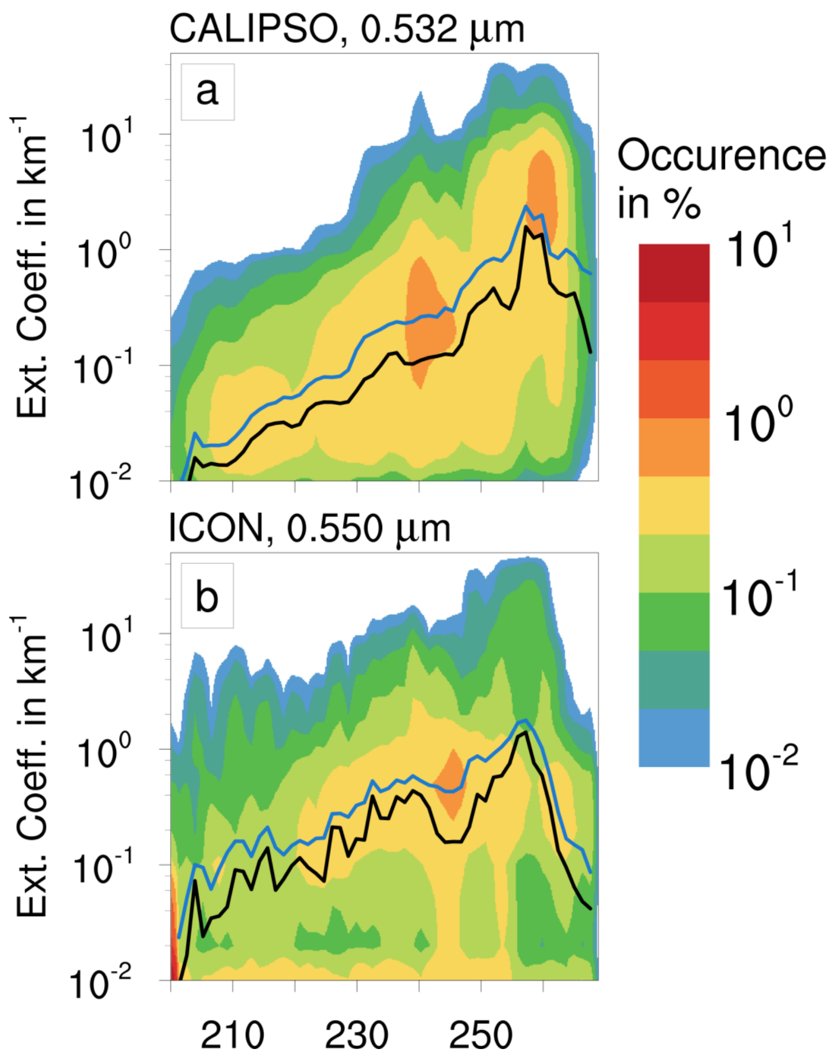



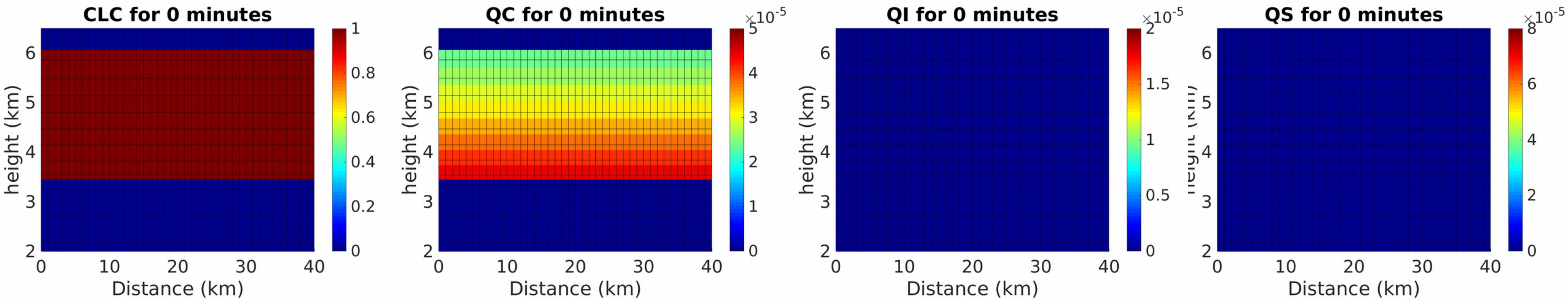

**Figure 5.** Two-dimensional probability distribution of the extinction coefficient with respect to temperature sampled along all tracks of CALIPSO crossing the simulation domain during the entire integration time for CALIPSO (a) and reference simulation (b). Black (blue) lines indicate average (median)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

# 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

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

## Mixed phase cloud






Pavel Khain

# 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

# Automatic (CALMO) calibration

- 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

**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**

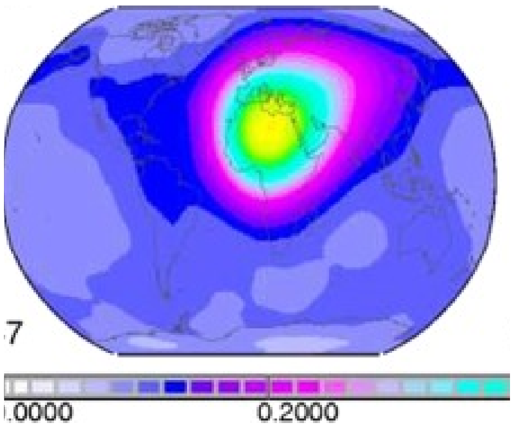
| | Basic | CAMS | SK basic | SK-SAM |
|---|---|---|---|---|
| radqcfact | 0.712 | 0.475 | 0.483 | 0.493 |
| radqifact | 0.498 | 0.489 | 0.501 | 0.496 |
| reff_ini_c (*$10^{-6}$) | 5.955 | 5.618 | | |
| qvsatfact_sgscl_rad | 0.009 | 0.014 | 0.017 | 0.018 |
| cloud_num_rad (*$10^{8}$) | 1.317 | 1.191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


New Aerosols
Options

# Aerosols input for COSMO radiation

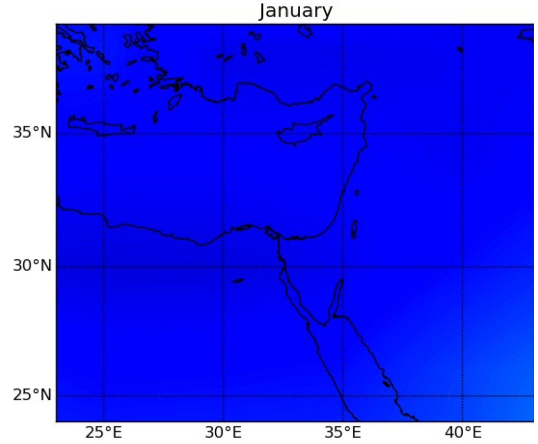
## Tanre (1983)

itype_aerosol = 1



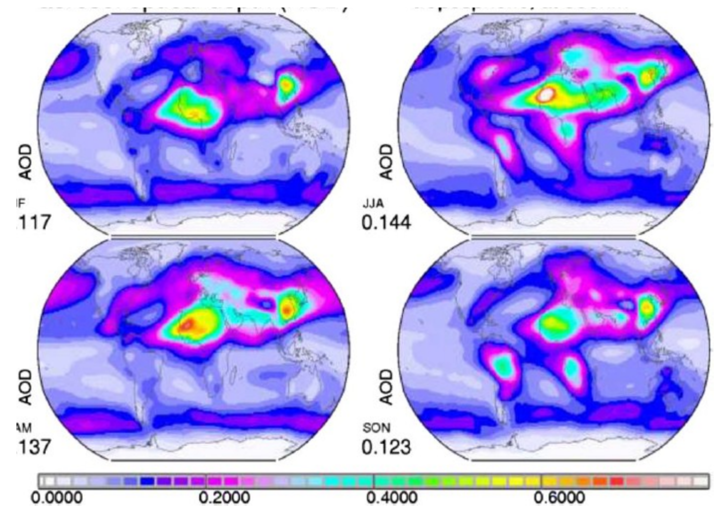

## Tegen (1997)

itype_aerosol = 2



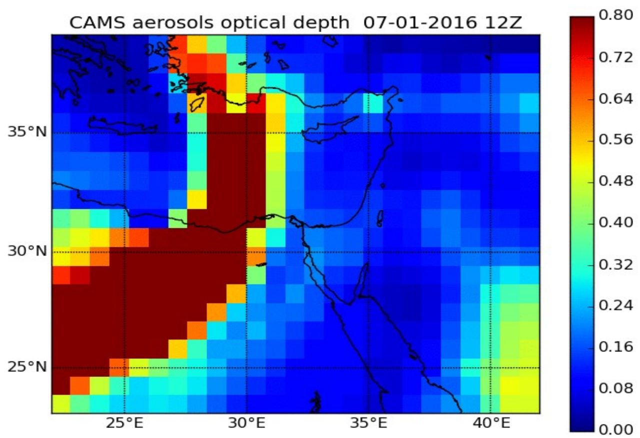

## MACv2 - Kinne (2013)

itype_aerosol = 3



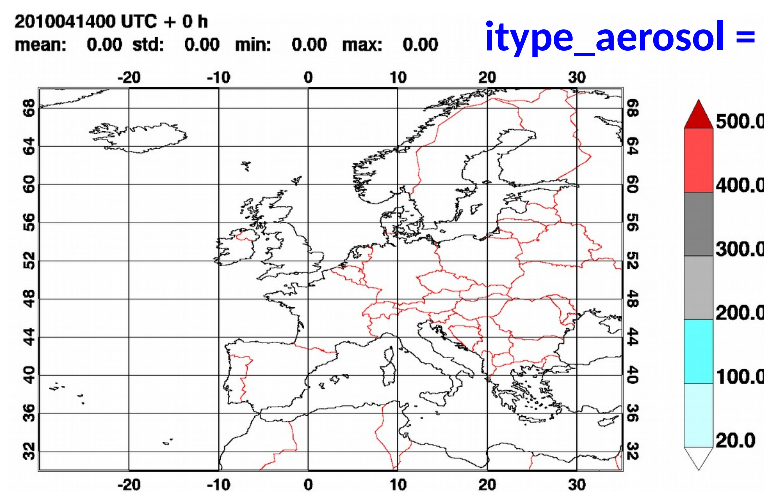

## CAMS-ECMWF

itype_aerosol = 4




## ICON-ART

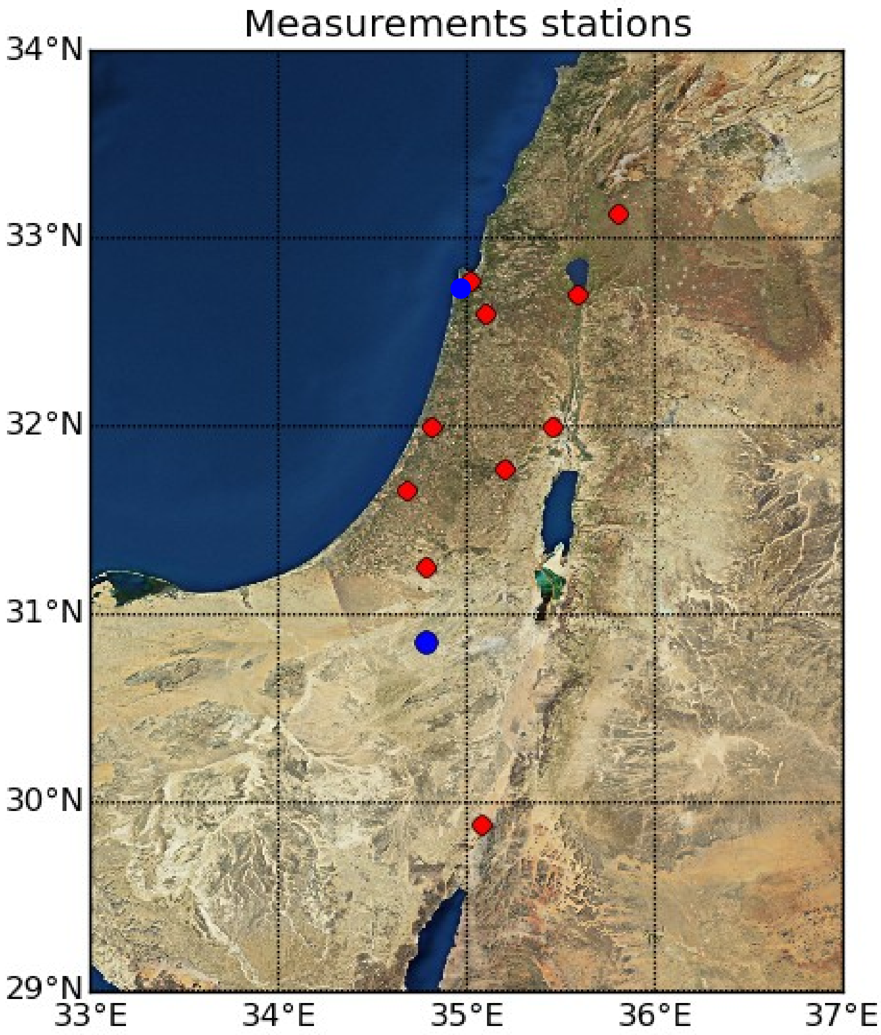
itype_aerosol = 5



# COSMO-CAMS verifications

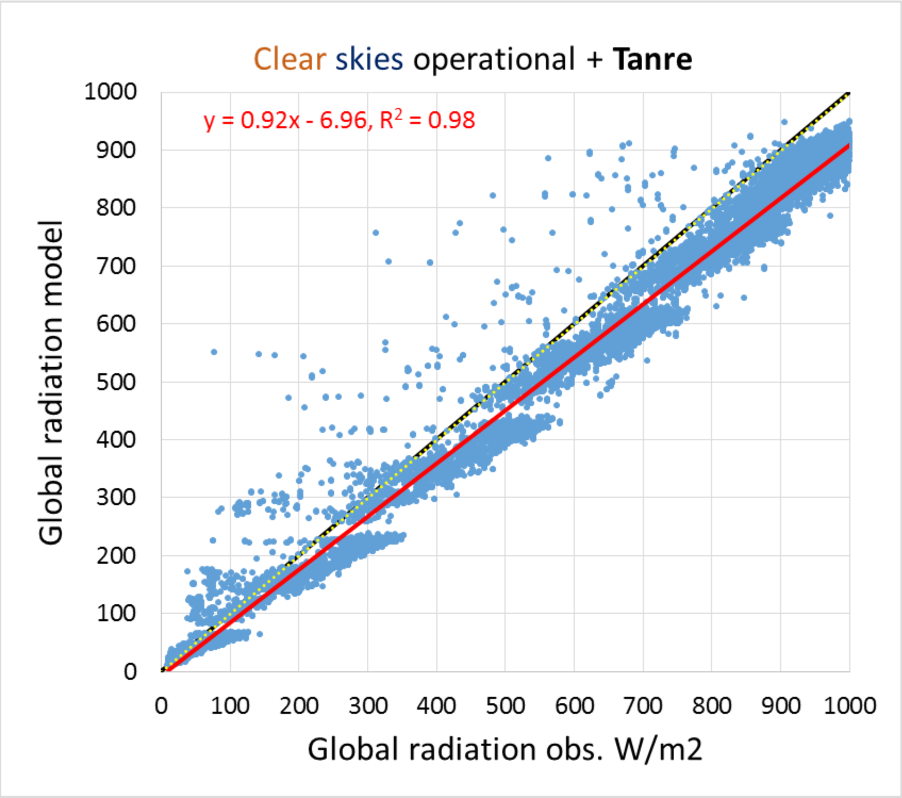
- 10 measurement stations (GR, T, Tmax)
- **2 AEORNET** station in Sede-Boker & Technion (AOD)

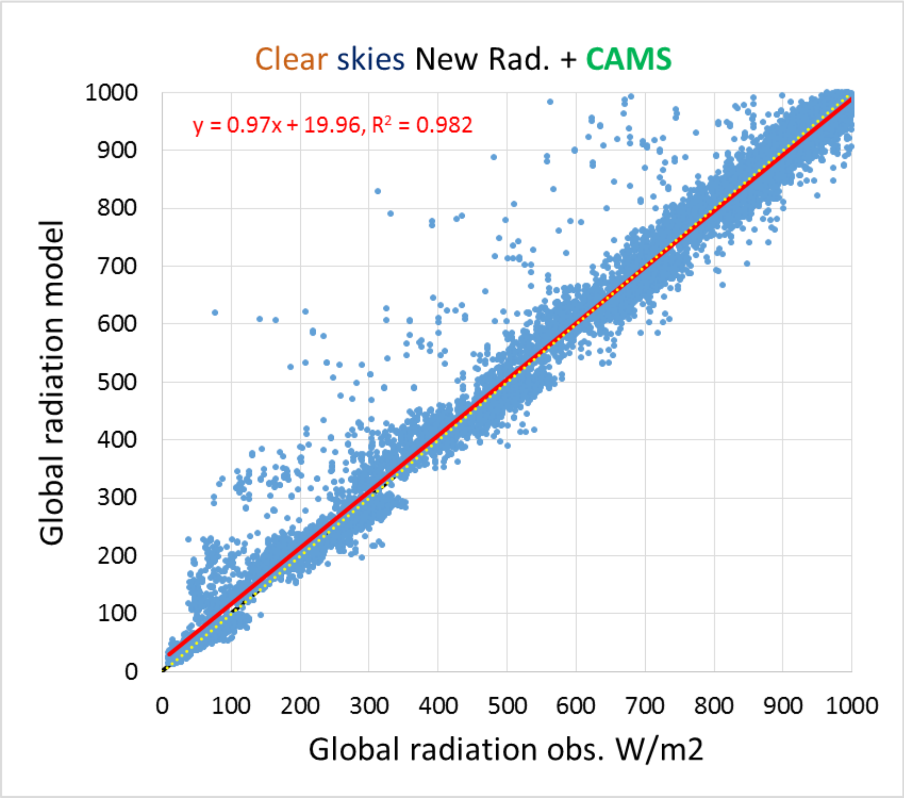
AERONET
AEROSOL ROBOTIC NETWORK



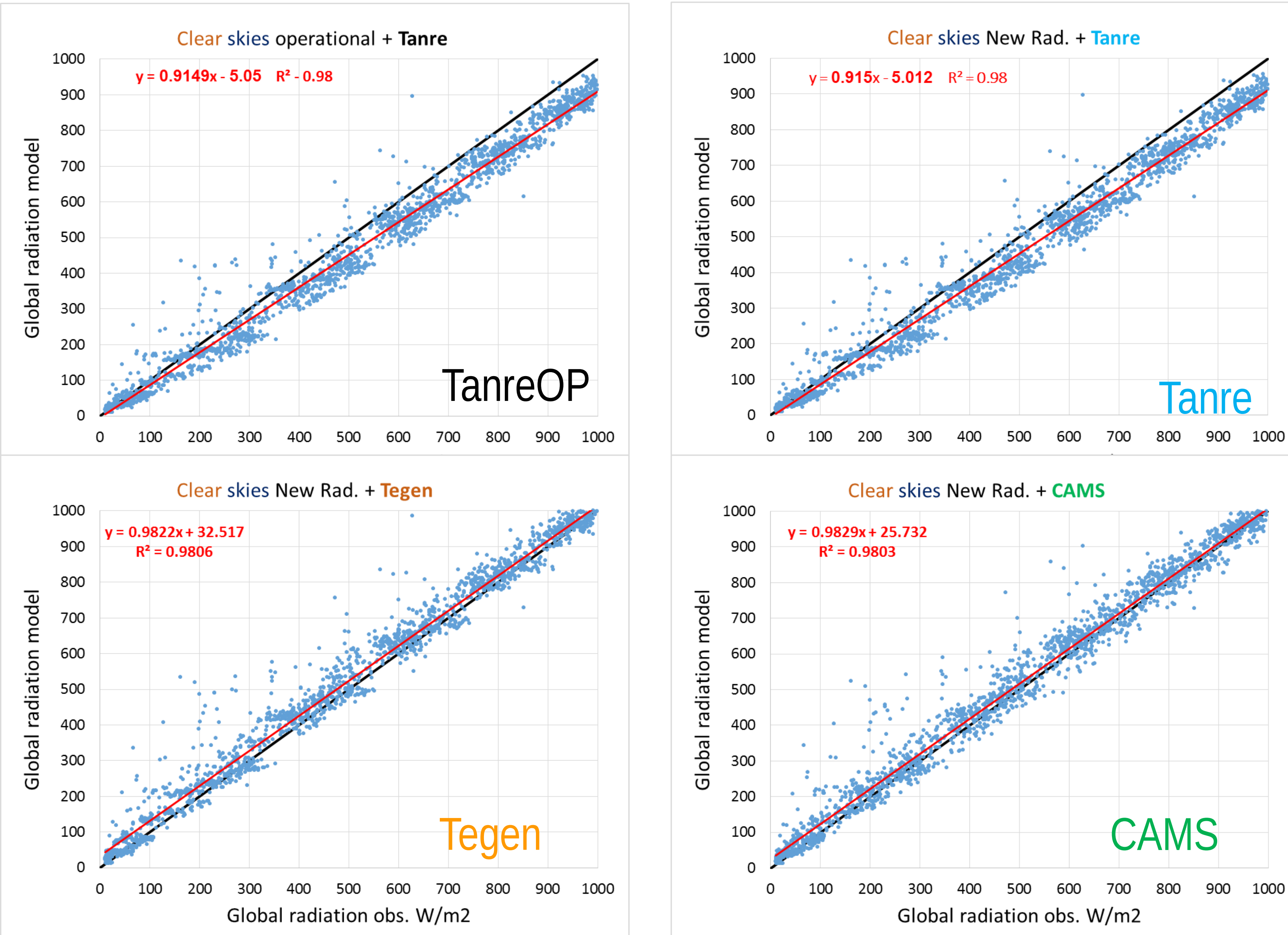
# Global radiation – model vs. Obs. clear skies

## Jun-Aug 2017



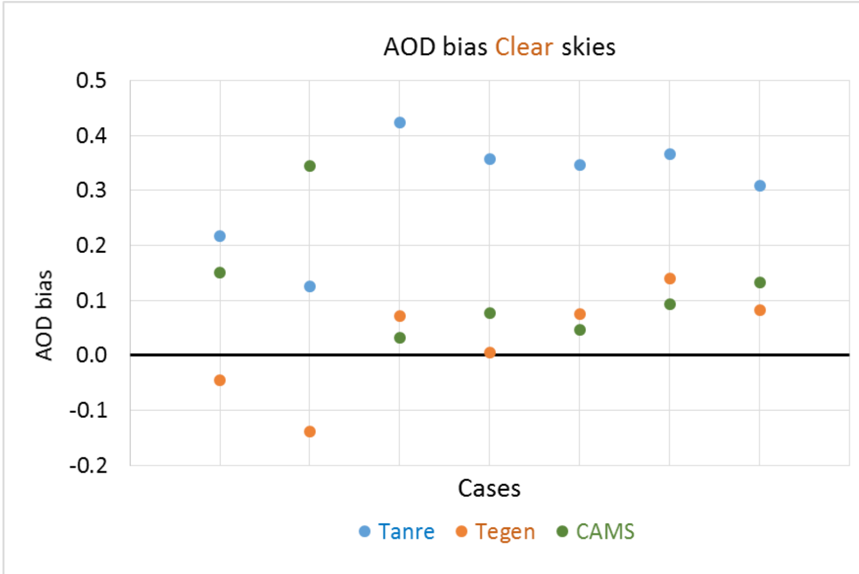



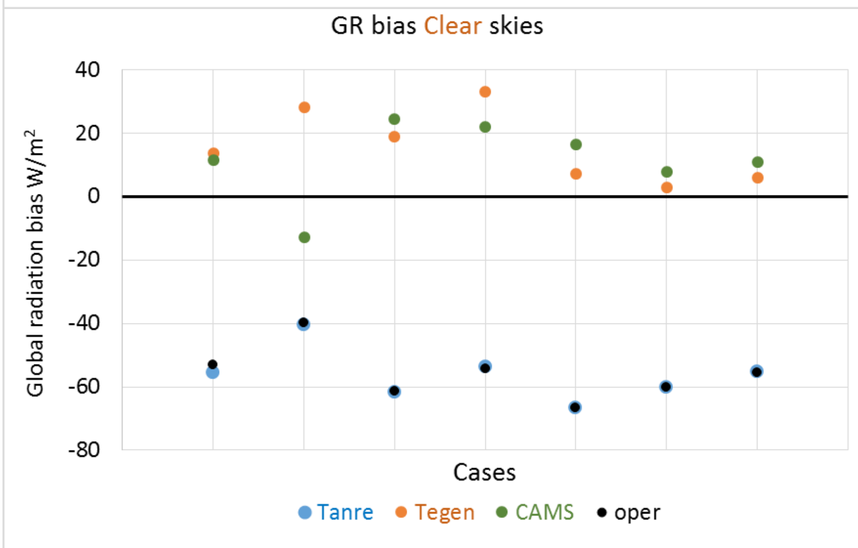
# 29 test cases in different weather situations



# Global radiation and AOD – model vs. Observations clear skies

Cases:
2015-05-17
2015-05-18
2016-02-14
2016-02-26
2016-04-18
2016-06-19
2016-06-24



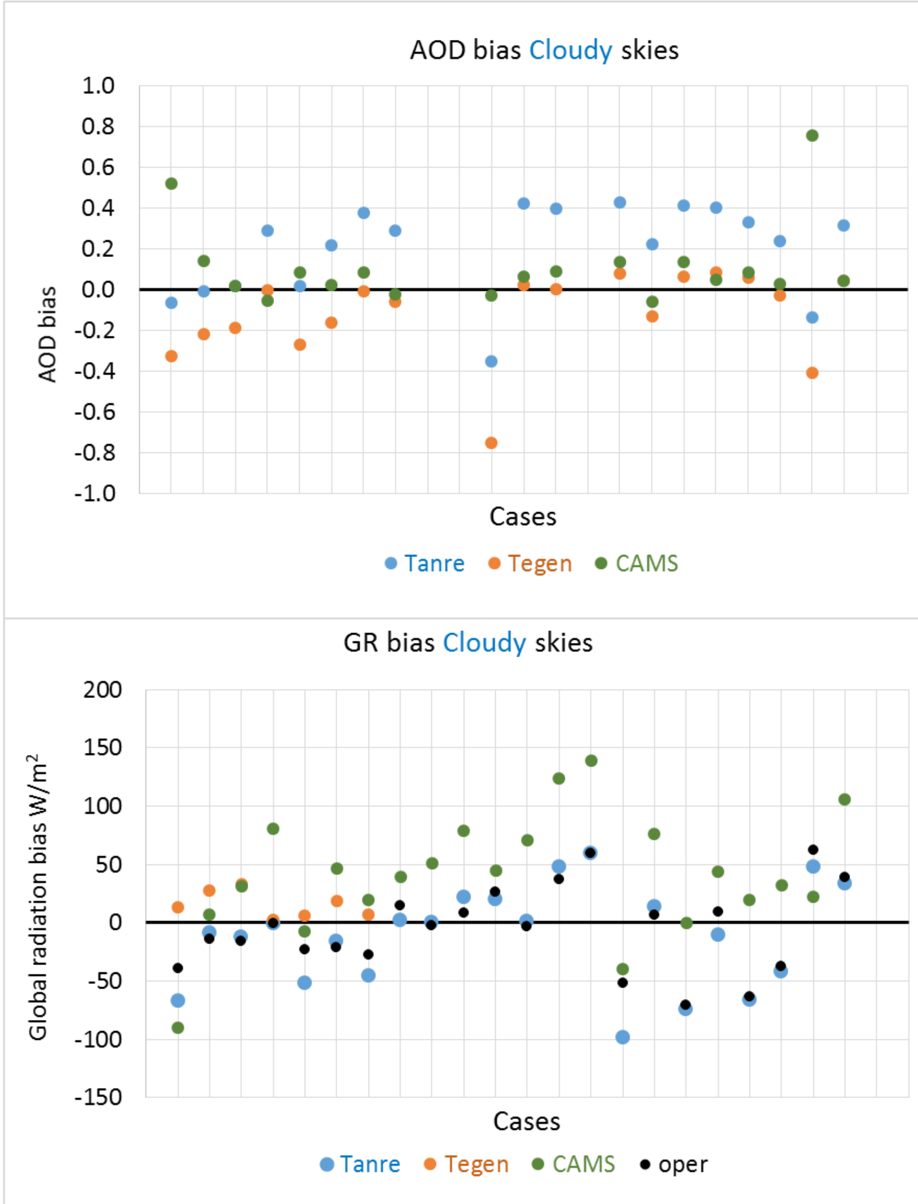

AOD bias:
Tanre 0.31
Tegen 0.03
CAMS 0.12

GR bias:

| | |
|---|---|
| TanreOP | -55.9 $W/m^2$ |
| Tanre | -56.2 $W/m^2$ |
| Tegen | 15.6 $W/m^2$ |
| CAMS | 11.4 $W/m^2$ |

# Global radiation and AOD – model vs. Observations cloudy skies

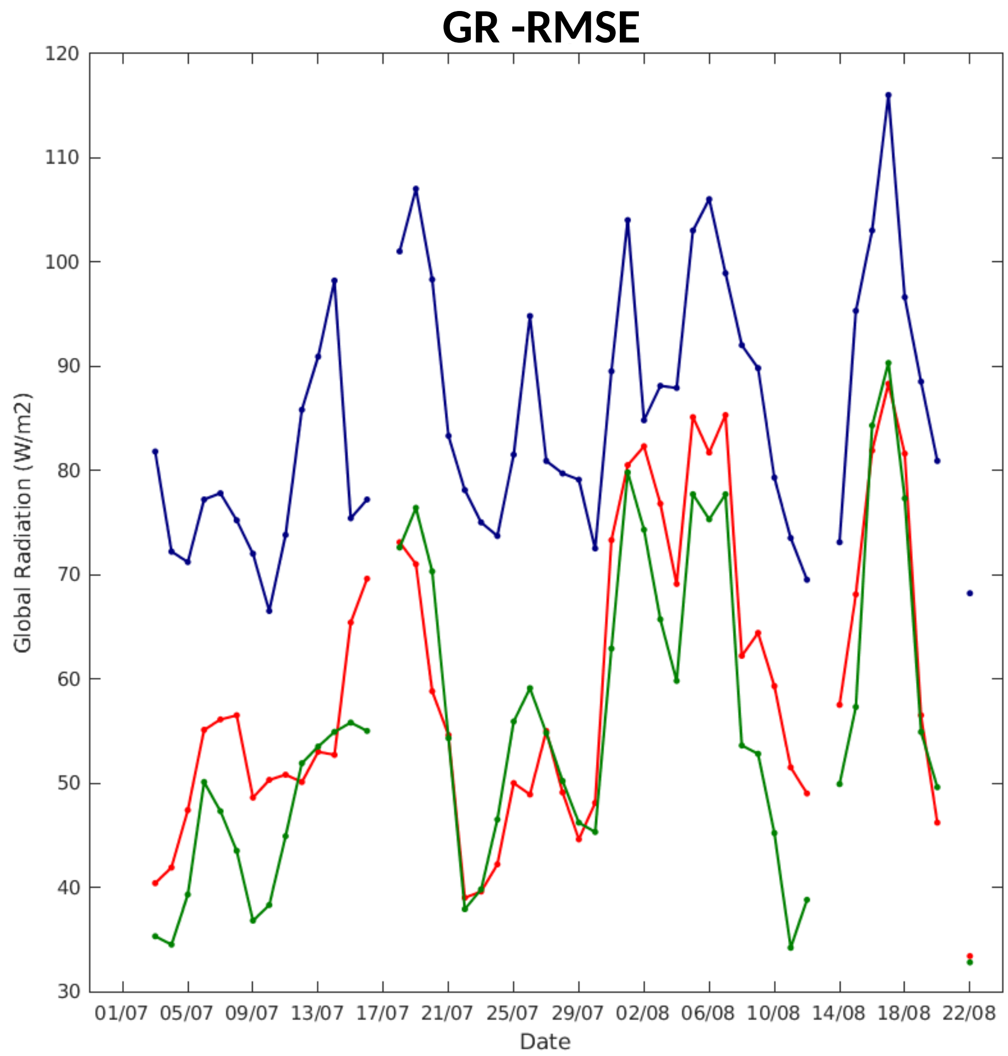
Cases:
2015-05-27
2015-09-14
2015-09-15
2015-10-07
2015-10-12
2015-11-08
2015-11-28
2015-12-17
2015-12-31
2016-01-01
2016-01-07
2016-01-13
2016-01-24
2016-01-26
2016-02-17
2016-02-21
2016-02-28
2016-03-23
2016-04-03
2016-04-06
2016-04-09
2016-04-12




AOD bias:
Tanre 0.20
Tegen -0.12
CAMS 0.11

GR bias:
TanreOP -4.8 W/m²
Tanre -11.1 W/m²
Tegen 54.2 W/m²
CAMS 40.7 W/m²

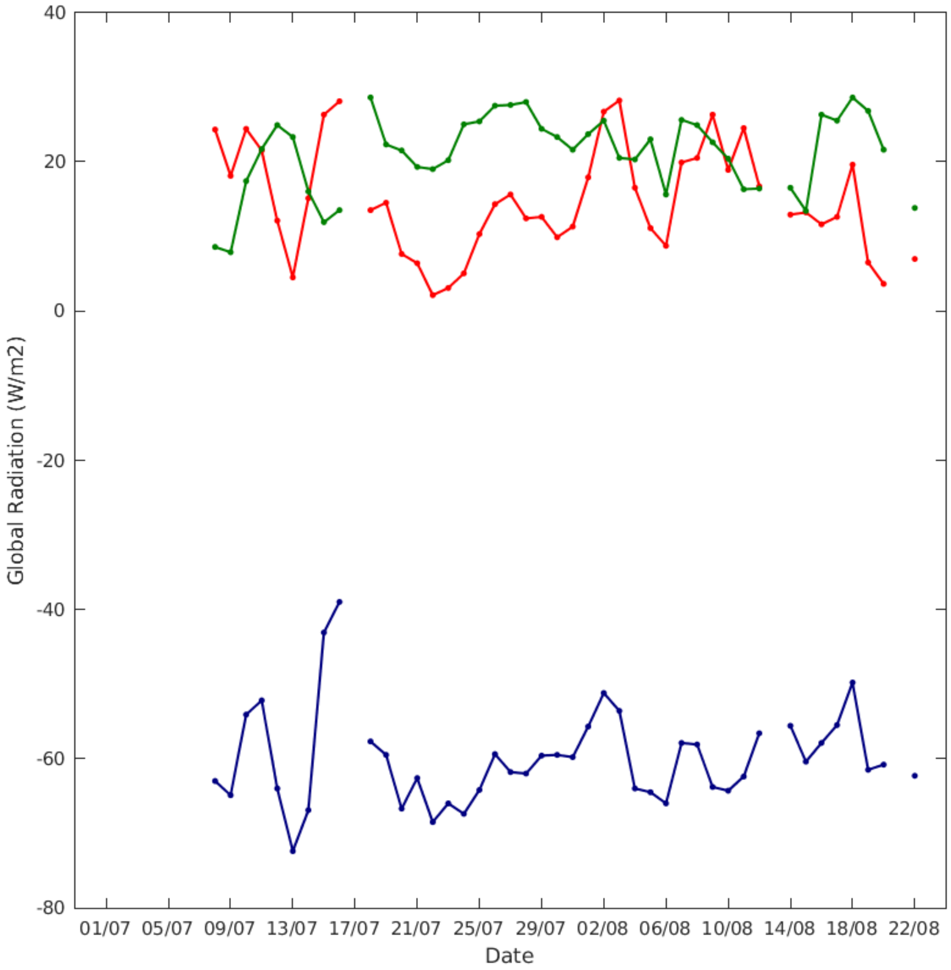
# New CLOUDRAD tested in IMS




EC / CAMS climatology
COSMO – default / Tanre
CLOUDRAD / CAMS

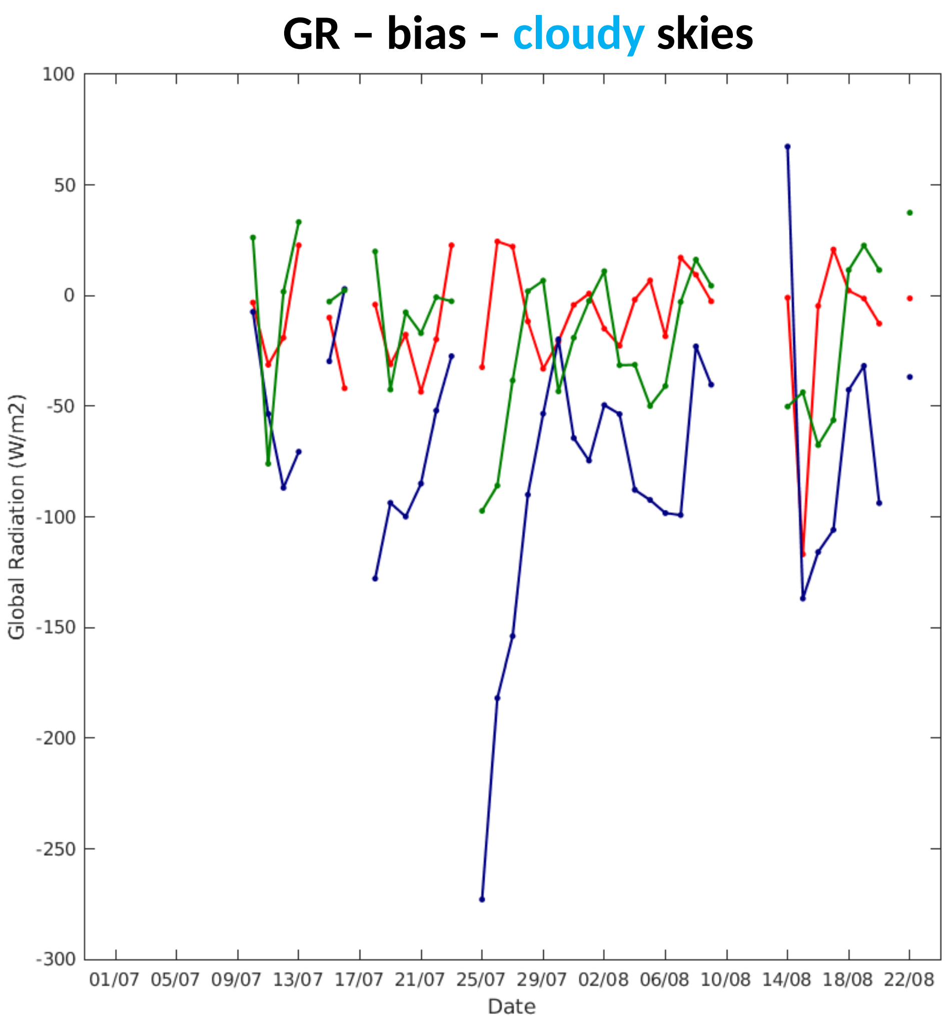
# New CLOUDRAD tested in IMS

GR – bias – clear skies




EC / CAMS climatology
COSMO – default / Tanre
CLOUDRAD / CAMS

# New CLOUDRAD tested in IMS



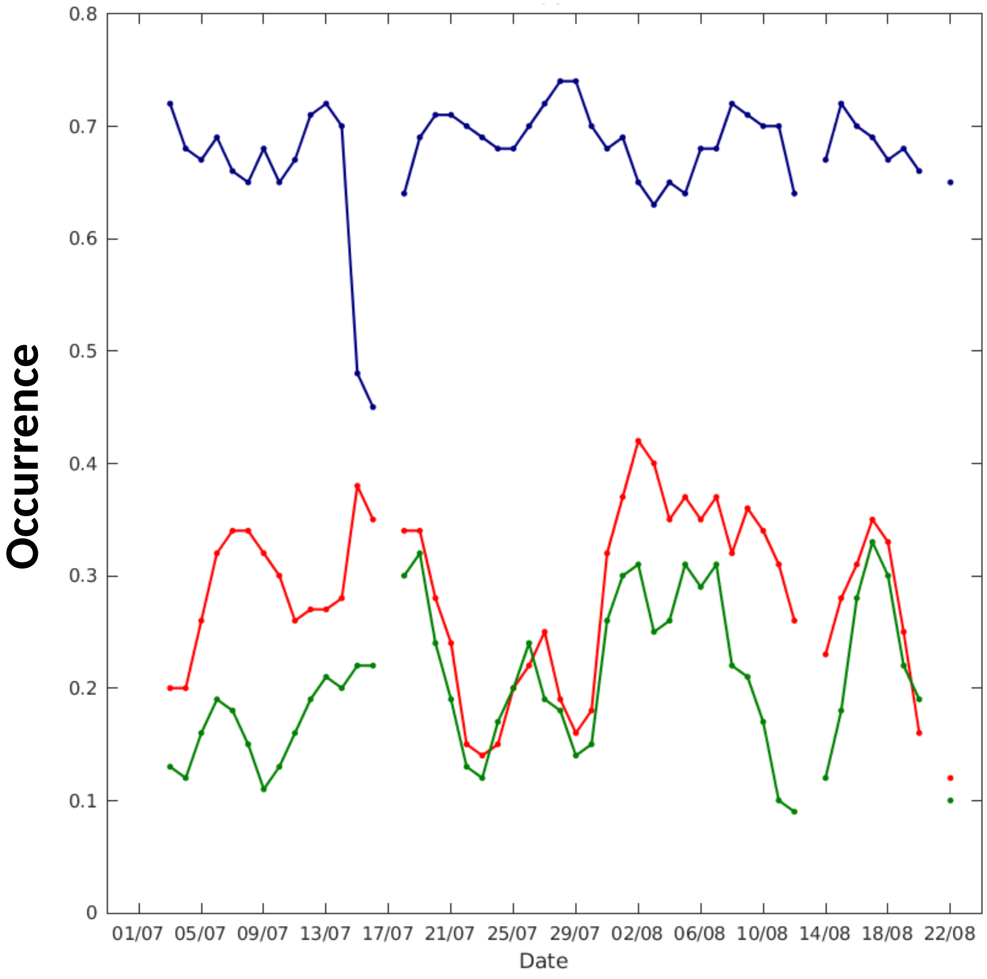

EC / CAMS climatology

COSMO – default / Tanre

CLOUDRAD / CAMS

# New CLOUDRAD tested in IMS

GR > 50 W/m² fiasco

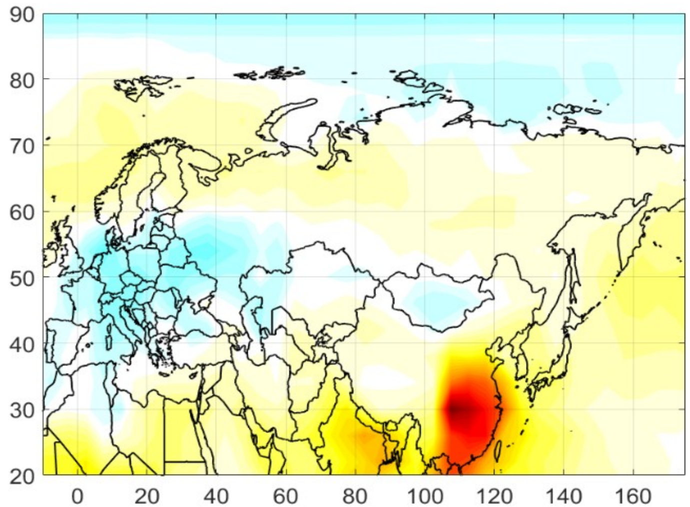



EC / CAMS climatology
COSMO – default / Tanre
CLOUDRAD / CAMS

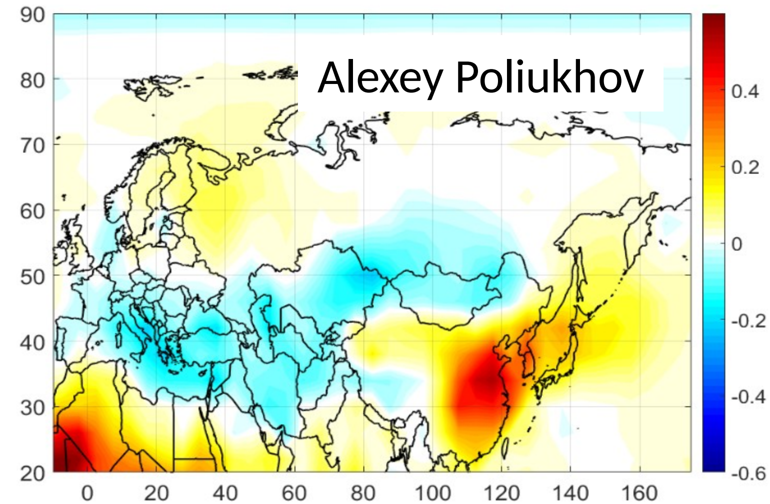
# Kinne-MACv2 (2013) vs. Tegen (1997)

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

**AOD**

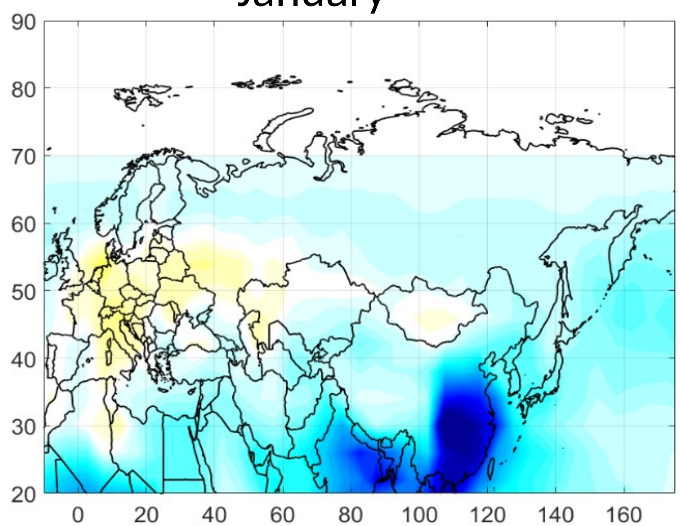



January

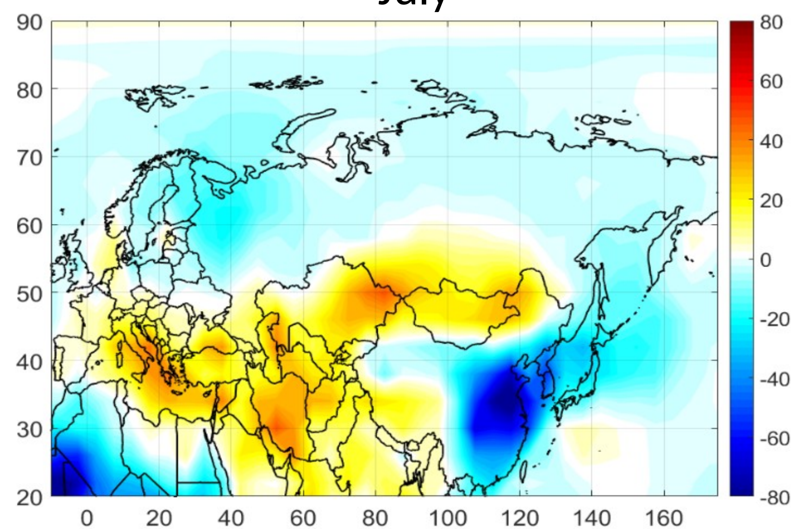



July

**SW**




January



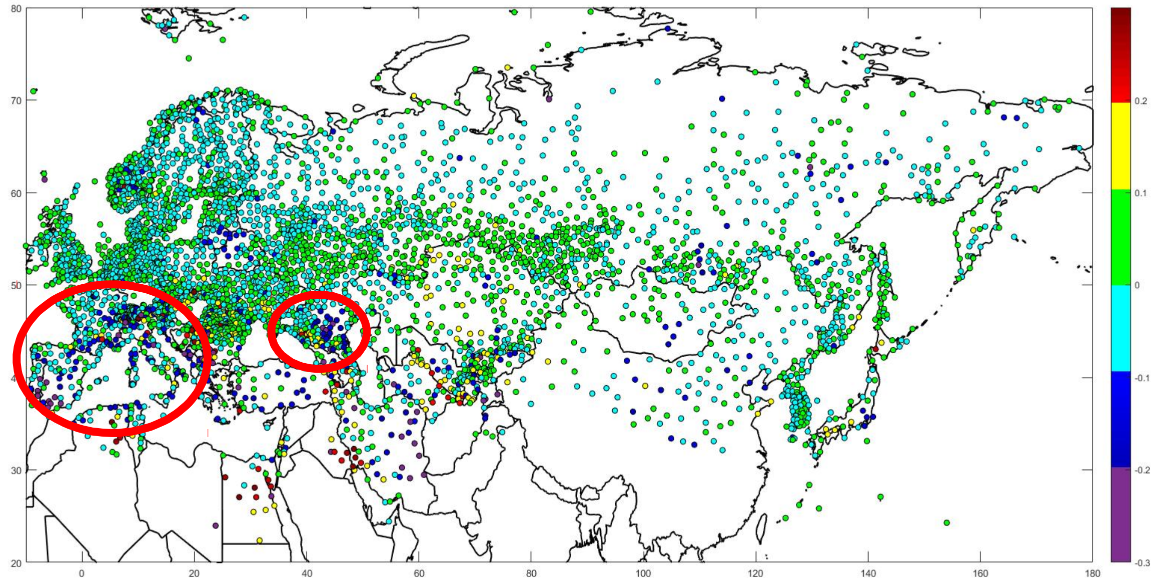

July

itype_aerosol = 3

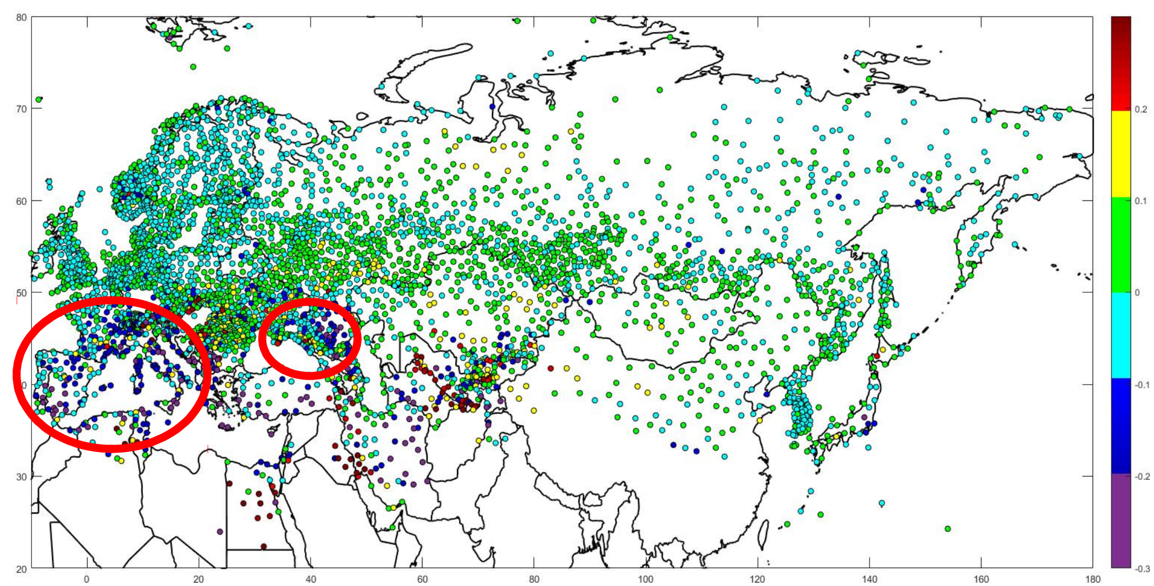
# The RMSE estimates obtained using various aerosol climatologies for **temperature at 2m** for ENA

**stations 4510**

Δ= RMSE(CAMS)- RMSE(Tanre)



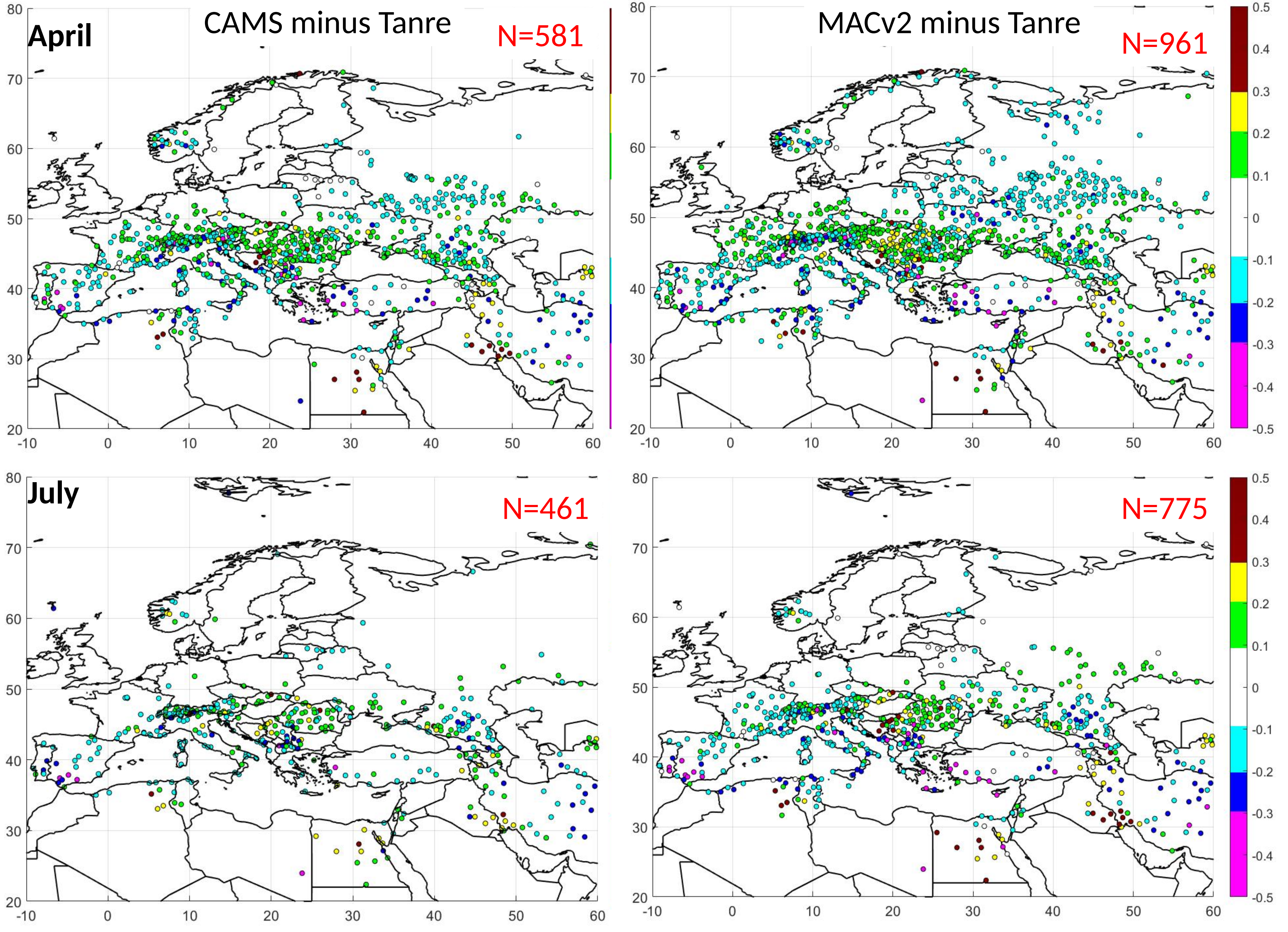
Δ= RMSE(MACv2) - RMSE(Tanre)



The most significant differences were observed in **south Europe** and **south European territory of Russia**

# Stations with significant differences $|\Delta RMSE| > 0.1^{\circ}$

Stations with significant differences



# RMSE for different cites and ENA

| | January | | April | | July | | October | |
|---|---|---|---|---|---|---|---|---|
| | CAMS-Tanre | MACv2-Tanre | CAMS -Tanre | MACv2 -Tanre | CAMS-Tanre | MACv2 -Tanre | CAMS-Tanre | MACv2 -Tanre |
| **Moscow** | * | 0.05- | **0.11-** | **0.16-** | 0.04- | 0.07- | 0.03- | 0.06- |
| **Lindenberg** | * | 0.04- | 0.08 | 0.10 | 0.03 | 0.04 | 0.04- | 0.04 |
| **Eilat** | * | **0.30-** | **0.31-** | **0.36-** | **0.11-** | **0.15-** | **0.53-** | **0.51-** |
| **Tiksi** | * | -0.03 | -0.03 | 0.05 | 0.01 | 0.01- | 0.01- | 0.02- |

*CAMS web-porltal doesn't provide the data for January (only from 25.01.2017) **

| RMSE for ENA | | | |
|---|---|---|---|
| | t2m | t850 | t500 |
| Tanre | 2.342 | 1.137 | **0.919** |
| Tegen | 2.337 | 1.137 | 0.921 |
| MACv2 | 2.339 | 1.136 | 0.924 |
| CAMS | **2.337** | **1.105** | 0.922 |

Red color means the smallest RMSE

# Operational NWP model

# Aerosols/Chemistry model

# Future aerosols models

# Future operational setup

# The solution

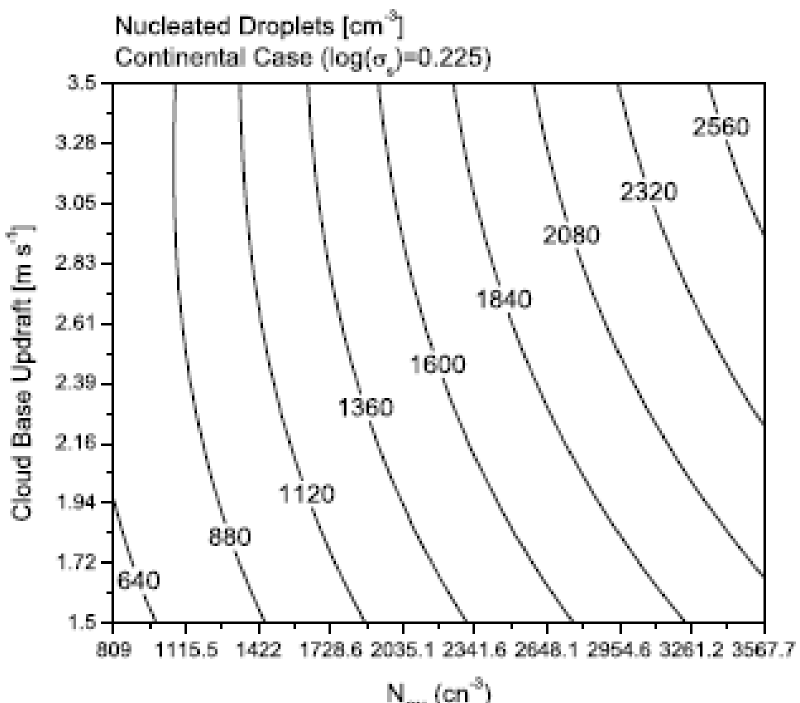

SGS clouds
&
Microphysics

# 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

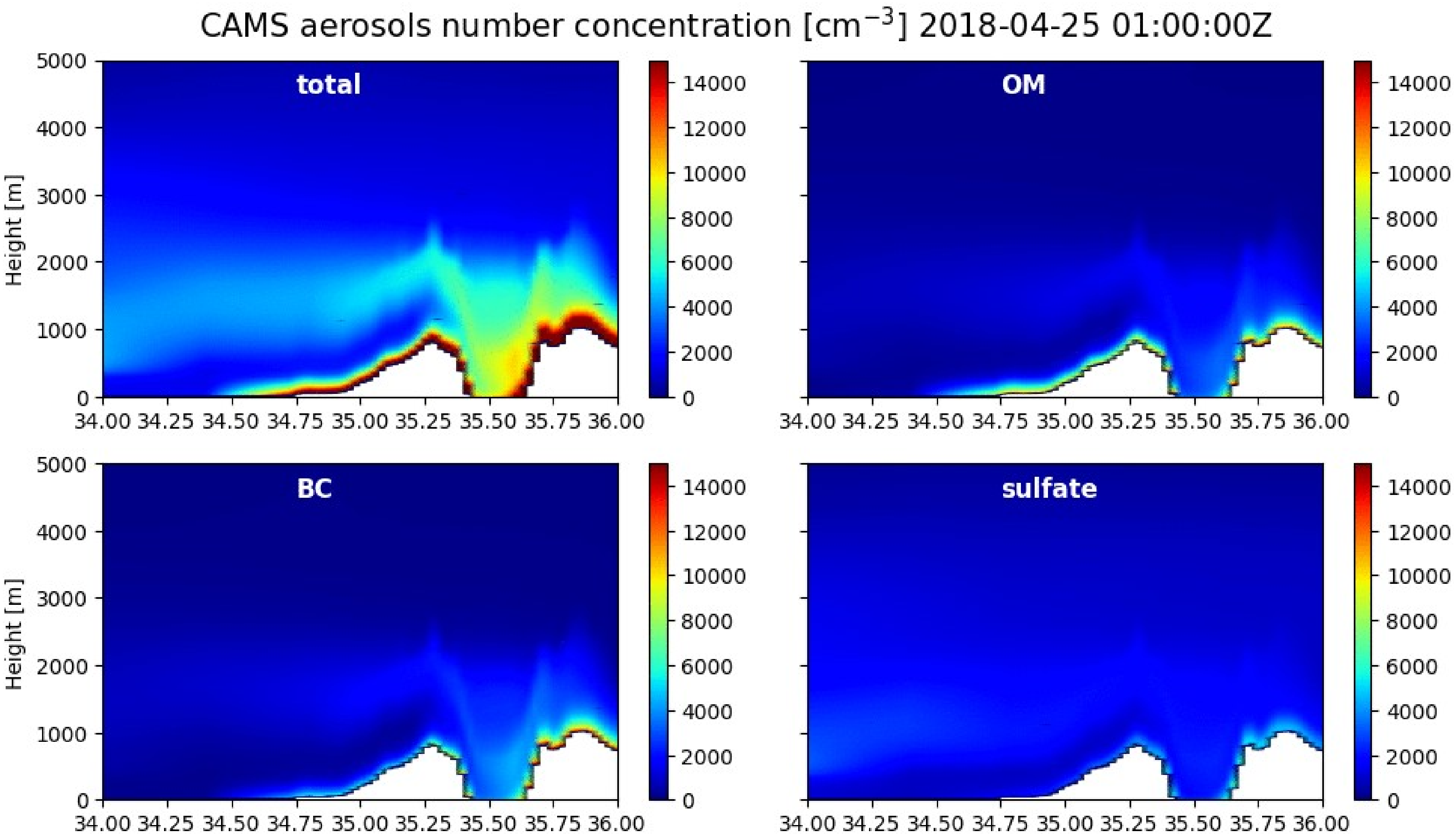
$$n_{ccn}^{SK} = f\left(n_{cn}, \log(\sigma), r_{mod}, w_{CB}\right)$$



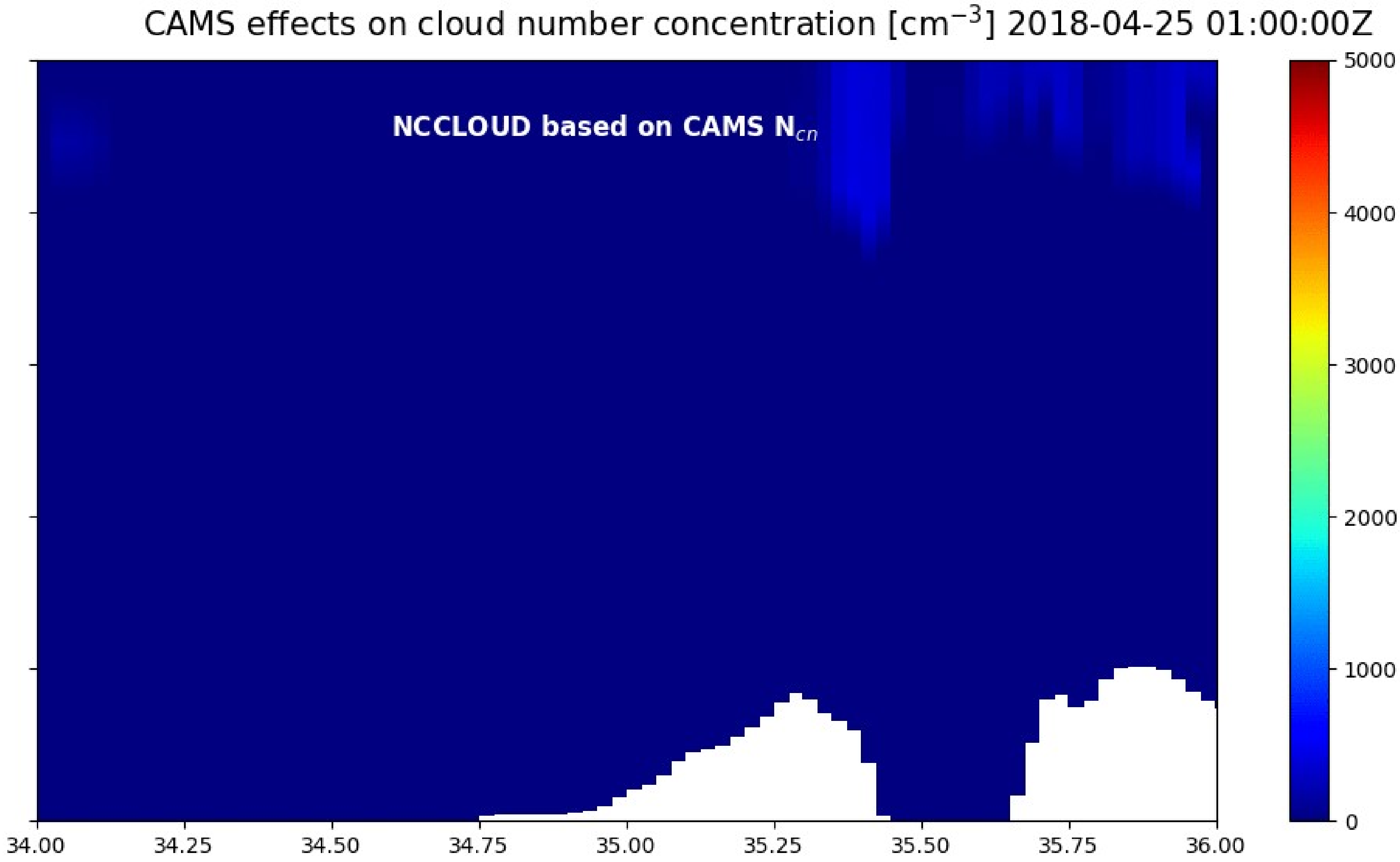

f

Segal & Khain (2006)

# CAMS aerosols number concentration



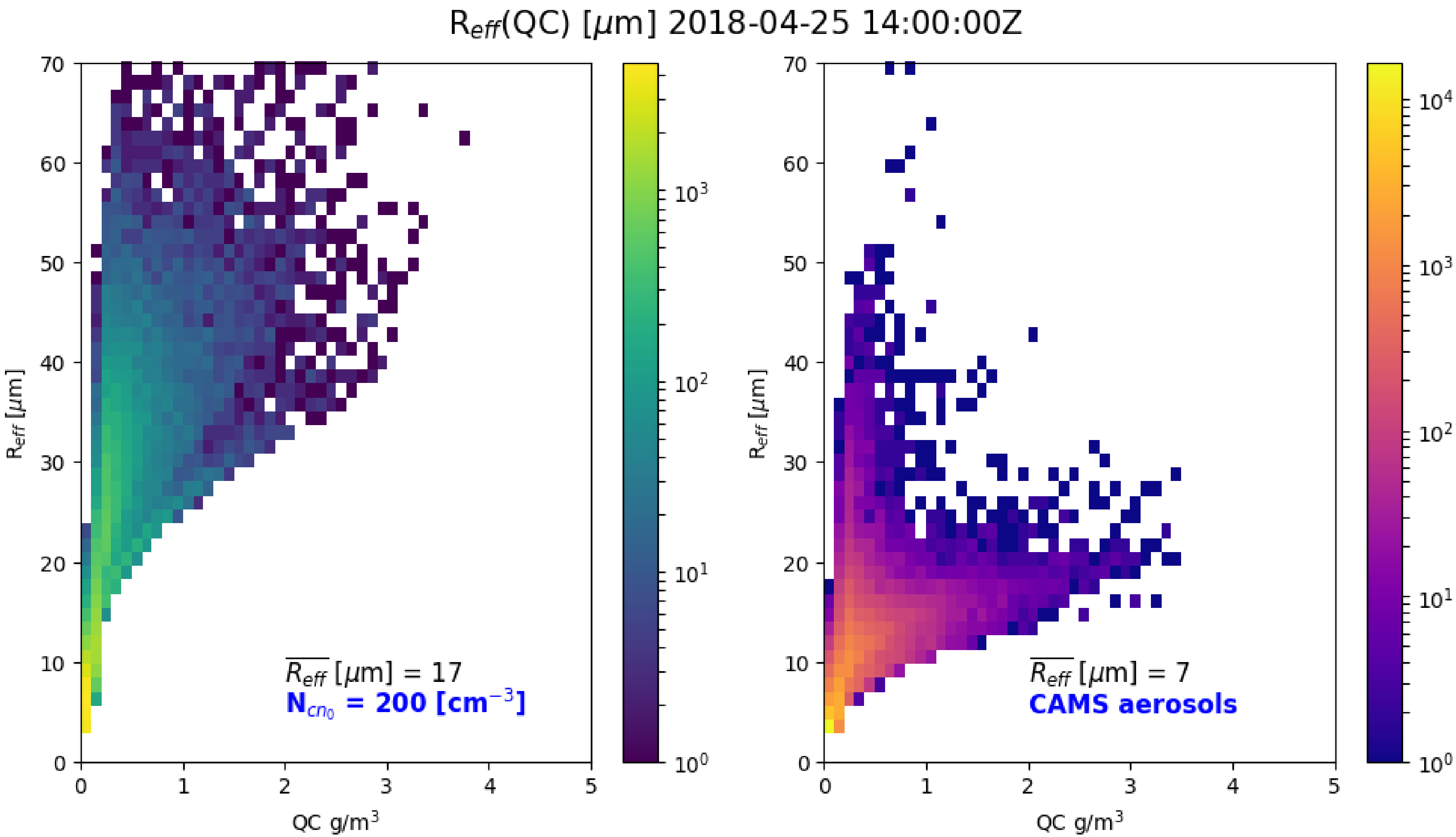
# New cloud droplets number concentration




**icloud_num_type_gscp/rad = 4**

# based on CAMS & Segal-Khain

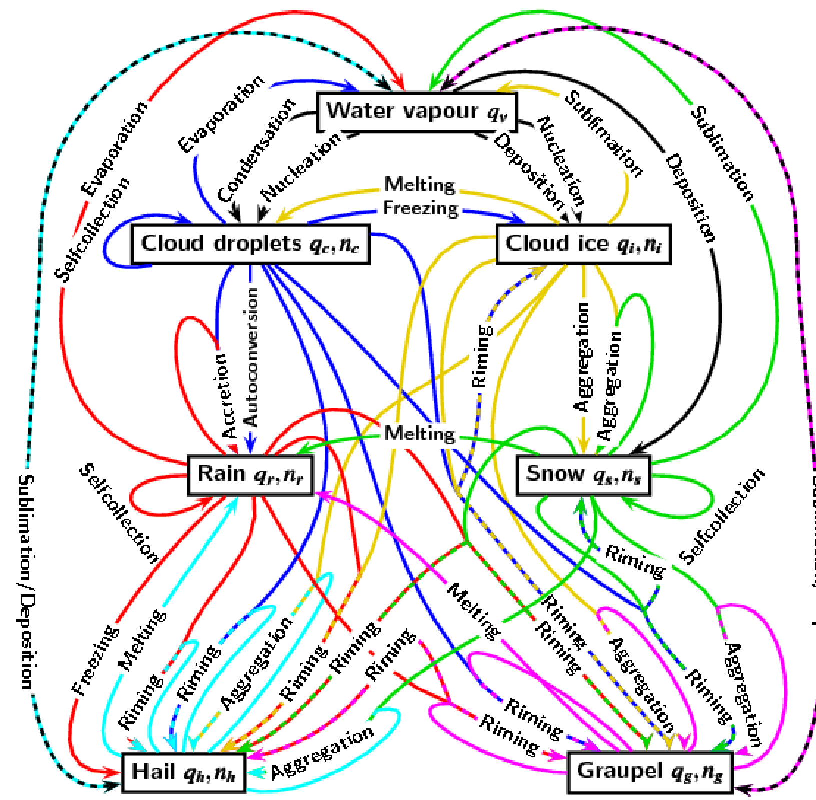
Peak event April 25 14Z



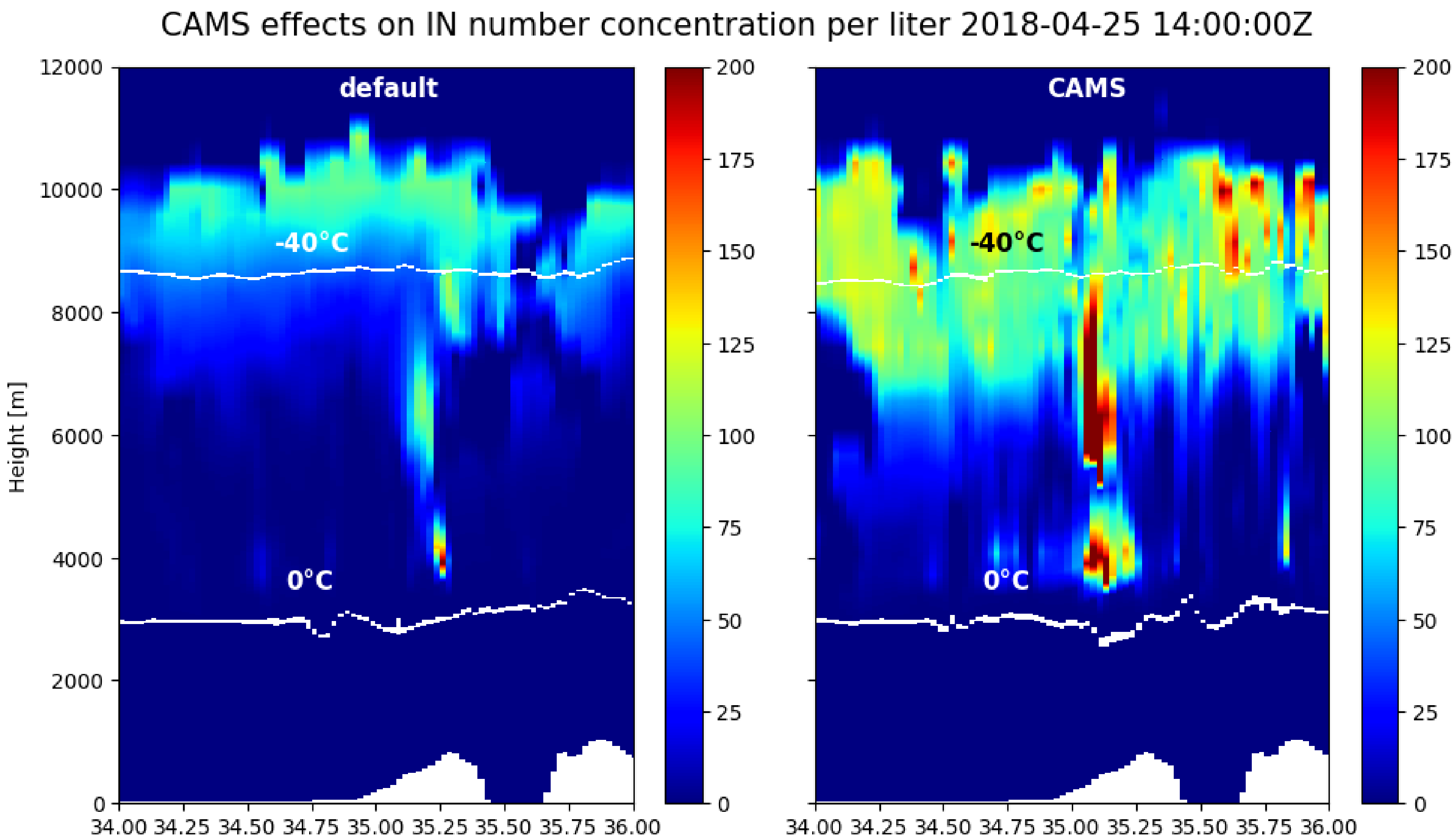
# Prognostic aerosols in ice nucleation

- 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:
  - $\text{nc\_dust} = 0.162\ cm^{-3}$
  - $\text{nc\_soot} = 15\ cm^{-3}$
  - $\text{nc\_organic} = 177\ cm^{-3}$

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



# Ice number concentrations based on CAMS



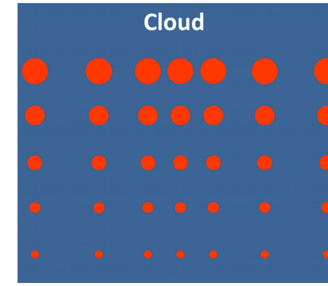

**Effective in 2-moment scheme only**

# $R_{eff}$ in Sub-Grid Scale Clouds

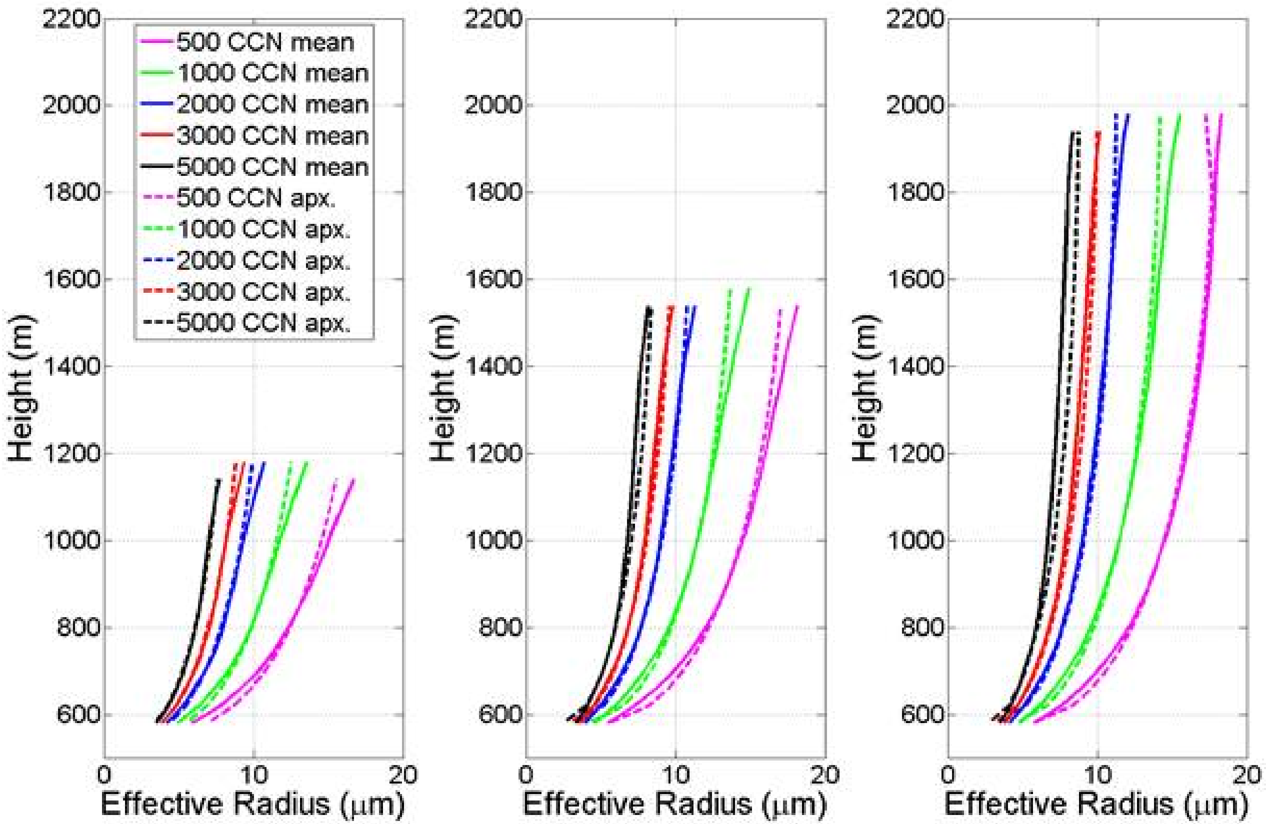
in Sub-Grid Scale Clouds

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

is does not change much horizontally and can be analitically estimated




$$\overline{R'_{eff}} = fct\left(CCN_{cloud\ base}, H_{above\ c.base}, T\right)$$




Pavel Khain

# Mean $R_{eff}$

Mean

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

$$\overline{R_e} = c_1 \left( \frac{\overline{qc}}{\overline{nc}} \right)^{c_2}$$

## Better calculation

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

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

From Segal-Khain using CAMS/ART !

Due to rain formation:

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

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:

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

**New MCSI**

**Radiative Solver**

Aknoledgments: Bodo Ritter

# The k-distribution Method

- For gases (…) the absorption is rapidly changing as a function wavelength. Line by line (LBL) methods are too expensive for NWP
- In the k-distribution method gases absorption spectra for each band is transformed from wavelength to cumulative probability space

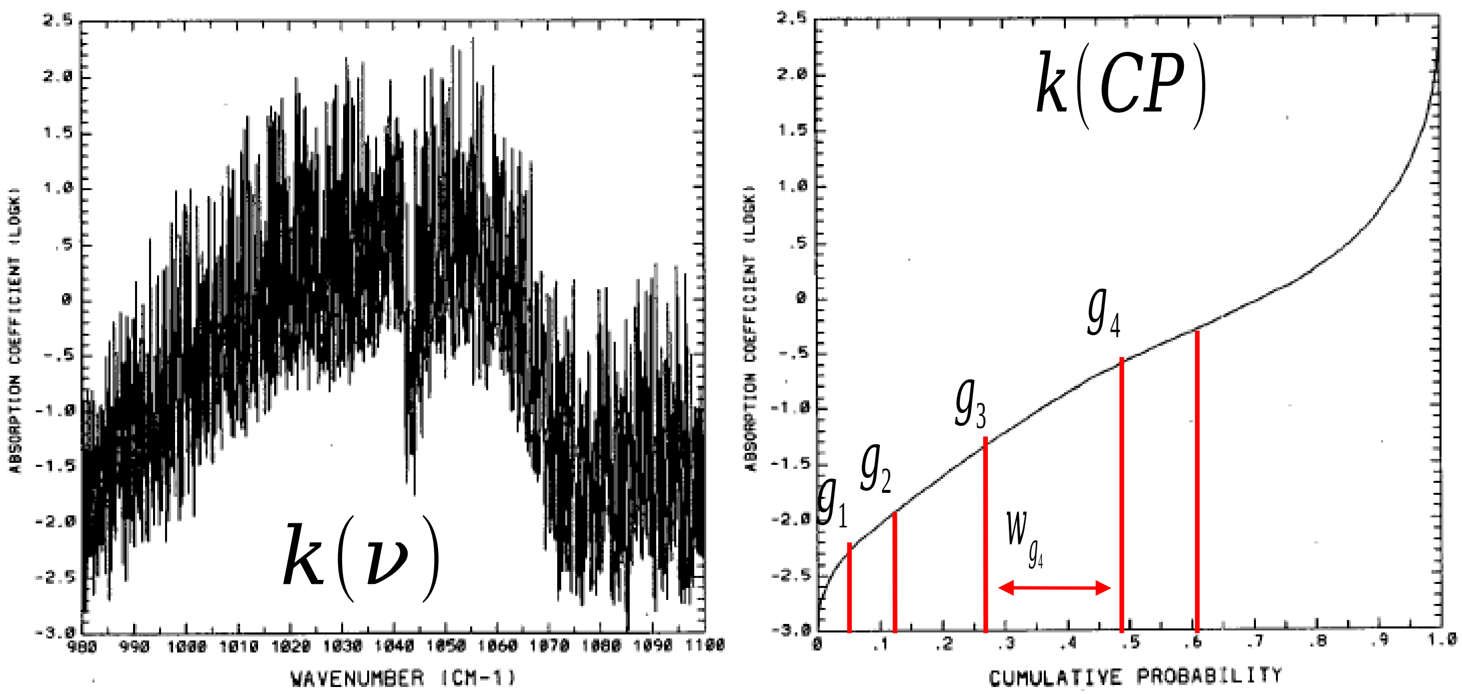
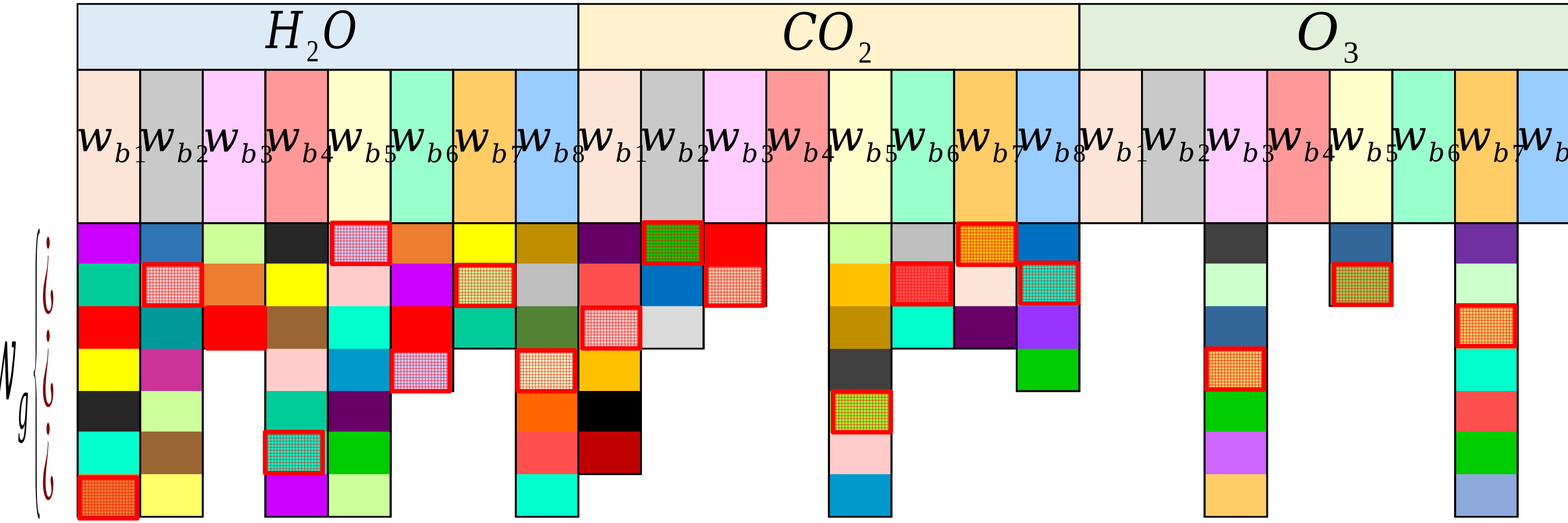



FIG. 1. Absorption coefficient $k$ in (cm atm)$^{-1}$ as a function of (a) wavenumber and (b) cumulative probability for the $O_3$ 9.6-$\mu$m band for a pressure of 25 mb and a temperature of 220 K.

Fu & Liou 1992

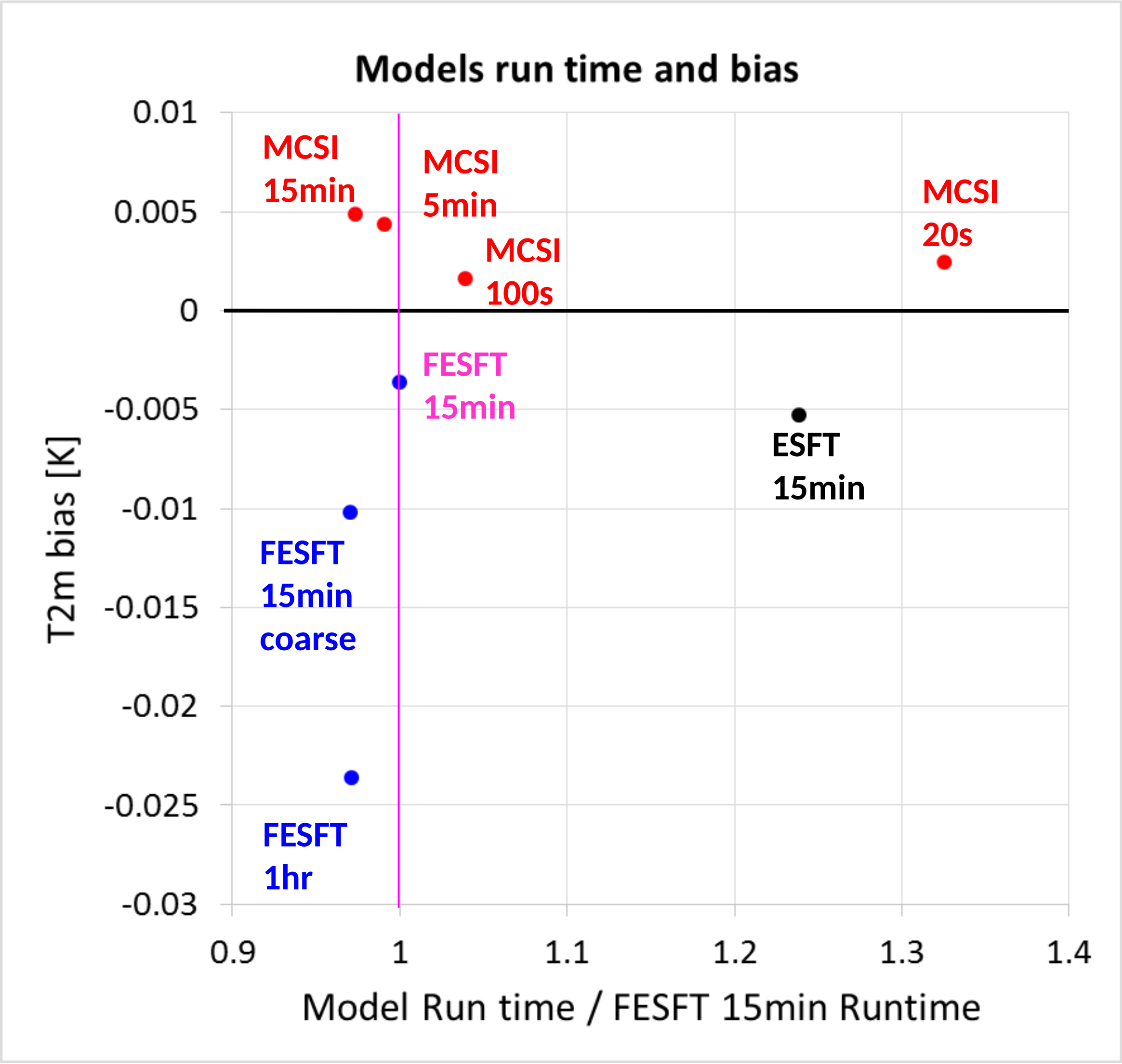
# COSOMO MCSI Diagram – Soft Version



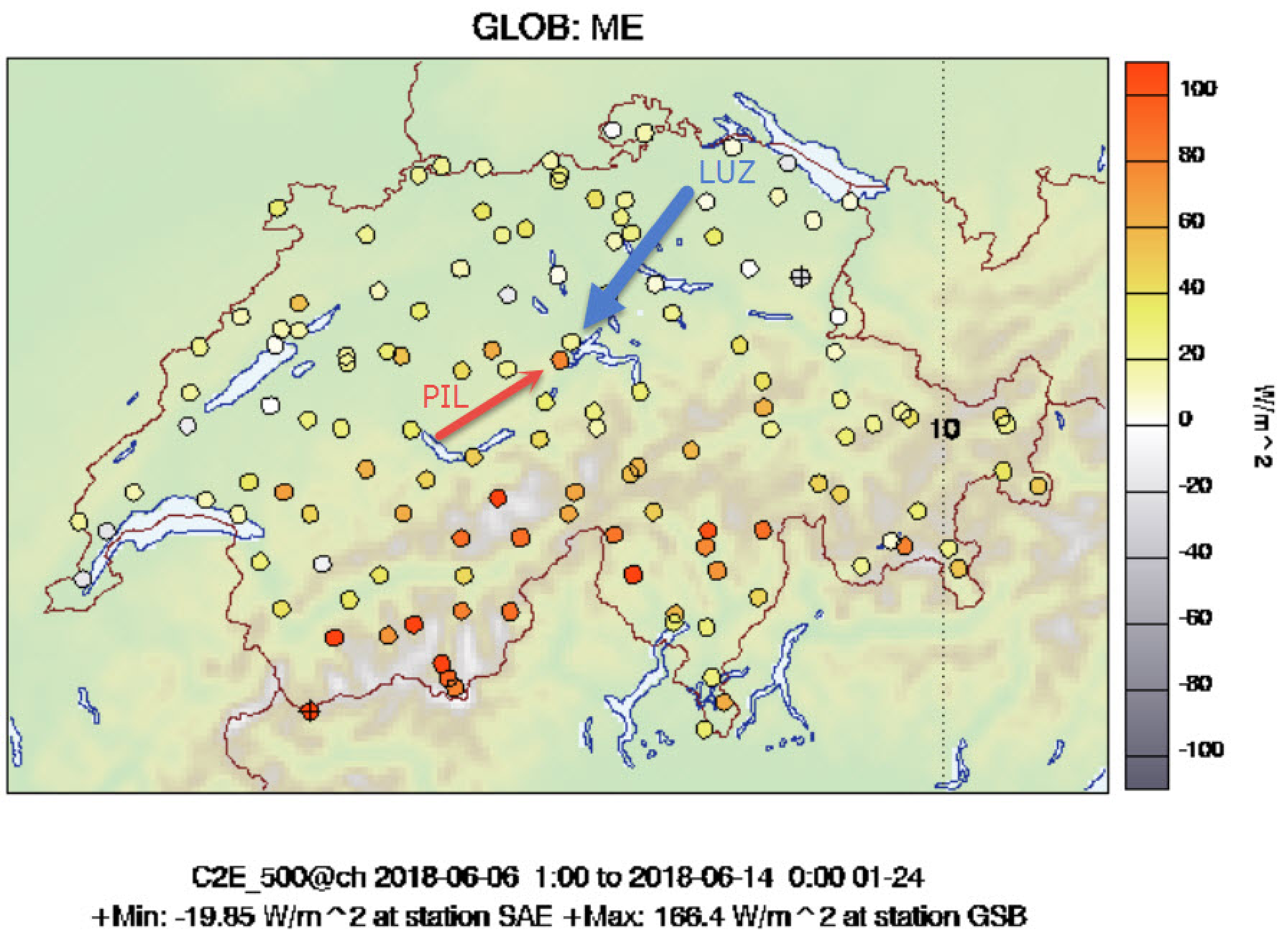

 Only 8 calls to inv_th/inv_so subrutines instead of 301 calls in ESFT!

$$CPU\,gain \approx \frac{calls\,decreas}{frequency\,increase} = \frac{301/8}{45} = \mathbf{0.83}$$

# Run Time & Errors Comparisons

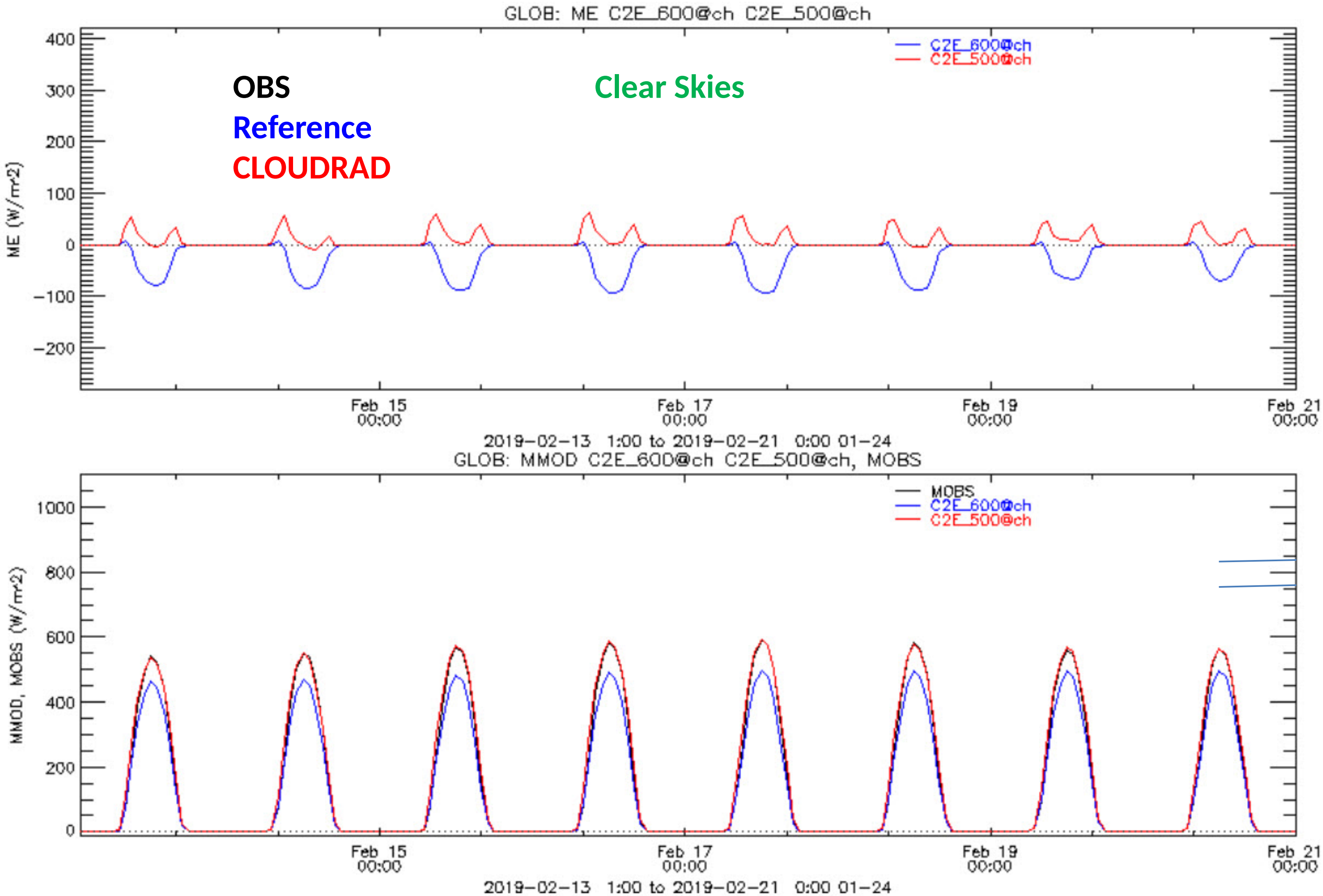


# CLOUDRAD tested in MeteoSwiss




Jonas Jucker & Andre' Walser

# CLOUDRAD tested in MeteoSwiss

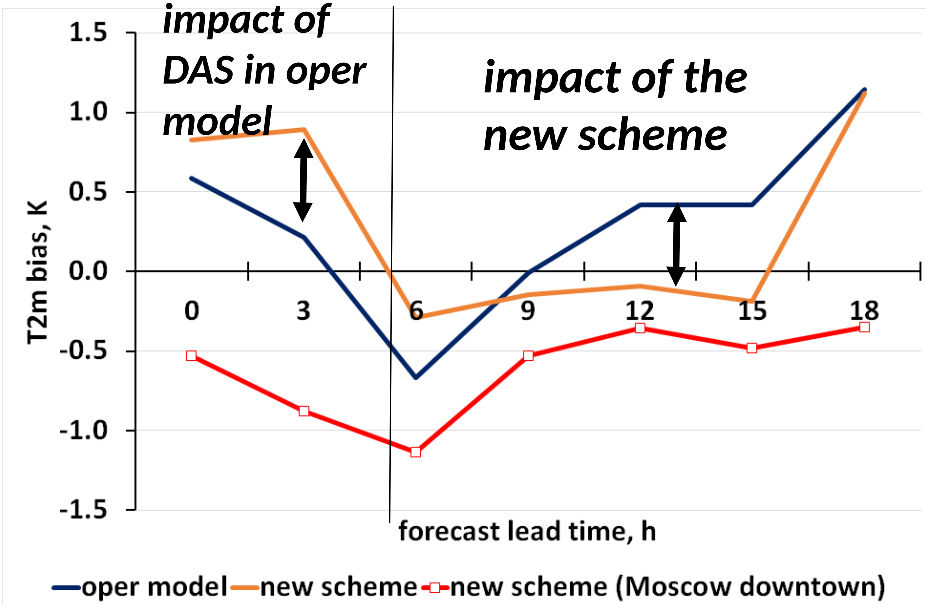


# CLOUDRAD tested in RHM

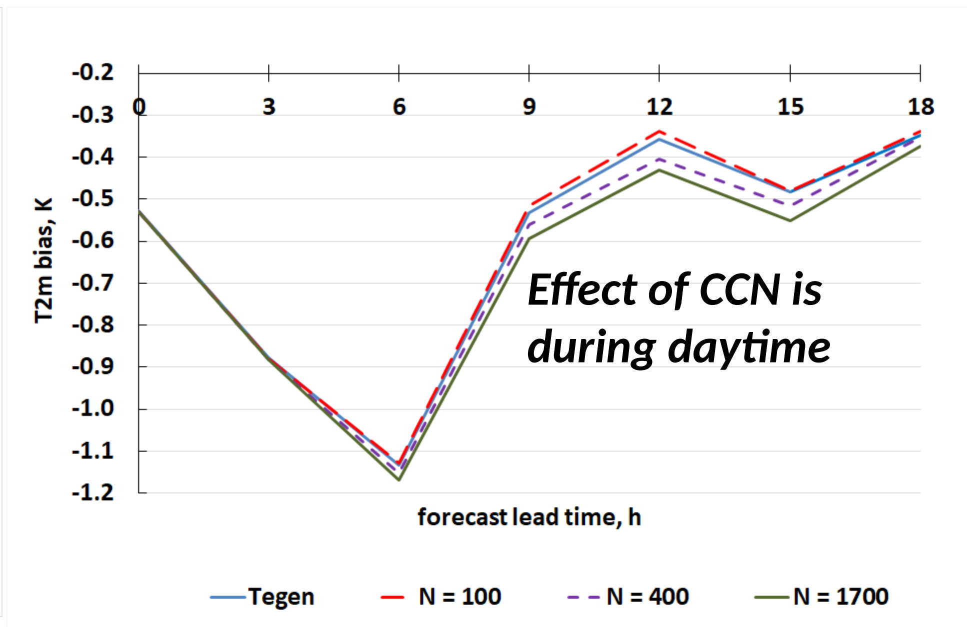
## Effect on T2m forecast

- Evaluation period: **April-October 2018**
- COSMO-Ru 2.2 km grid spacing, operational version and with the new scheme (**CCN** from Tegen climatology or constant)

*T2m bias for the whole domain (130 stations) and Moscow city center (4 stations)*




*T2m bias under different CCN Moscow city center (4 stations)*



# Concluding remarks and outlook

- New COSMO version incl. CLOUDRAD is now available – **go for it !!!**
- Newsletter (soon to be published?)
- 6 months extension until Feb-2020 (verifications, documentations)
- Next project: **C**louds and **A**erosols **I**mprovements in **I**CON **R**adiation Scheme (**CAIIR**) – "Same same - but different", Two years Mar2020-Feb2022
  - Cloud optics revised
  - Aerosols inputs: CAMS forecast, CAMS climatology, Kinne climatology, 2D advection scheme
  - Microphysics - $R_{eff}$
  - Convection scheme developments


Thanks for your attention!