Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Towards revised cloud radiation coupling for the COSMO Model

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Outline

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- ➔ COSMO-model and it‘s current radiation and cloud schemes
- ➔ Recent developments towards more consistent coupling
- ➔ Open questions

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The COSMO-Model

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- Non-hydrostatic, compressible limited area model for numerical weather prediction, regional climate simulations (COSMO-CLM) and fully online coupled aerosol / reactive trace gases chemical dispersion model (COSMO-ART)

- Worldwide and „broadband“ user community:
  - COSMO-Consortium: 7 European NWS
  - Diverse research at universities (real cases / idealized)
  - CLM-Community: > 50 member institutions, > 200 members
  - COSMO-ART: used by research institutes, but also for operational pollen, mineral dust and volcanic ash forecasts
  - Operational at ~ 30 NWS worldwide

Numerical weather prediction at DWD in 2013

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Global model GME

Grid spacing: 20 km

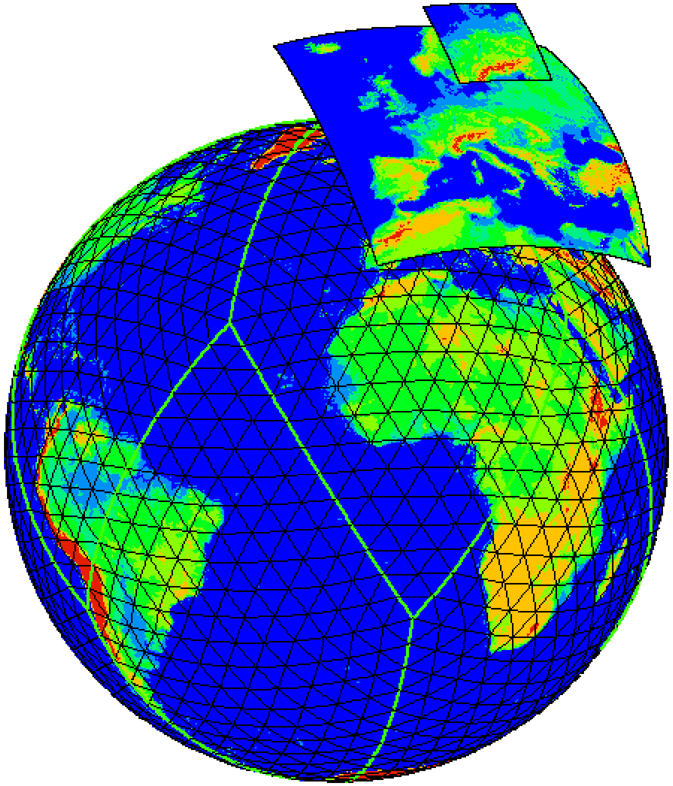
Layers: 60

Forecast range:

174 h at 00 and 12 UTC

48 h at 06 and 18 UTC

1 grid element: 346 km^2



COSMO-EU

Grid spacing: 7 km

Layers: 40

Forecast range:

78 h at 00 and 12 UTC

48 h at 06 and 18 UTC

1 grid element: 49 km^2

COSMO-DE (-EPS)

Grid spacing: 2.8 km

Layers: 50

Forecast range:

21 h at 00, 03, 06, 09,

12, 15, 18, 21 UTC

1 grid element: 8 km^2

COSMO radiation scheme

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- Ritter and Geleyn (1992)
- Delta-two-stream approximation
- 8 spectral bands only (3 visible, 5 infrared)
- Includes aerosol scattering (climatology or COSMO-ART)
- Clouds: grid scale (QC and QI), subgrid scale, convective
- For the gridscale clouds, only a fraction k=0.5 of qi and/or qc is considered in the radiation scheme („tentative“ effective factor to take into account subgrid scale variability).
- Optical properties of hydrometeors are pure fct(qx) derived for „typical clouds“

$$R_e = a_1 + a_2 \rho_x$$

$$\frac{\beta_{ext}}{\rho_x} = c_1 + \frac{c_2}{R_e} \qquad \omega = \frac{\beta_{sca}}{\beta_{ext}} = c_3 + c_4 R_e \qquad g = c_5 + c_6 R_e$$

- Operationally called only every 1 h (COSMO 7km) resp. 15 min (2.8 km)

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COSMO cloud microphysics

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- Fully prognostic conventional 1-moment bulk schemes
  - **Cloud drops:** Gamma distribution for autoconversion
  - **Cloud ice:** monodisperse, N_i = fct(T) similar to Cooper (1986)
  - **Rain:** Gamma distribution (μ=0 reduces to Marshall-Palmer)
  - **Snow:** Exponential PSD, N_0 = fct(T)
  - **Graupel:** Exponential PSD, fixed N_0

$$f(D) = N_0 \, e^{-\lambda D}$$

$$f(D) = N_0 \, D^{\mu} \, e^{-\lambda D}$$

- Seifert-Beheng 2-moment bulk scheme
  - Additional **hail** class
  - All species are full 2-moment
  - All PSDs assumed generalized Gamma

$$f(x) = N_{0x} \, x^{\mu_x} \, e^{-\lambda_x x^{\nu_x}}$$

- Upcoming revisions of the 1-moment scheme: ice sedimentation, two-moment ice, improved ice nucleation, improved supercooled liquid in mixed-phase clouds, improved melting of snow

- Side note: 2-moment scheme can be fully coupled to COSMO-ART aerosols (a 2-moment 5-class bulk aerosol formulation)

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COSMO subgrid scale clouds

- **CLC = fct(QC, QI, generalized RH_g, convective CLC_CON)**
  - RH_g: blending in mixed-phase region between water and ice saturation, using prescribed ice fraction
    f_{ice} = linear ramp function of T between 0 (-5˚C) and 1 (-25˚C) (Deardorff?)
    $RH_g := (QV+QC+QI) / QV_{sat,g} = (QV+QC+QI) / (QV_{sat,water} *(1-f_{ice}) + QV_{sat,ice}*f_{ice})$
  - $CLC\_SGS = MAX (0, MIN (1, (RH_g - \xi) / (c_L - \xi)))^{2}$
    with: $\xi = 0.95 - c_1 * \sigma * (1-\sigma) * (1 + c_2*(\sigma-0.5))$,
    $c_1 = 0.8$, $c_2 = sqrt(3)$, $c_L = 1.0$
    $\sigma = p / p_s$ (height parameter)
    (dep. on RH_g see next slide)
  - But CLC_SGS = 1 for gridscale clouds (QC and/or QI > 0) !
  - CLC_CON = 0.35*(TOP_CON-BAS_CON) / 5000.0
    (for both „shallow" and „full" convection parameterization)
  - Finally weighted average: CLC = CLC_SGS + CLC_CON * (1 – CLC_SGS)

- **Water contents of SGS clouds:**
  - of SGS clouds: $QC\_SGS = 0.005 * QV_{sat,g} * (1-f_{ice})$ (0.005 = 0.01 * subgr. variab. fact. 0.5)
    $QI\_SGS = 0.005 * QV_{sat,g} * f_{ice}$
  - of convective clouds: $QC\_CON = 0.01 * QV_{sat,g} * (1-f_{ice})$ ($= 2.0 \times 0.005 * QV_{sat,g} * (1-f_{ice})$)
    $QI\_CON = 0.01 * QV_{sat,g} * f_{ice}$

- **Finally: combined water contents as input for radiation:**
  - QX_RAD = QX_CON * CLC_CON + max[QX_SGS, 0.5*QX] * CLC_SGS * (1 – CLC_CON)
    with $X \in \{C,I\}$

COSMO subgrid scale clouds

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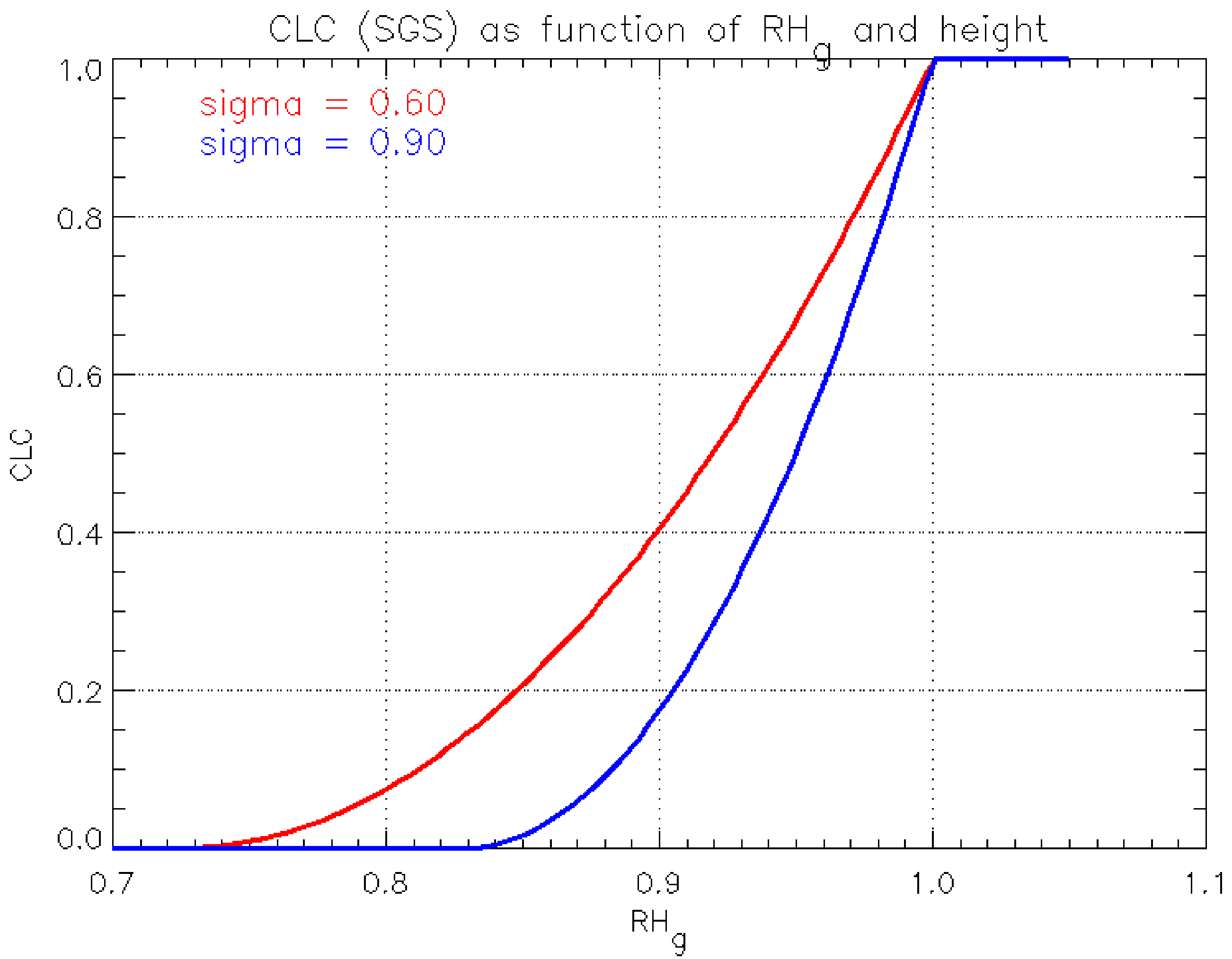
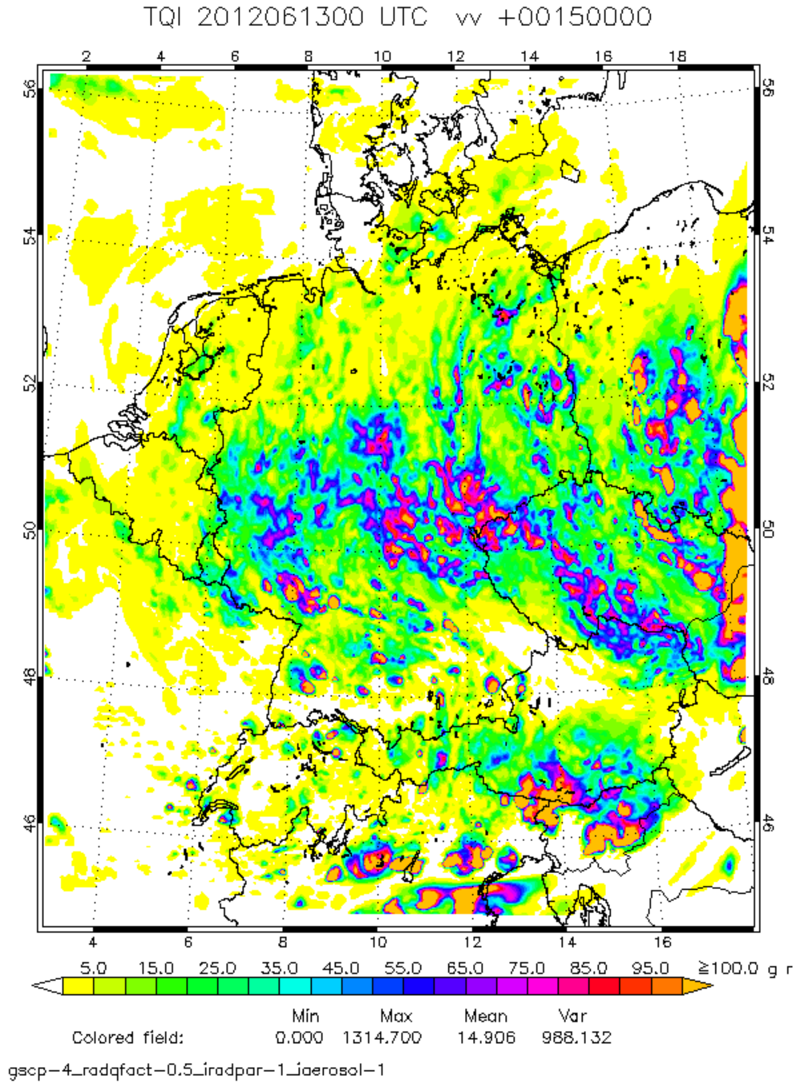
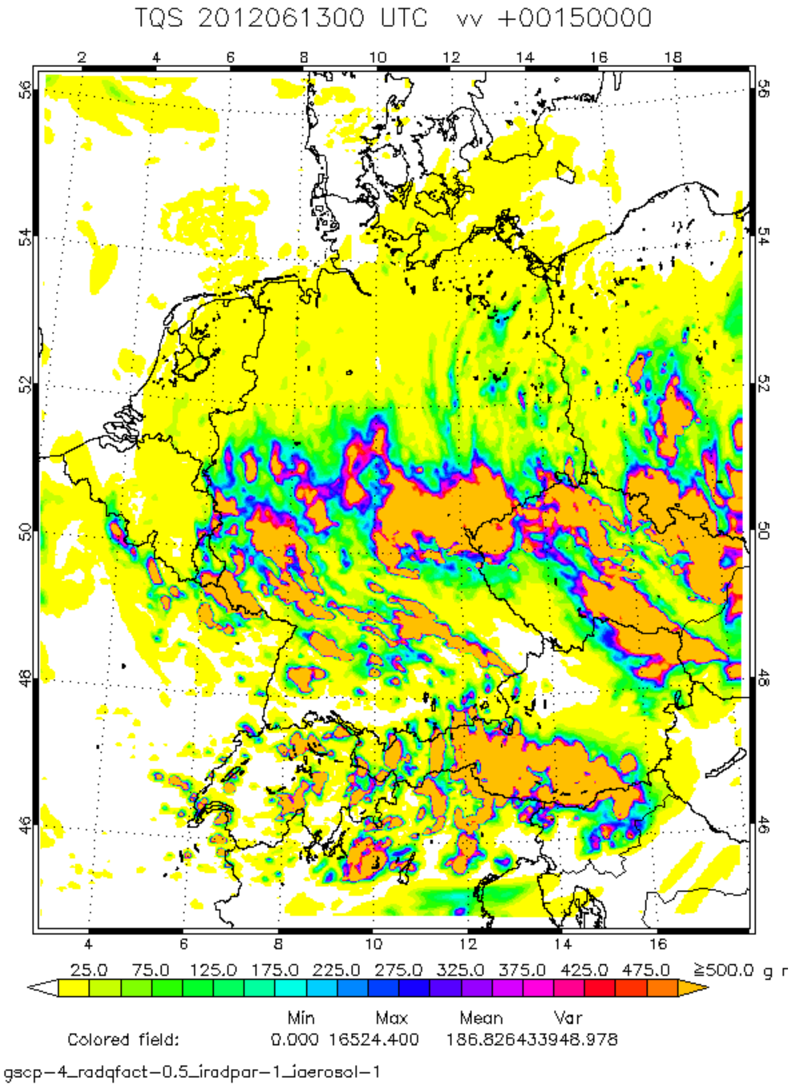


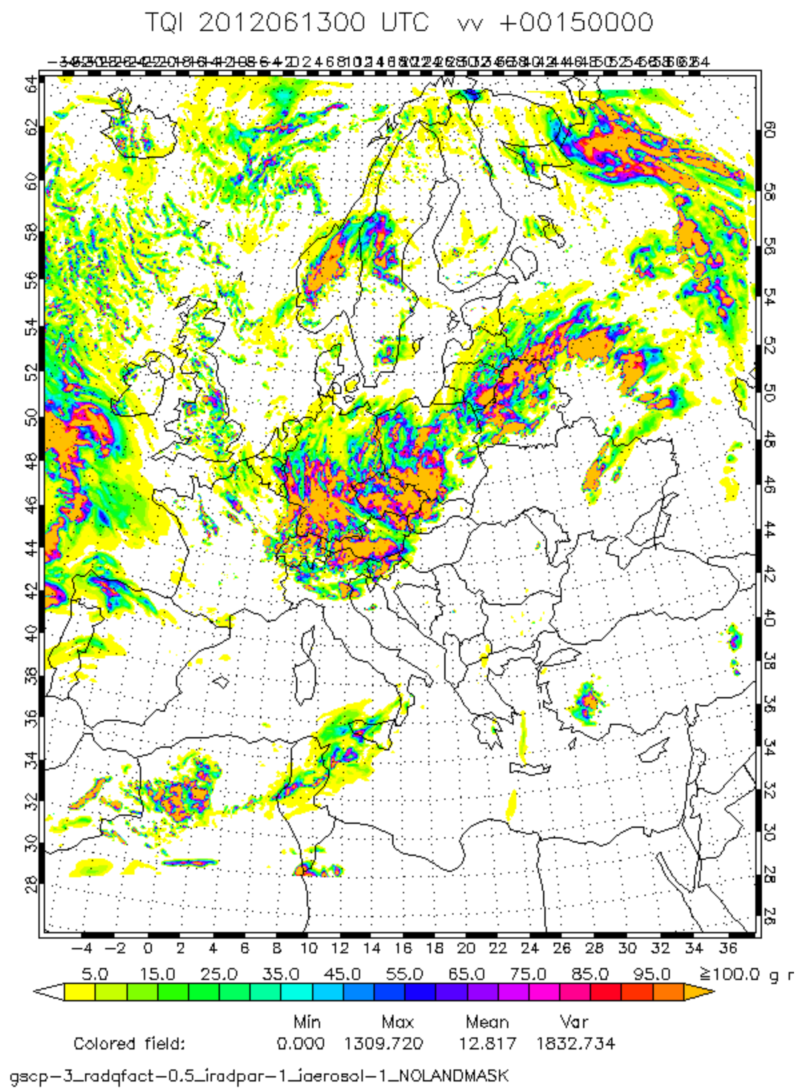
sigma = P / PS

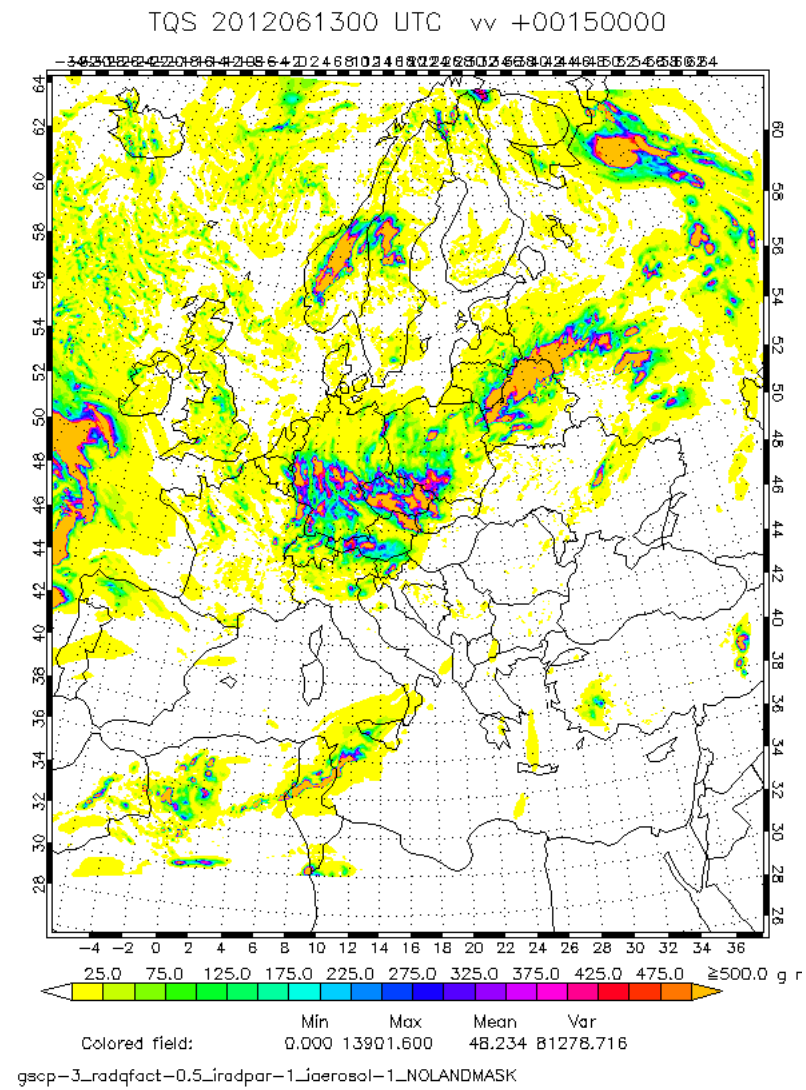
Motivation for changes





Motivation for changes





Some issues in cloud-radiation coupling

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- In the COSMO radiation scheme (Ritter & Geleyn 1992), the optical properties (extinction coeff., single scattering albedo, asymmetry factor) only depend on qc respectively qi.
  - Nowadays more modern parameterizations based on an effective radius R_e are available.
  - From inherent assumptions about N(D) and particle shapes in state-of-the-art microphysical models R_e can be deduced.
  - Then: optical properties = fct (qx, R_e)
- Inhomogeneity factor 0.5 still appropriate for today's models?
- There are also other hydrometeors than QC and QI!

ρ_c

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Revised optical properties

- β_{ext}, ω, $g = fct(R_e, q_x, \lambda)$
- R_e for grid scale clouds derived from cloud microphysics (1-mom, 2-mom)
- For cloud droplets:
  Parameterisation of **Hu and Stamnes (1993)**, spectrally remapped to the 8 spectral intervals of RG92.
- For cloud ice:
  - Visible spectral region: optionally
    Key et al. (2002), assuming horizontally aligned hexagonal plates or
    Fu et al. (1998), assuming randomly oriented hexagonal needles
  - Infrared region:
    Fu et al. (1996), assuming randomly oriented hexagonal needles
  - **Important: Definition of R_e is different for different authors and different spatial orientation!**

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Recalling scattering parameters

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For a certain wavelength:

$$\beta_{ext} = \int_0^\infty \sigma_{ext}(D)\, N(D)\, dD \qquad \left(\beta_{abs} = \int_0^\infty \sigma_{abs}(D)\, N(D)\, dD \right)$$

$$\omega = \frac{\beta_{sca}}{\beta_{ext}} = 1 - \frac{\beta_{abs}}{\beta_{ext}}$$

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

with: $g' = \int_{-1}^{1} \cos\theta\, P(\cos\theta)\, d\cos\theta$

(First moment of the scattering function)

Parameterizations from literature

- Either give **β'_{ext} (= β_{ext}/LWC) , ω , g** as **regression functions of (R_e,λ)** directly for many wavelengths λ,
- or averaged over more or less „narrow“ wavelength bands.
- In any case, necessary to average/aggregate them onto the RG92 wavelength bands:

$$e^{\left(-\overline{\beta'}_{ext}(R_e)\,\rho_c\,\Delta z\right)} \stackrel{!}{=} \frac{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\, e^{\left(-\beta'_{ext}(R_e,\lambda)\,\rho_c\,\Delta z\right)}\, d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\, d\lambda}$$

(Further averaging of $\overline{\beta}'_{ext}$ over: „typical“ range of model dz and certain PDF of gridscale ρ_c)

$$\overline{\omega} = \frac{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\beta_{ext}\,\omega\, d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\beta_{ext}\, d\lambda}$$

$$\overline{g} = \frac{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\beta_{sca}\, g\, d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} S(\lambda)\beta_{sca}\, d\lambda}$$

Definition of Re for droplets

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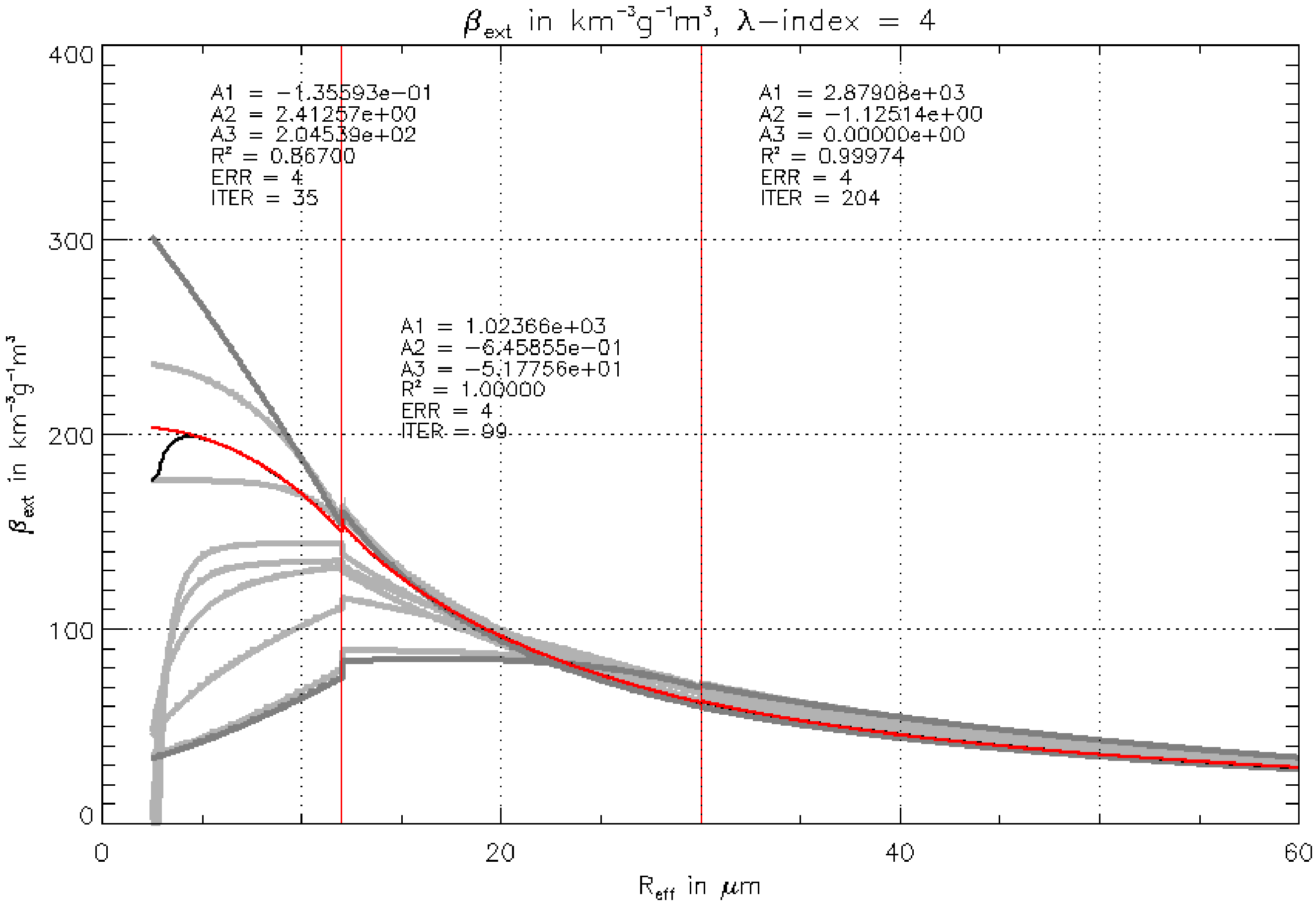
- Motivated by: $$\lim_{\frac{\pi D}{\lambda}\to\infty} \frac{\sigma_{ext}}{A_{geo}} = 2 \qquad A_{geo} = \frac{\pi}{4} D^2$$

- Specific Ext. Factor: $$\frac{\beta_{ext}}{\rho_x} = \frac{2\frac{\pi}{4} M_2}{\frac{\pi}{6}\rho_w M_3} = \frac{3}{2\rho_w R_e} \qquad M_i = \int_0^\infty D^i N(D)\, dD$$

- Therefore: $$R_e = \frac{1}{2}\frac{M_3}{M_2} = c_1 \left(\frac{\rho_x}{n_x}\right)^{c_2}$$

Cloud droplets

➔ based on Hu and Stamnes (1993):



RG92 wavelength interval **no. 4** (infrared)

Cloud droplets

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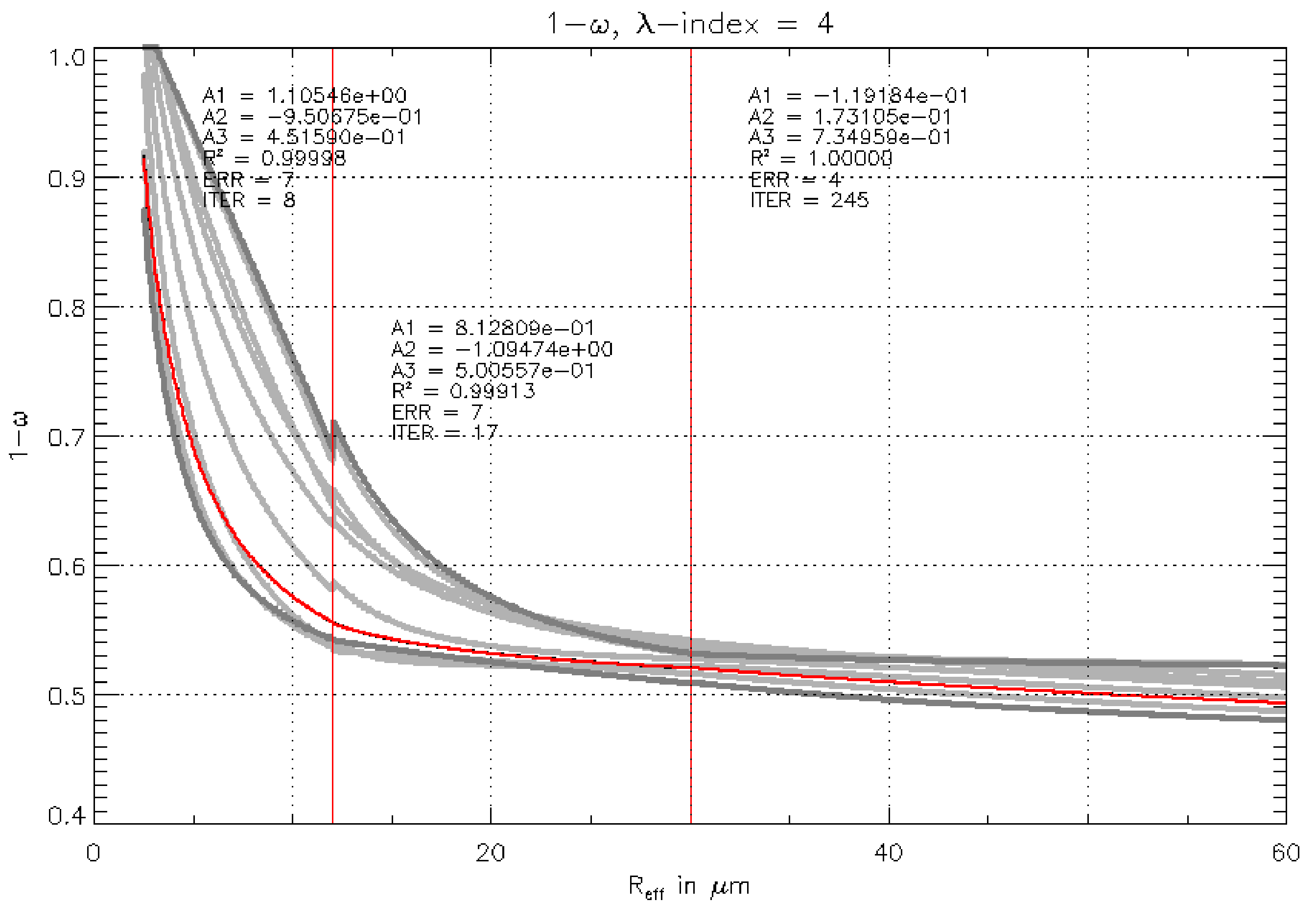
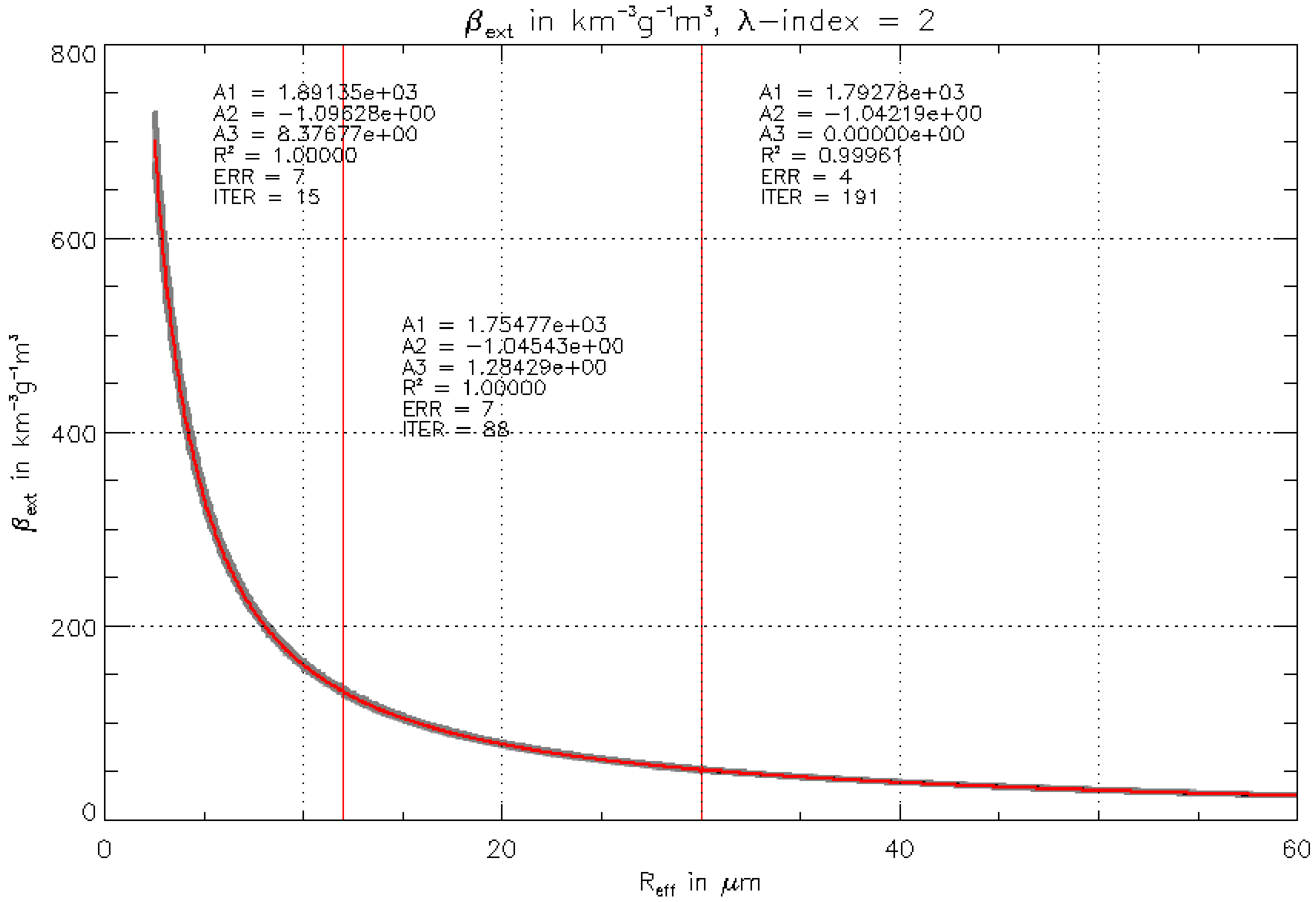
➔ based on Hu and Stamnes (1993):



RG92 wavelength interval **no. 4** (infrared)

Cloud droplets

→ based on Hu and Stamnes (1993):



RG92 wavelength interval **no. 2** (central visible)

Cloud droplets

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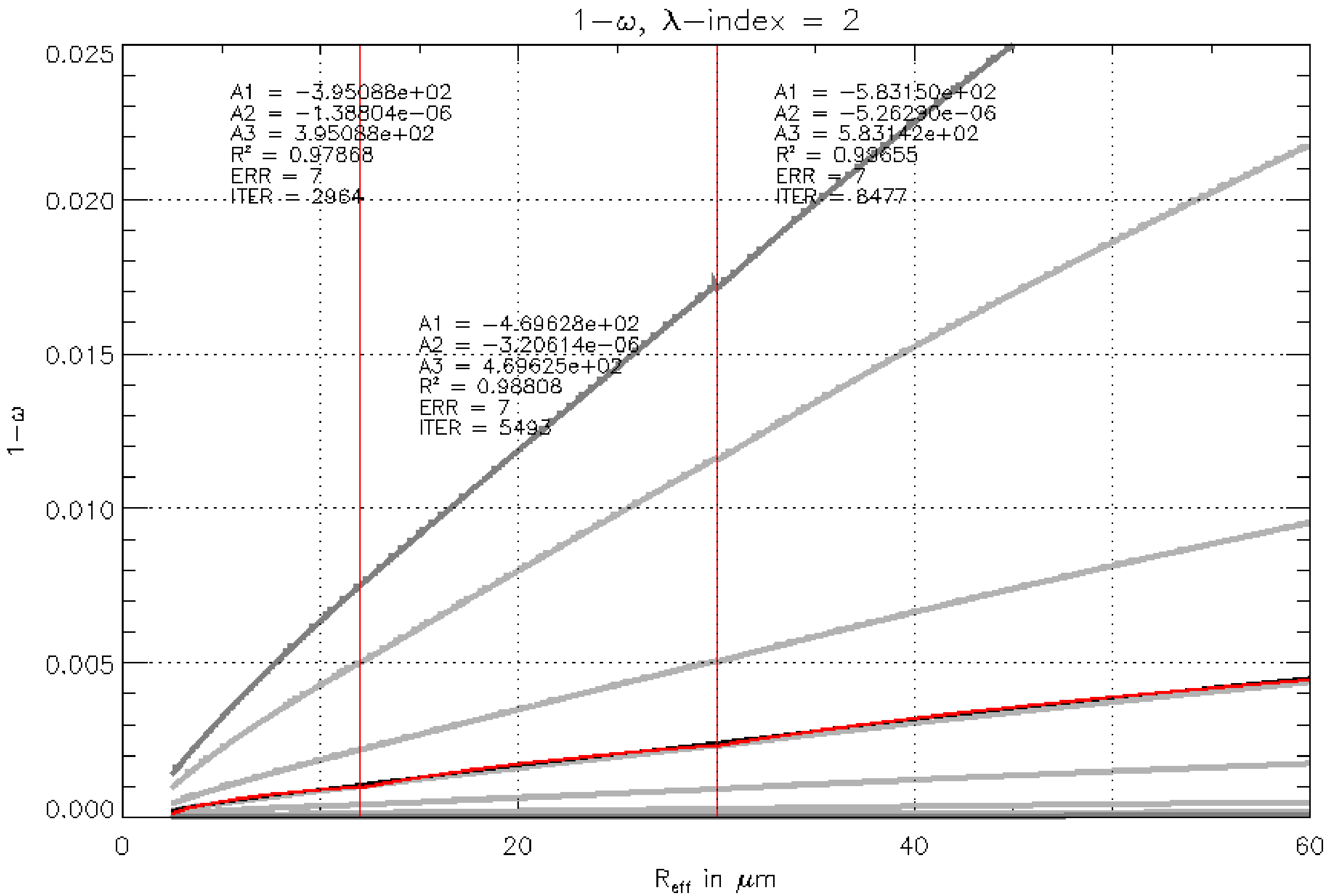
➔ based on Hu and Stamnes (1993):



RG92 wavelength interval **no. 2** (central visible)

Cloud droplets comparison to RG92

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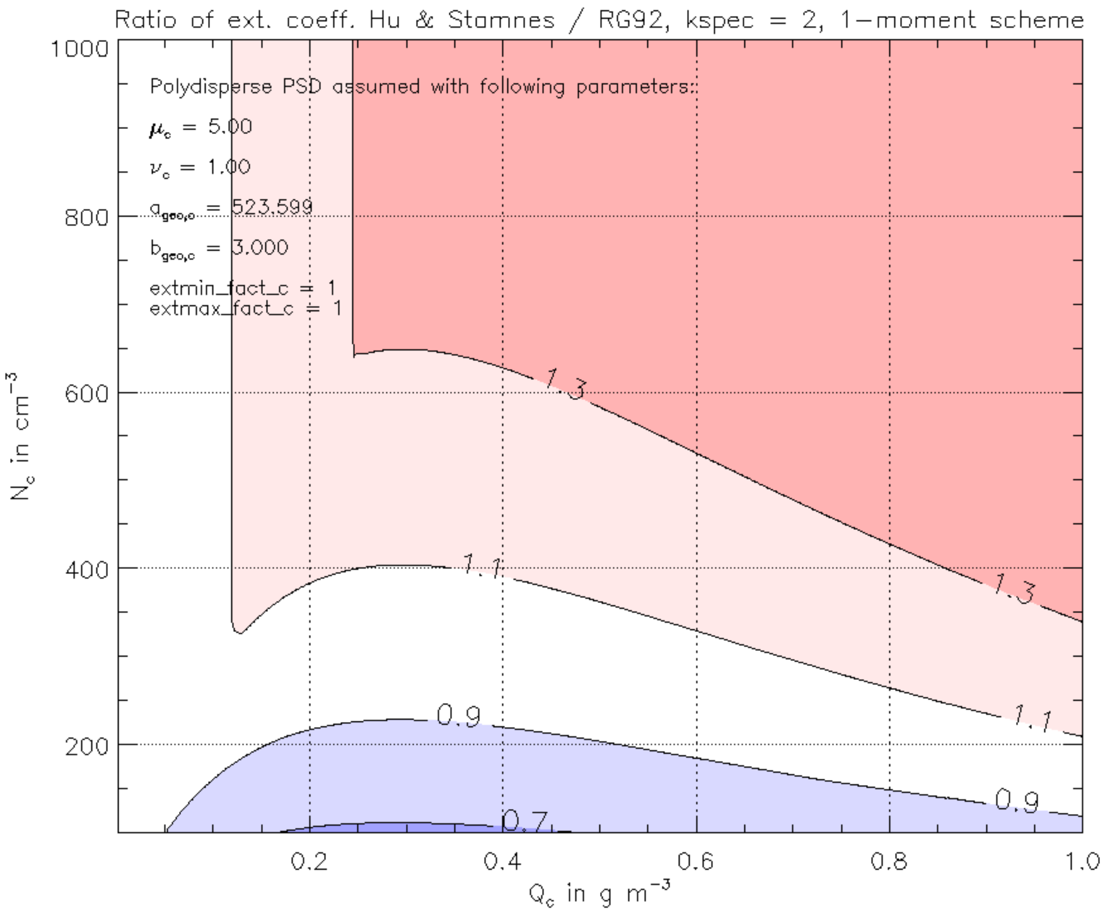
➔ If grid scale qc > 0: from cloud microphysics:



$$f(D) = N_0 D^\mu e^{-\lambda D}$$

$\mu = 5.0$

$N_c = \texttt{cloud\_num}$

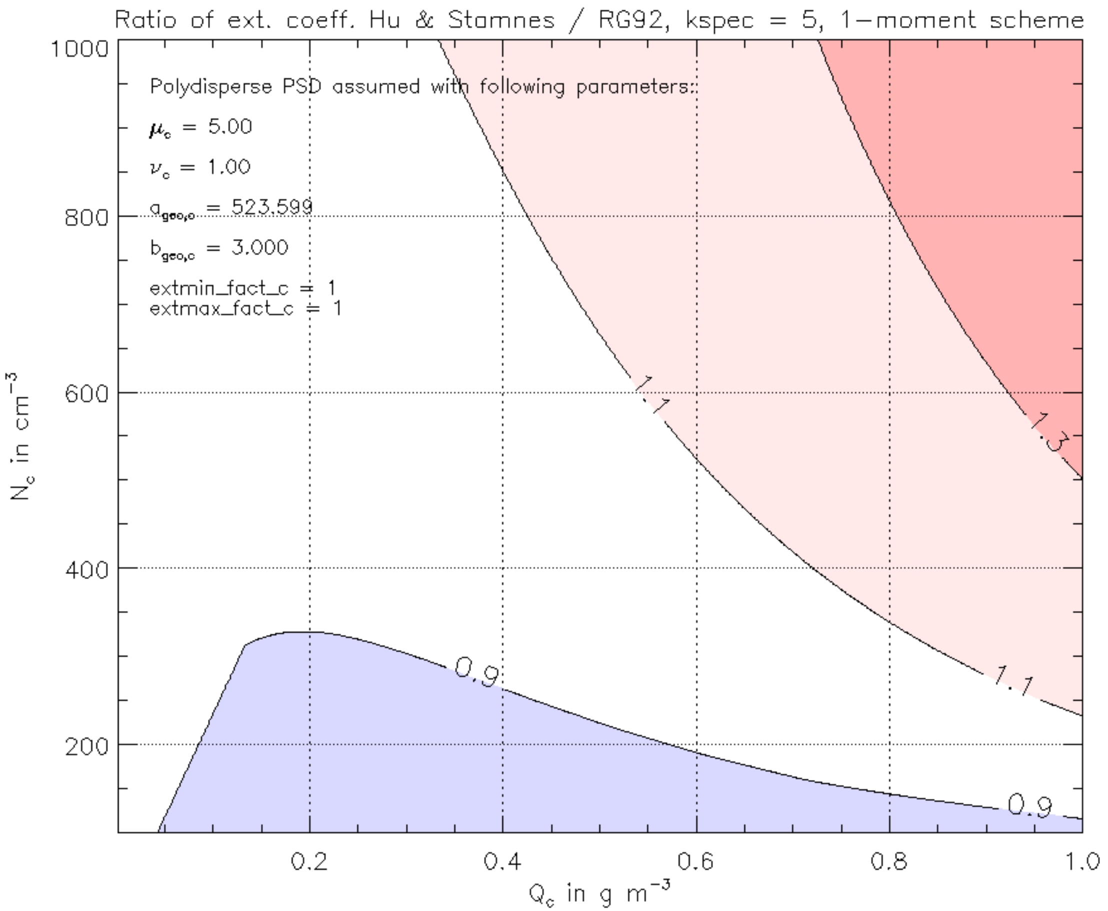
q_c prognostic

Spectral interval „2“ (visible range)

β_{ext} ratio HS / RG92

Cloud droplets comparison to RG92

➔ If grid scale qc > 0: from cloud microphysics:



$$f(D) = N_0 D^{\mu} e^{-\lambda D}$$

$\mu = 5.0$

$N_c = \texttt{cloud\_num}$

q_c prognostic

Spectral interval „5"
(infrared range)

β_{ext} ratio HS / RG92

Sugrid scale water clouds

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- Pure subgrid scale clouds ??? → R_e = 10 µm (or 5? or 15? **TUNING**)
- Real case studies by Anna Possner (ETHZ) and a Master student for some fog cases in Switzerland and comparing 1-moment and 2-moment microphysics, indicates that for these cases a smaller value should be used, e.g., 5 µm, but that might depend on the case.
- There are explicit relations of R_e = fct(LWC) in literature, derived from measurements for certain cloud types and regions in the world.
  (see next slides for an example, but not implemented yet!)
- SGS cloud water content = **P1** * $QV_{sat,g}$ * $(1 – f_{ice})$

  P1 is now a tuning parameter, replacing the formerly constant 0.005. (May contain also a subgrid scale variability factor, see later – radqc_fact)
- „Coarser grid“ radiation calculations??? → The definition of R_e suggests spatial averaging of $1/R_e$, weighted by ρ_c

Outlook: Subgrid scale water clouds

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 104, NO. D6, PAGES 6145–6153, MARCH 27, 1999

Relationships between cloud droplet effective radius, liquid water content, and droplet concentration for warm clouds in Brazil embedded in biomass smoke

Jeffrey S. Reid,[1] Peter V. Hobbs, Arthur L. Rangno, and Dean A. Hegg
Department of Atmospheric Sciences, University of Washington, Seattle

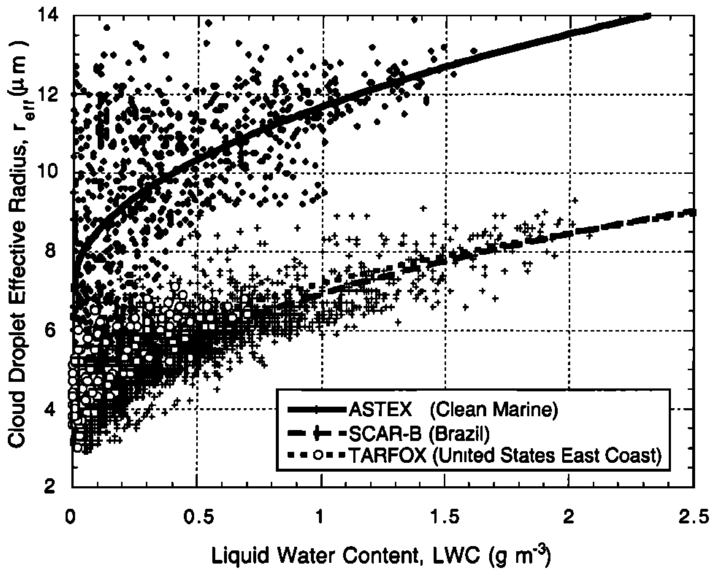

Figure 6. Cloud droplet effective radius (r_{eff}) versus liquid water content (LWC) for cumulus clouds in clean marine air over the northeastern Atlantic Ocean (diamonds, Atlantic Stratocumulus Transition Experiment (ASTEX)), in urban-industrial air off on the U.S. east coast (circles, Tropospheric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

Just an example on measurements of Re in water clouds, that are subscale to our models.

There are more papers on field experiments out there!

Something like that could replace the currently constant assumption for Re in subgrid scale water clouds in the model!

Definition of Re for ice particles

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- Depends on particle spatial orientation assumption and might be different for different parameterizations!
- **Fu et al. (1996, 1998)** assume randomly oriented hexagonal columns.
- If L = length and D = width of the needles, $x = aL^b$ (mass-size-relation from the cloud microphysics scheme) and the particle shape determine D(L). Then, using the PSD shape assumption N(L) from microphysics:

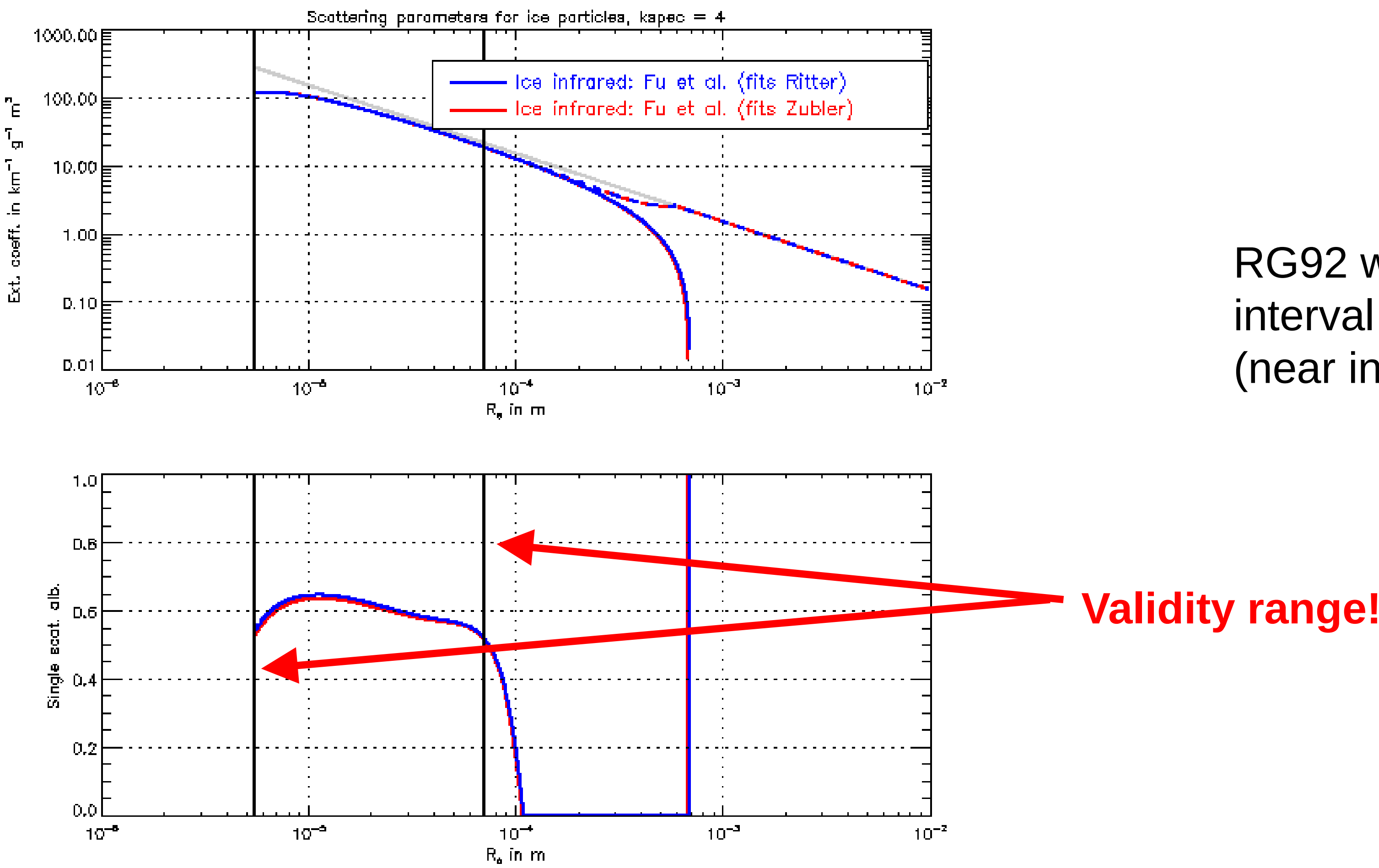
$$R_e = \frac{\int_0^\infty D(L)^2 \, L \, N(L) \, dL}{2 \int_0^\infty \left(D(L) \, L + \frac{\sqrt{3}}{4} D(L)^2 \right) N(L) \, dL} = \frac{\int_0^\infty V(L) \, N(L) \, dL}{\sqrt{3} \int_0^\infty \overline{A}(L) \, N(L) \, dL}$$

$$\sim \frac{\int \text{Total volume of ice}}{\int \text{Total orientation averaged shadowed area} = \frac{\text{surface area}}{4}}$$

$$R_e = \frac{0.5}{c_1(a,b) \left(\frac{\rho_i}{n_i(T)} \right)^{c_2(b)} + c_3(a,b) \left(\frac{\rho_i}{n_i(T)} \right)^{c_4(b)}} = \frac{0.5}{c_1 \, \overline{x}_i^{c_2} + c_3 \, \overline{x}_i^{c_4}}$$

Cloud ice

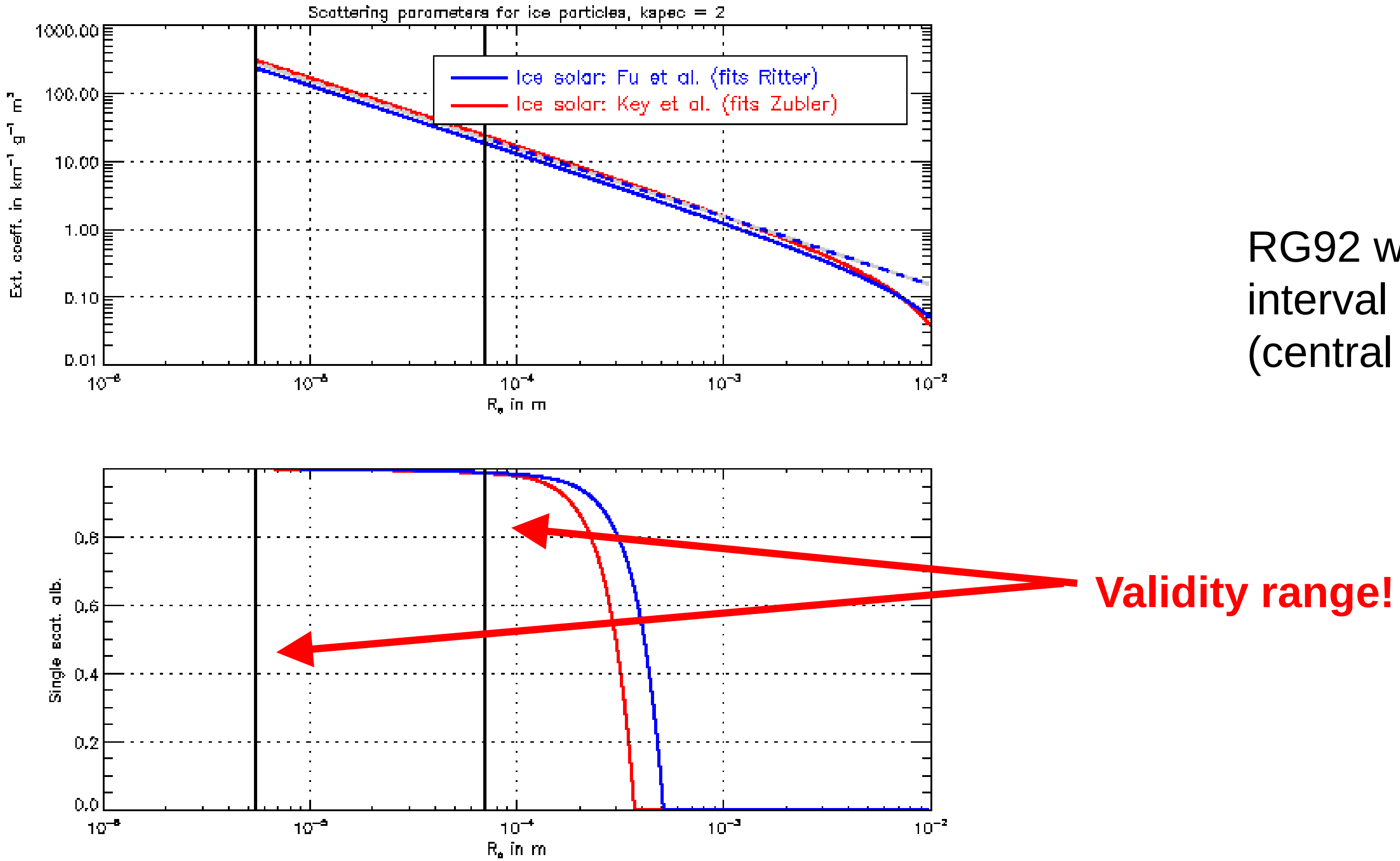
➔ based on Fu et al. (1996):



RG92 wavelength interval **no. 4** (near infrared)

Cloud ice

➔ based on Fu et al. (1998):



RG92 wavelength interval **no. 2** (central visible)

Cloud ice (visible; Fu et al.)

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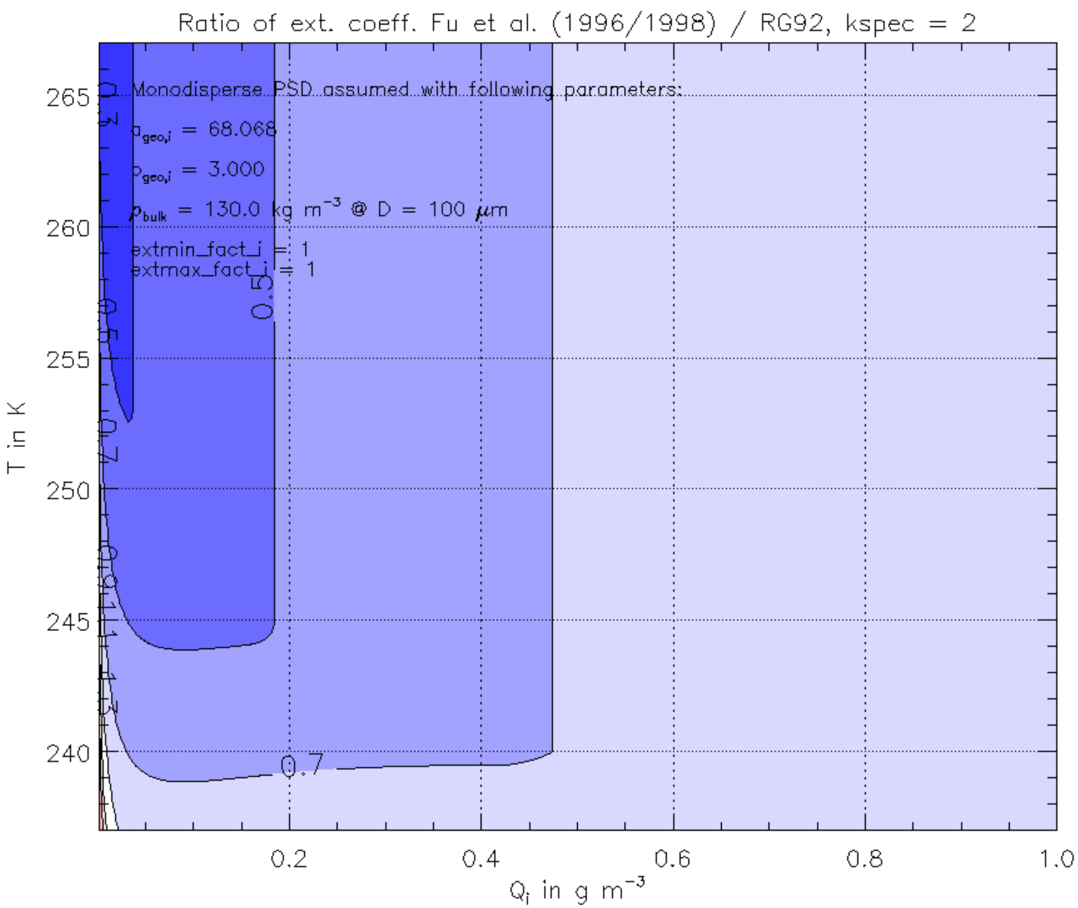
➔ If grid scale qi > 0: from cloud microphysics:



$$f(D) = \text{monodispers}$$

$$N_i(T) = a \exp(b(T_3 - T))$$

q_i prognostic

$$m_i = 130\,D^3 \quad \text{(SI-units)}$$

Spectral interval „2“ (visible range)

β_{ext} ratio Fu / RG92

Cloud ice (infrared; Fu et al.)

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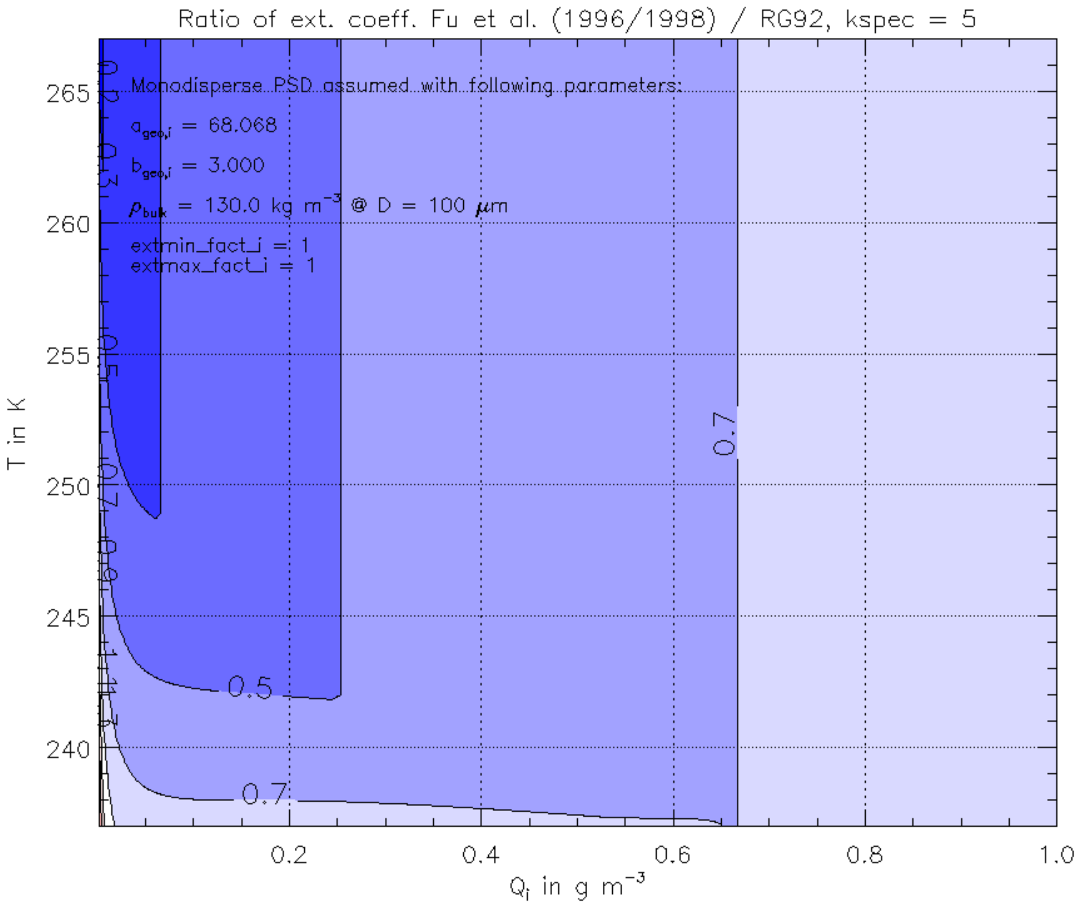
➔ If grid scale qi > 0: from cloud microphysics:

$f(D) \;=\;$ monodispers

$N_i(T) \;=\; a \exp\left(b\,(T_3 - T)\right)$

q_i prognostic

$m_i \;=\; 130\,D^3$ (SI-units)



Spectral interval „5“ (infrared range)

β_{ext} ratio Fu / RG92

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Subgrid scale ice clouds

➔ SGS ice content:= **P2** * $QV_{sat,g}$ * f_{ice}

P2 is now a tuning parameter, replacing the formerly constant 0.005. (May contain also a subgrid scale variability factor, see later – radqi_fact)

➔ **n_i = fct(T)** from COSMO microphysics

from this and SGS ice content and assumption about PSD (monodisperse or generalized gamma), compute R_e

➔ Scattering parameters from R_e and SCS ice content

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Include grid scale qs, qg and qr into radiative calculations

- Comutation of R_e the same as for QC resp. QI. For QS and QG the mass-size relations for snow and graupel are used, not the ones for cloud ice. But still we assume simple hexagonal shapes for the particles. However, parameterizations of β_{ext} , ω and g only valid for r <~ 70 µm, therefore large-size-approximation for larger R_e
- Large-size approximation for β_{ext} :
  - Based on $\beta_{ext} \rightarrow 2$ for $\pi D/\lambda >> 1$ and spherical particles
  - For rain: constrain the fits so that they are asympotically correct
  - For snow and graupel: recompute $R_{e,LS}$ and blend into QI fits, based on $2\pi R_e/\lambda_{RG92}$:
- Large-size approximation for ω and g: constant extrapolation towards larger sizes

Large size approximation

- Beta_ext for rain:

$$\lim_{\frac{\pi D}{\lambda}\to\infty} \frac{\sigma_{ext}}{A_{geo}} = 2 \qquad A_{geo} = \frac{\pi}{4} D^2$$

$$\boxed{\frac{\beta_{ext}}{\rho_x}} = \frac{2\frac{\pi}{4} M_2}{\frac{\pi}{6}\rho_w M_3} = \boxed{\frac{3}{2\rho_w R_e}} \qquad M_i = \int_0^\infty D^i N(D)\, dD$$

$$R_e = \frac{1}{2}\frac{M_3}{M_2} = c_1 \left(\frac{\rho_x}{n_x}\right)^{c_2}$$

Large size approximation

- Beta_ext for snow / graupel:

$$\lim_{\frac{\pi D}{\lambda} \to \infty} \frac{\sigma_{ext}}{A_{geo}} = 2\, f_{trans} \qquad 0 < f_{trans} < 1 \qquad A_{geo} = \frac{\pi}{4} D^2$$

$$\frac{\beta_{ext}}{\rho_x} = \frac{2 \frac{\pi}{4} M_2\, f_{trans}}{\frac{\pi}{6} \bar{\rho}_{bulk} M_3} = \frac{3\, f_{trans}}{2\, \bar{\rho}_{bulk} R_{eLS}} \qquad \bar{\rho}_{bulk} = \frac{a_g \int_0^\infty D^{b_g} N(D)\, dD}{\frac{\pi}{6} M_3}$$

$$R_{eLS} = \frac{1}{2} \frac{M_3}{M_2} = c_3 \left(\frac{\rho_x}{n_x} \right)^{c_4}$$

- Blending of $\beta_{ext,Fu}$ (R_e) → $\beta_{ext,LS}$ (R_{eLS})

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Resulting scattering parameters

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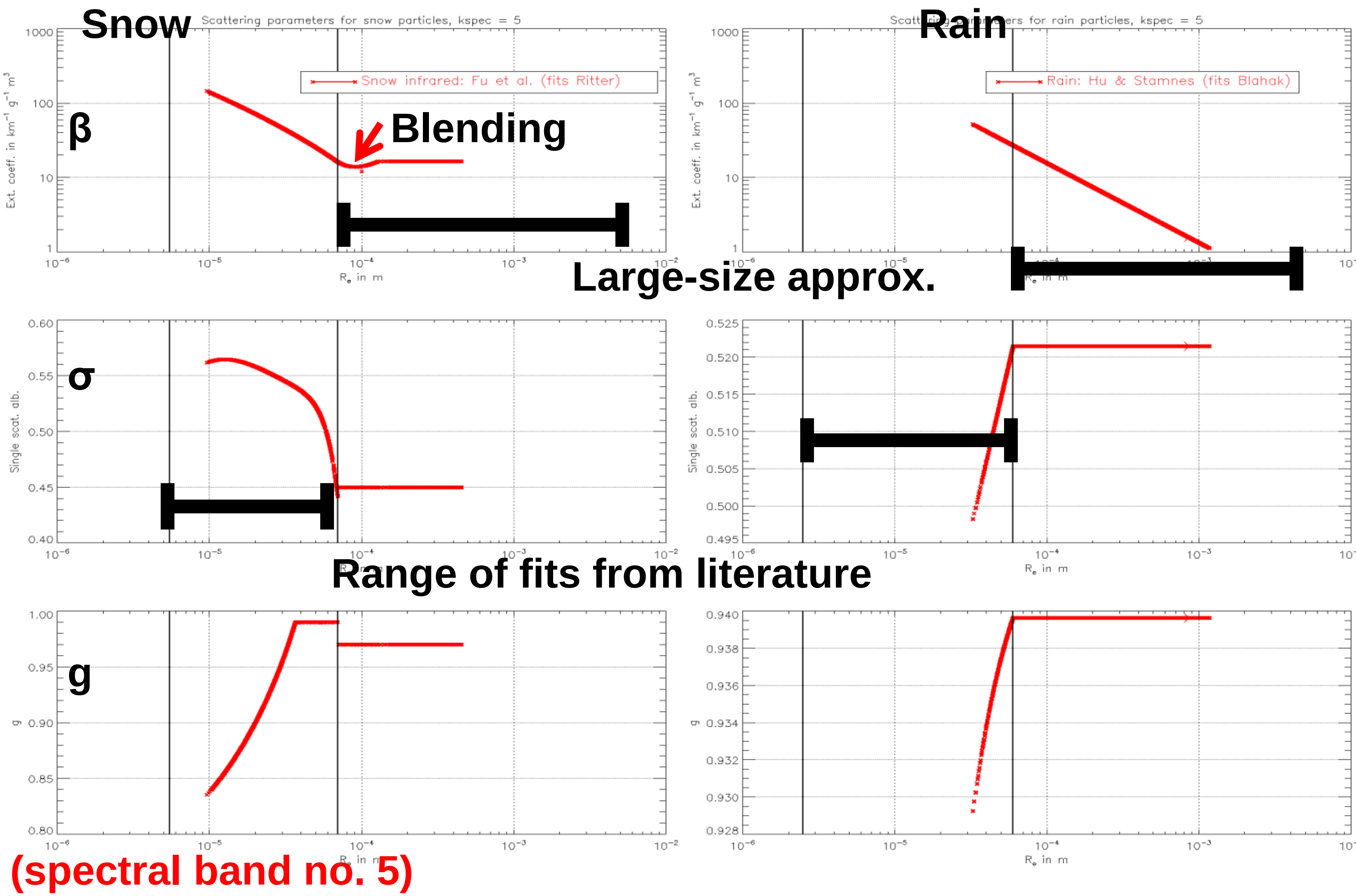

Constant extrapolation of ω and g

➔ Very recent paper on single particle scattering parameters up to 20 mm diameter: constant extrapolation only good in the visible, not IR!

Spectrally Consistent Scattering, Absorption, and Polarization Properties of Atmospheric Ice Crystals at Wavelengths from 0.2 to 100 μm

PING YANG,* LEI BI,* BRYAN A. BAUM,+ KUO-NAN LIOU,# GEORGE W. KATTAWAR,@ MICHAEL I. MISHCHENKO,& AND BENJAMIN COLE*

(JAS, 2013)

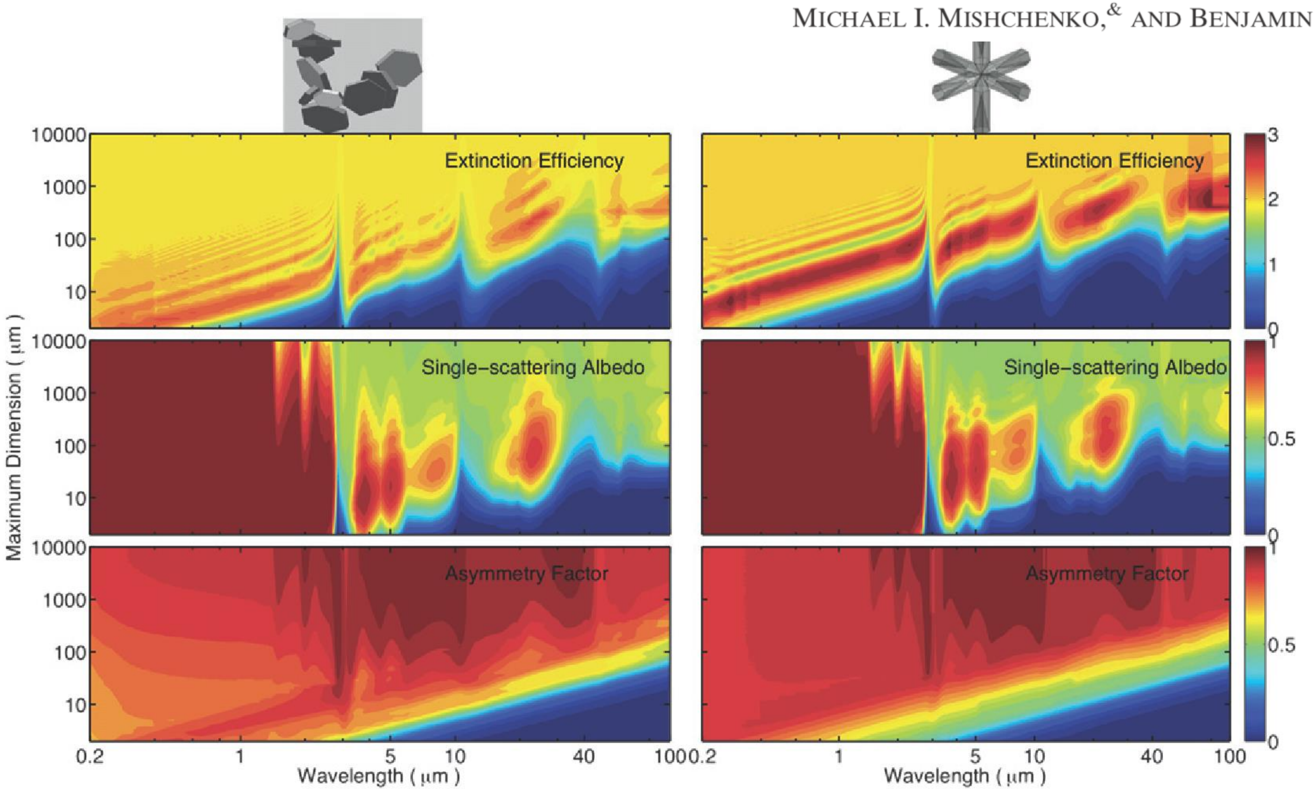

FIG. 10. Contours of the extinction efficiency, the single-scattering albedo, and the asymmetry factor for an aggregate of (left) 10 plates and (right) a hollow bullet rosette.

Outlook: new parameterizations of Quiang Fu

- Quiang provided an extended data set for β_{ext}, ω and g for R_e up to 3 mm. Need to do the spectral remapping to the RG92 wavelength bins.
- Fu (2007): Effective aspect ratio (AR) much better predictor of g than R_e . Again, parameterization available up to size of 3 mm. **Distinction of smooth and rough surfaces (strong difference in scattering function)!** Need to implement calculation of AR and parameterization in COSMO and decide on assuming rough or smooth surfaces.

A New Parameterization of an Asymmetry Factor of Cirrus Clouds for Climate Models

QIANG FU

Department of Atmospheric Sciences, University of Washington,

(Manuscript received 6 September 2006, in final form 4 J

$$\mathrm{AR} = \frac{\int_{L_{\min}}^{L_{\max}} (D/L) A_c n(L)\, dL}{\int_{L_{\min}}^{L_{\max}} A_c n(L)\, dL}$$

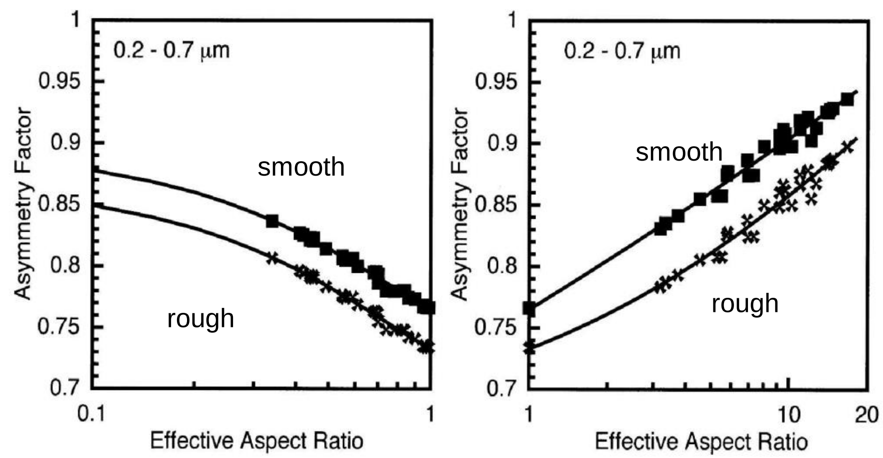

FIG. 4. Asymmetry factor vs the mean effective AR in the spectral interval 0.2–0.7 μm for (left) AR smaller than 1 and (right) AR larger than 1. The square and × symbols in each panel represent reference results from the geometric ray-tracing calculations using 28 measured ice crystal size distributions for ice particles with smooth and rough surfaces, respectively. The curves are from the parameterizations developed in this study.

Some model specific tuning

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- ➔ Cloud drops: R_e based on $n_c = n_{c0}$ * „exponential decrease with height“
  n_{c0} = new tuning parameter (representing aerosol conditions)
- ➔ Cloud ice: R_e based on n_i = fct(T) from microphysics scheme
- ➔ Snow: R_e based on exponential PSD intercept parameter N_{0s} = fct(T) from microphysics scheme
- ➔ Model seems to produce sometimes very high column integrated values of TQC, TQI and TQS, and „the light wents out“ below such clouds.
  Therefore a clipping of QC, QI and QS is applied so that TQC, TQI and TQS do not exceed some threshold **(3 new tuning parameters)**.
  Currently under closer investigation using Lindenberg Obs data, but not conclusive yet.

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TQX clipping – PDFs from Lindenberg and COSMO-EU

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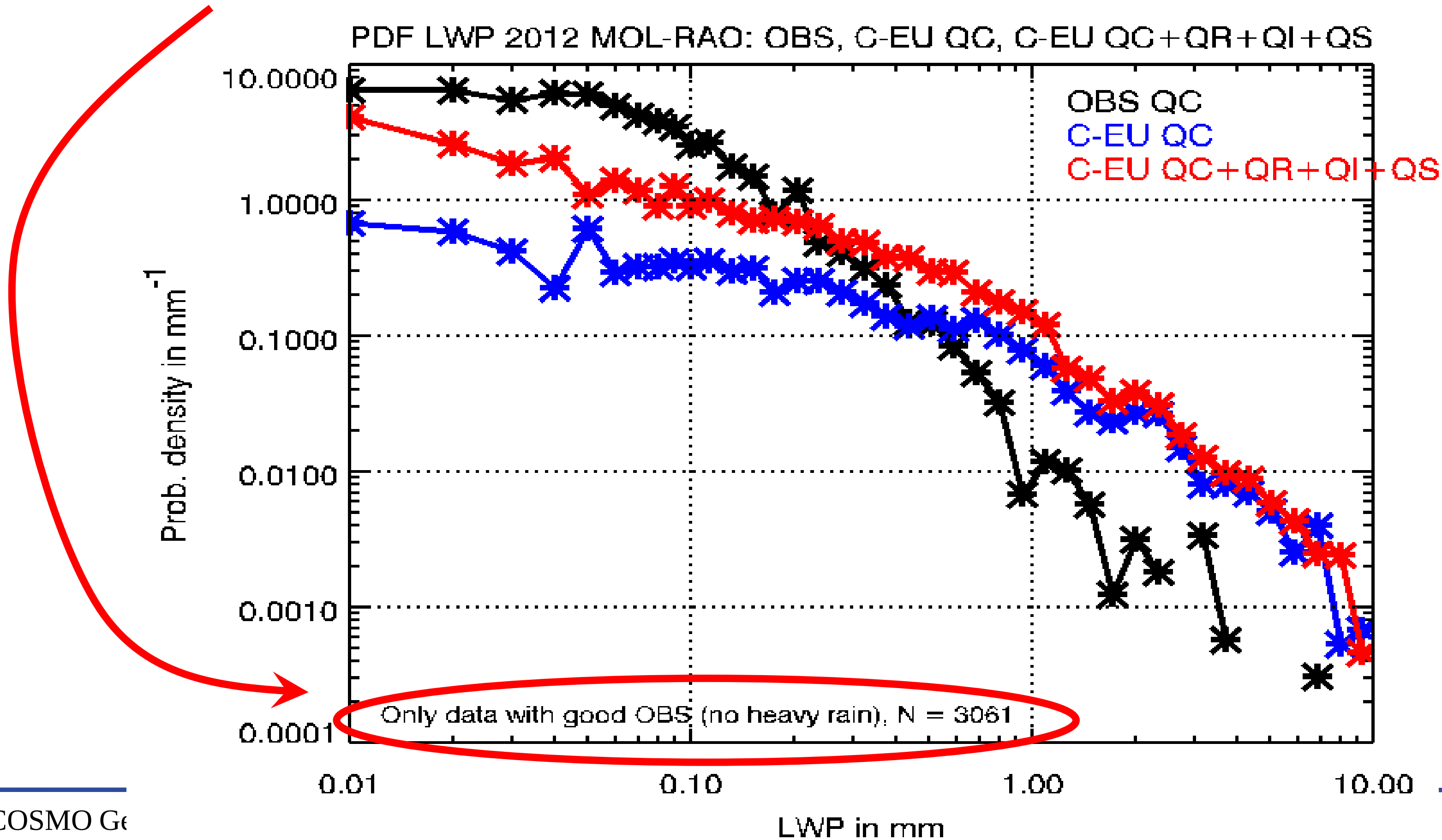
- Observed vs. modeled PDFs of TQC and total column integr. Hydrometeors
- Model seems to show more very high values (similar also in COSMO-DE)
- However, the conditional sampling possibly contaminates the comparison!



Outlook: $n_c(x,y,z)$ from aerosol climatology

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- Instead of choosing a constant n_{c0}, this parameter can be estimated on a climatological basis from aerosol climatologies, e.g., Tegen (1997). Although there might be more recent and perhaps more accurate climatologies, we start with Tegen, because it is already implemented in the COSMO model as an option.
- Tegen: average monthly values of total optical thickness of 5 aerosol species: sea salt, sulfuric acid, other organics, black carbon and dust, where the black carbon is already contained in the „other organics".
- Optical thicknesses derived from longterm global transport modeling and assumptions on the mean specific extinction coefficient. Back-conversion for each of the 4 species (without black carbon):
  - Tau / beta = column integrated aerosol mass per area
  - Assumptions on mean bulk density and mean mass radius lead to column integrated number per area
  - Assumption of an exponential vertical profile leads to number densities
  - Assumption on the soluble fraction of each species leads to CN number densities

Outlook: $n_c(x,y,z)$ from aerosol climatology (2)

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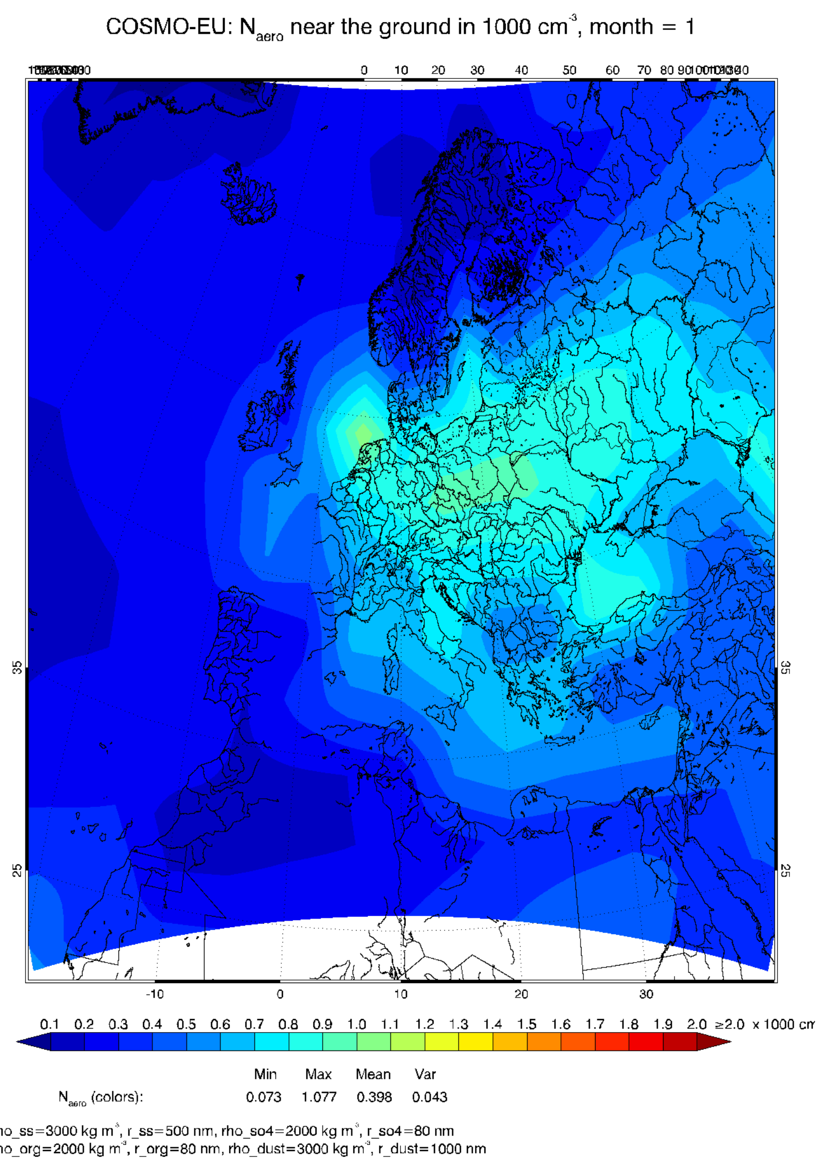
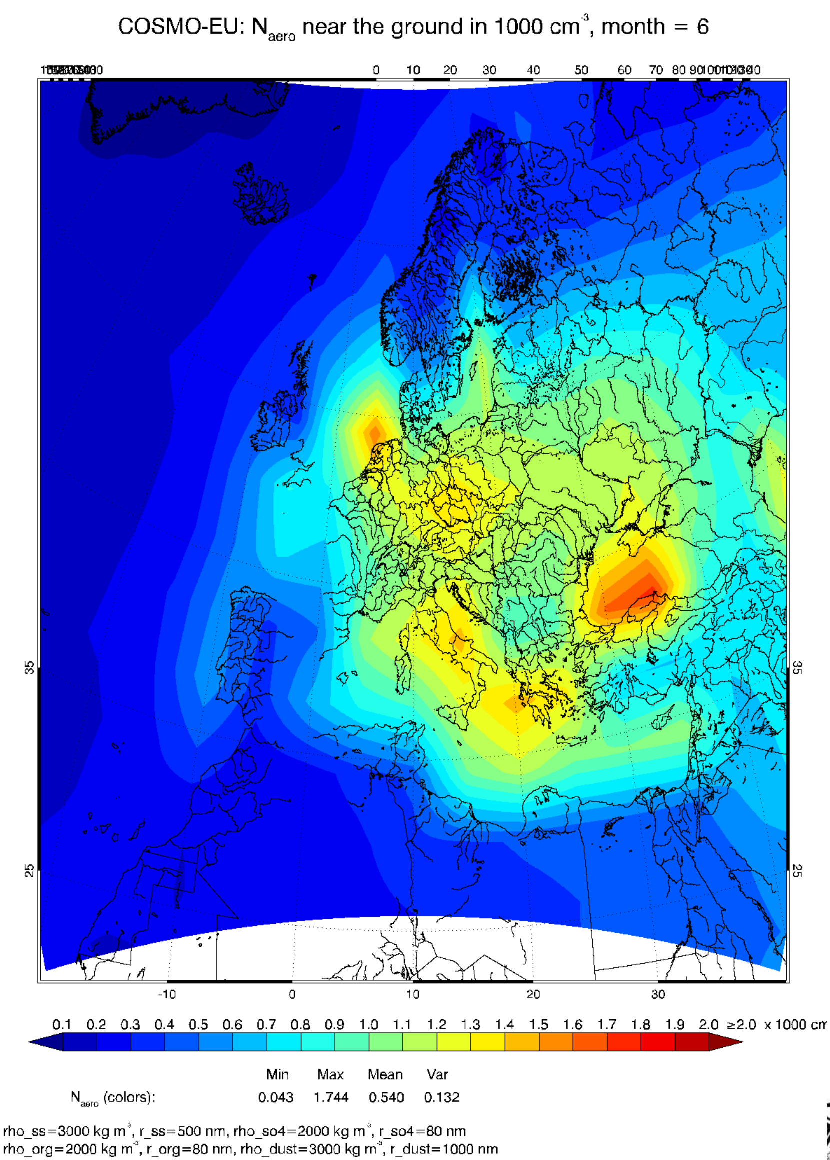
- ➔ Activation of CN to n_c is parameterized after Segal and Khain (2006) as function of CN, w, and mean radius and width of an assumed log-normal aerosol distribution (4D lookup tables):
  - ➔ In „active“ clouds, activation at cloud base, exponential decrease within the cloud above.
  - ➔ „Active“ = w at cloud base > some w_{min}; here: n_c value from lookup tables only at cloud base and assume exponential decrease above
  - ➔ All other clouds (q_c >0): derive n_c from lookup table based on local CN and w
  - ➔ For interpolation: choose fixed mean aerosol radius and distribution width
  - ➔ 2D interpolation of n_c as function of CN and w.
  - ➔ Ideas: smoothing of w to the effective model resolution;
    w_eff = w_smooth + a*sqrt(2*TKE/3)   „/3“ because only vert. comp.;
    activation scheme with PDF(w) = N(w_eff,sigma_w) und sigma_w nach dem JGR-Paper wie beim UM.

Outlook: CN_sfc from aerosol climatology





Outlook: $n_c(x,y,z)$ from aerosol climatology

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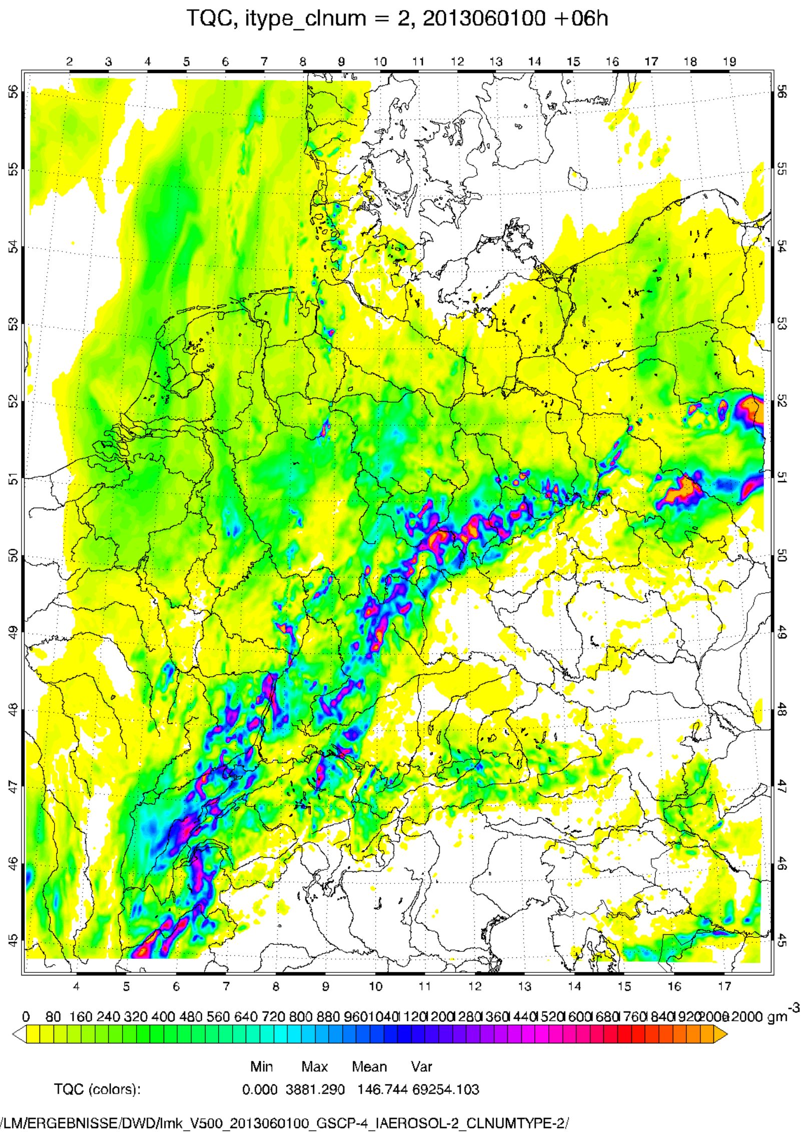
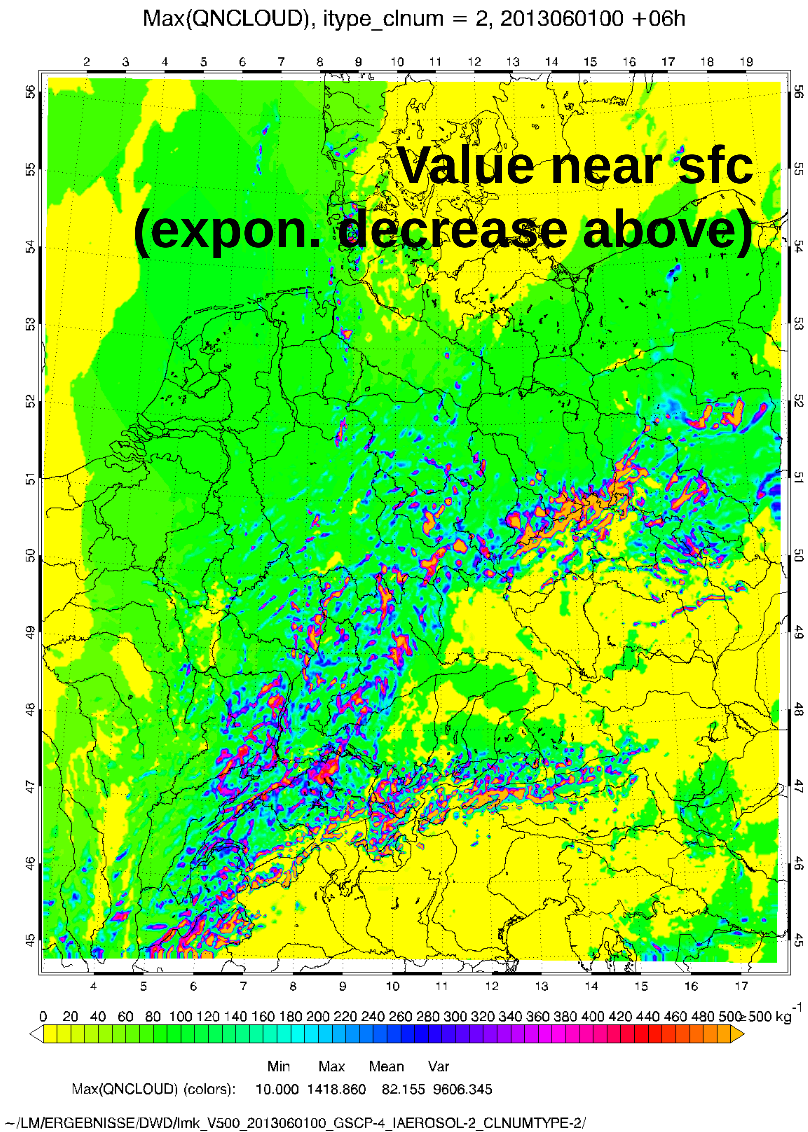




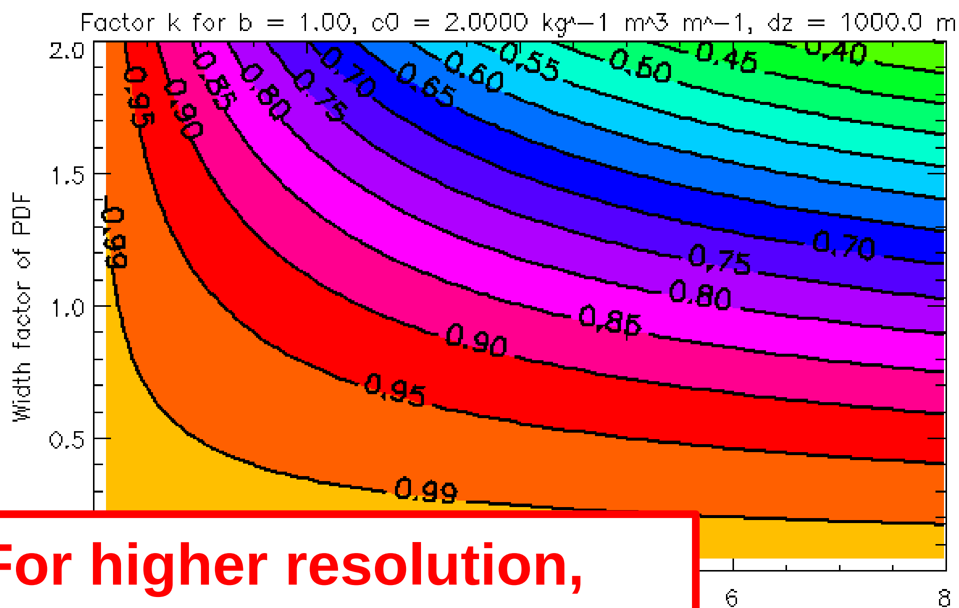
Subgridscale variability, factor k

$$e^{(-k\, c_0\, \bar{\rho}_c\, \Delta z)} \overset{!}{=} \int_0^\infty PDF(\rho_c)\, e^{(-c_0\, \rho_c\, \Delta z)}\, d\rho_c$$

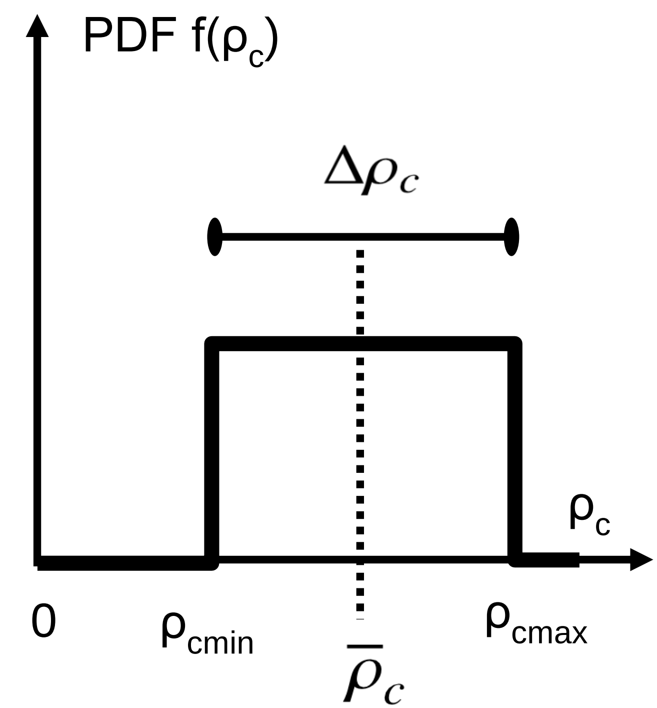
$$k = \frac{1}{c_0\, \bar{\rho}_c \Delta z} \ln \left[\frac{\Delta\rho_c\, c_0\, \Delta z}{\exp(-c_0\, \rho_{cmin}\, \Delta z) - \exp(-c_0\, \rho_{cmax}\, \Delta z)} \right]$$

$\bar{\tau}$

cloudy grid box ρ_c



For higher resolution, k = 0.5 seems too low!



$$\text{width factor} = \frac{\Delta\rho_c}{\bar{\rho}_c} \leq 2$$

Case study: 1.6.2013 (C-DE)

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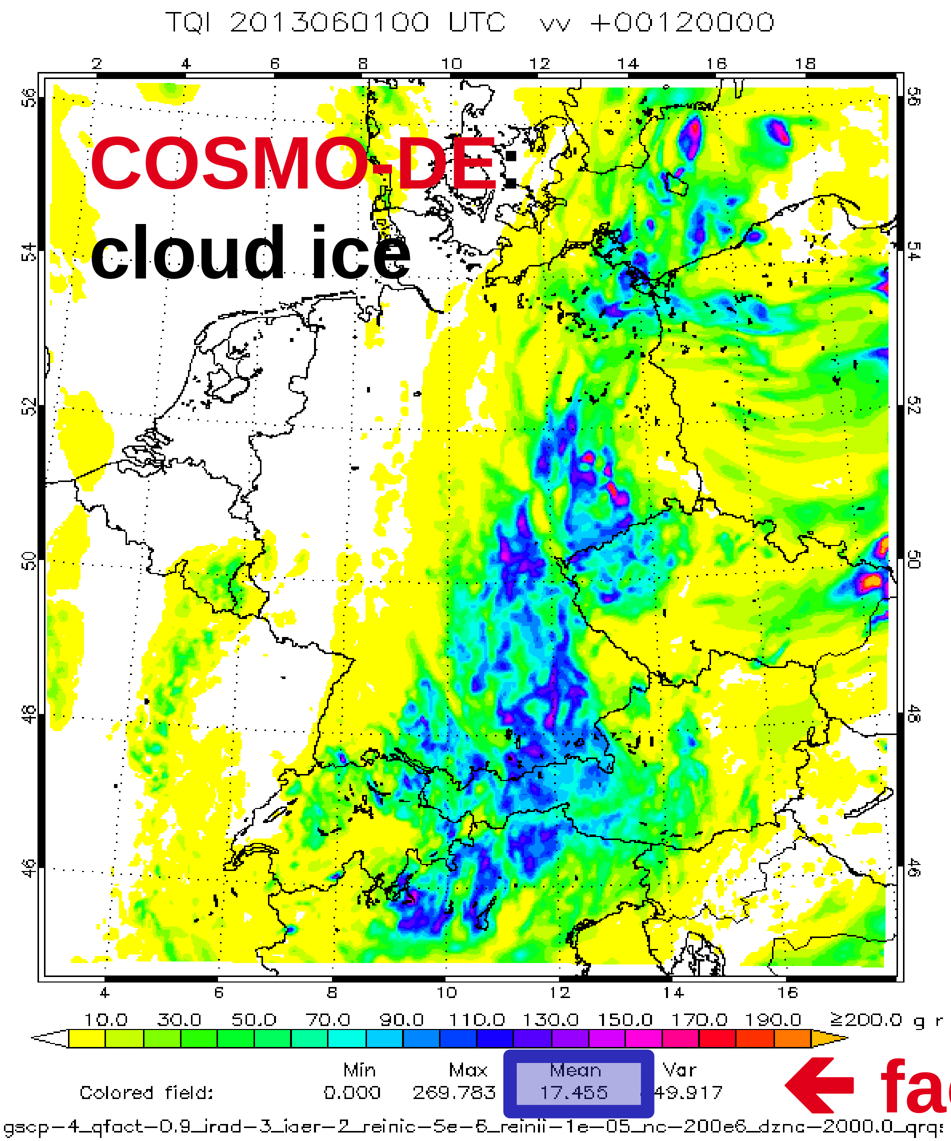

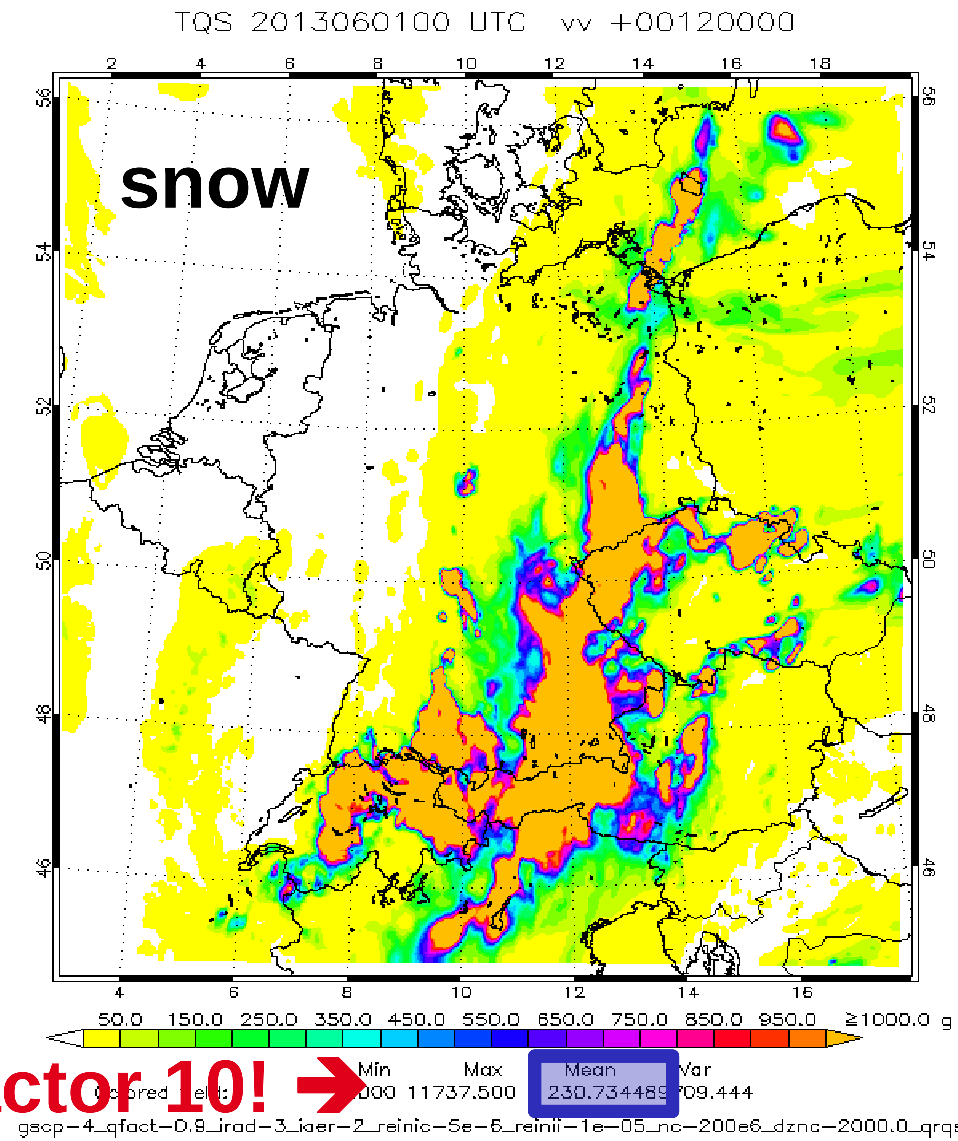

← factor 10! →

Case study: 1.6.2013 (C-DE)

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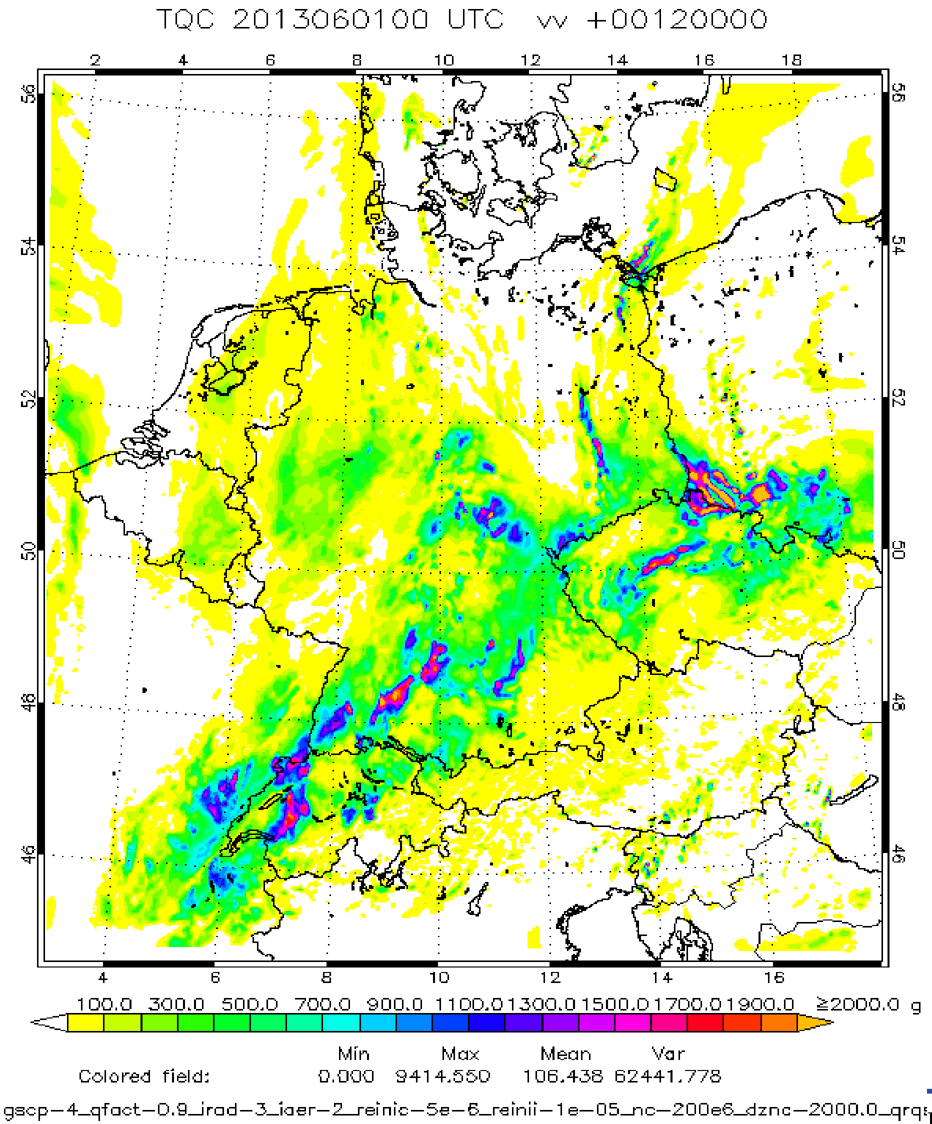
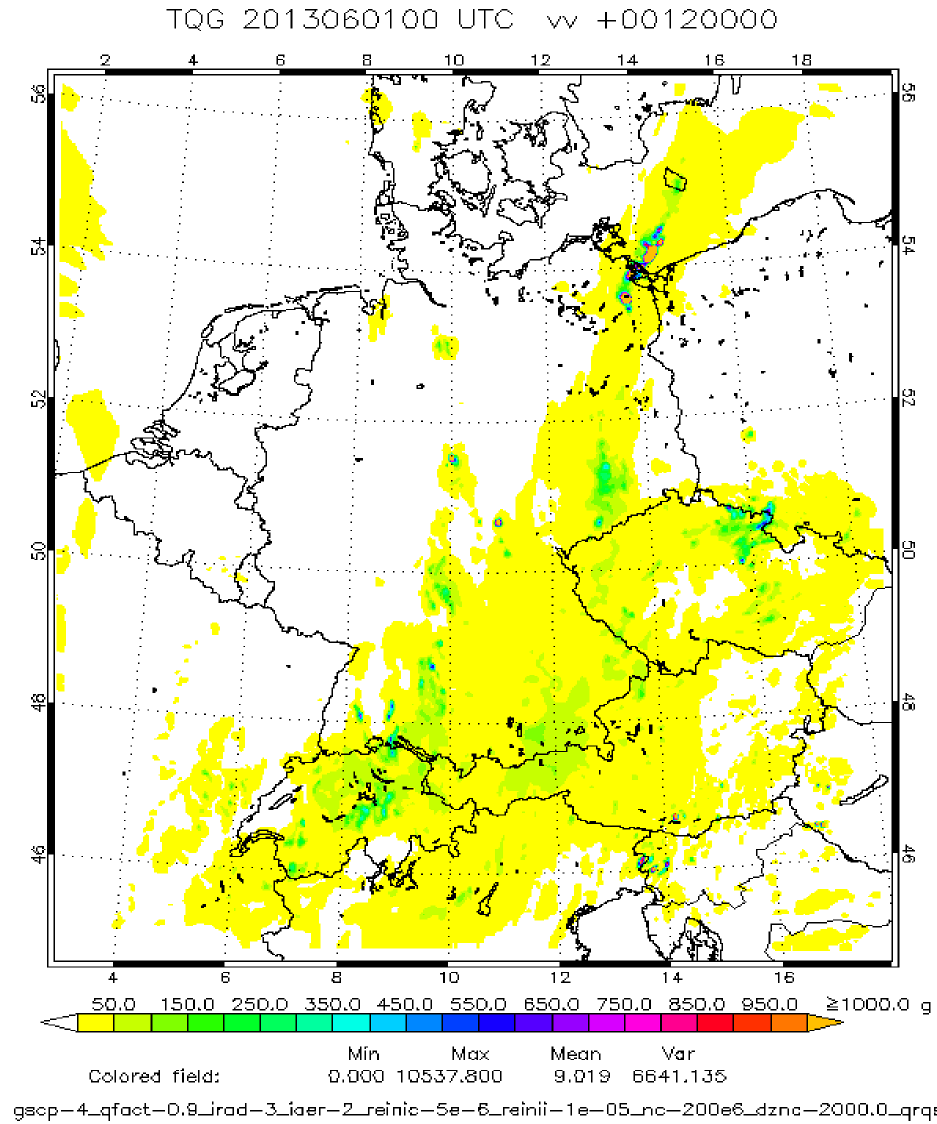
Wetter und Klima aus einer Hand





Case study: 1.6.2013 (C-DE)

Deutscher Wetterdienst
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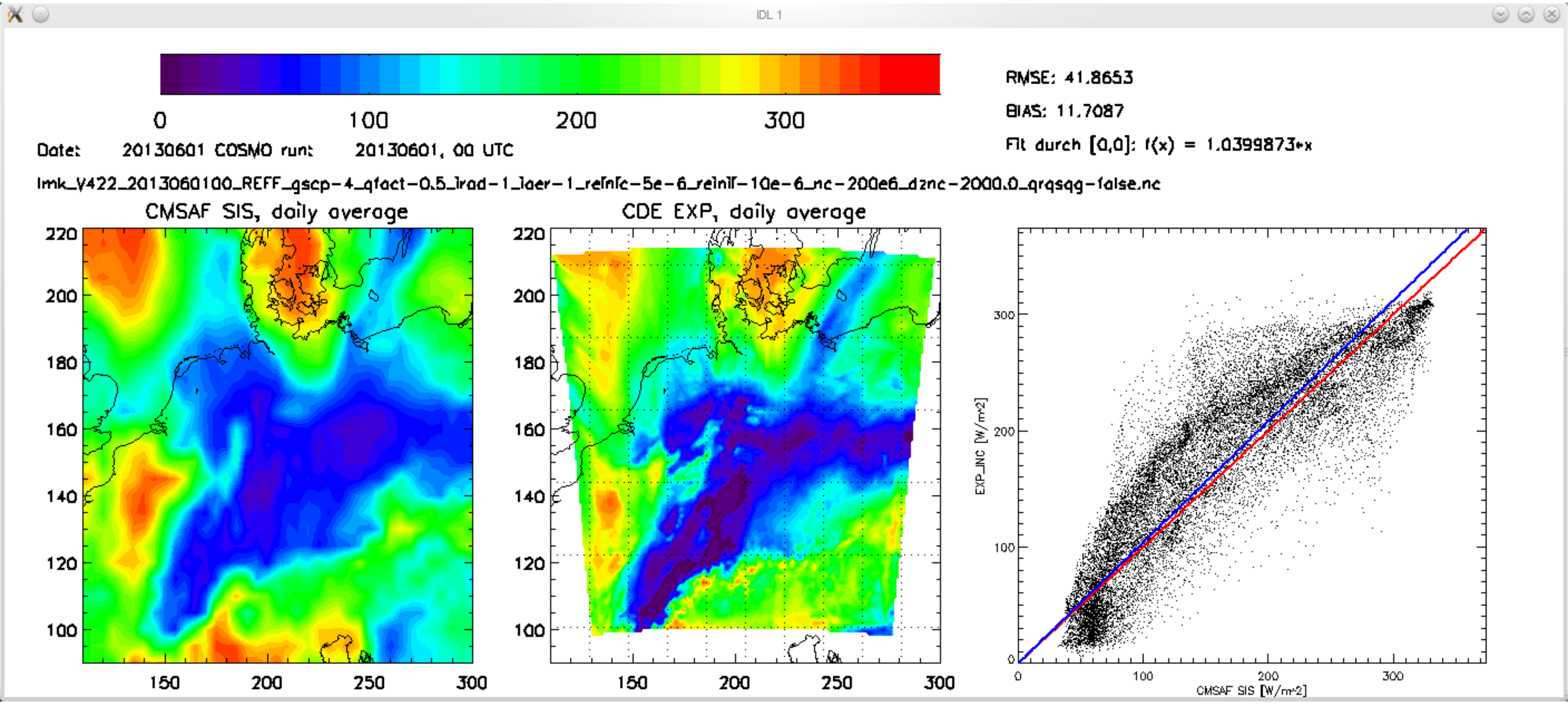
Comparison of shortwave downward fluxes at the ground with CMSAF satellite product



Case study: 1.6.2013 (C-DE)

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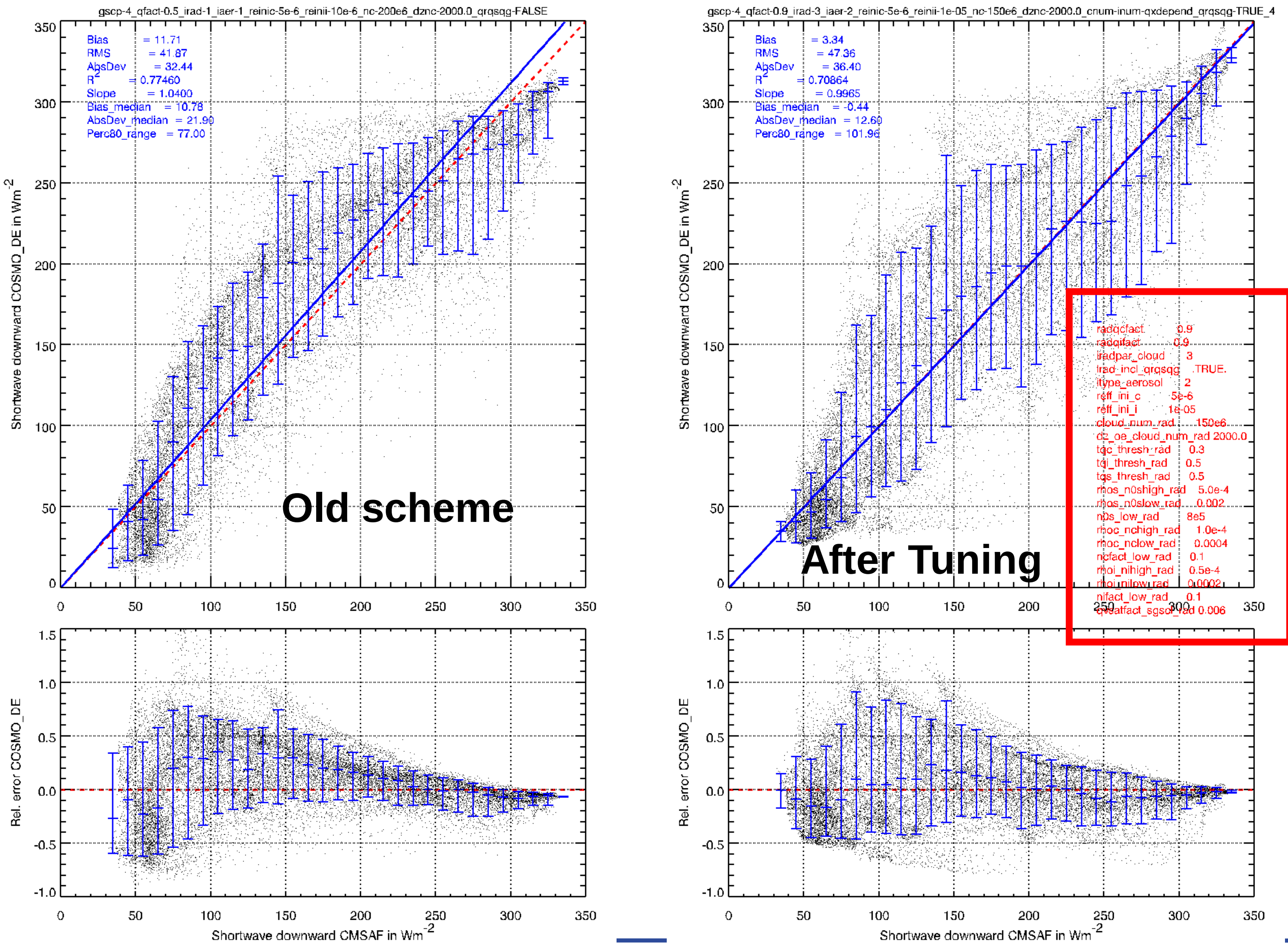

After „optimal“ tuning of the various new tuning parameters to minimize some composite error measure

Case study: 1.6.2013 (C-DE)
closer look at sensitivities

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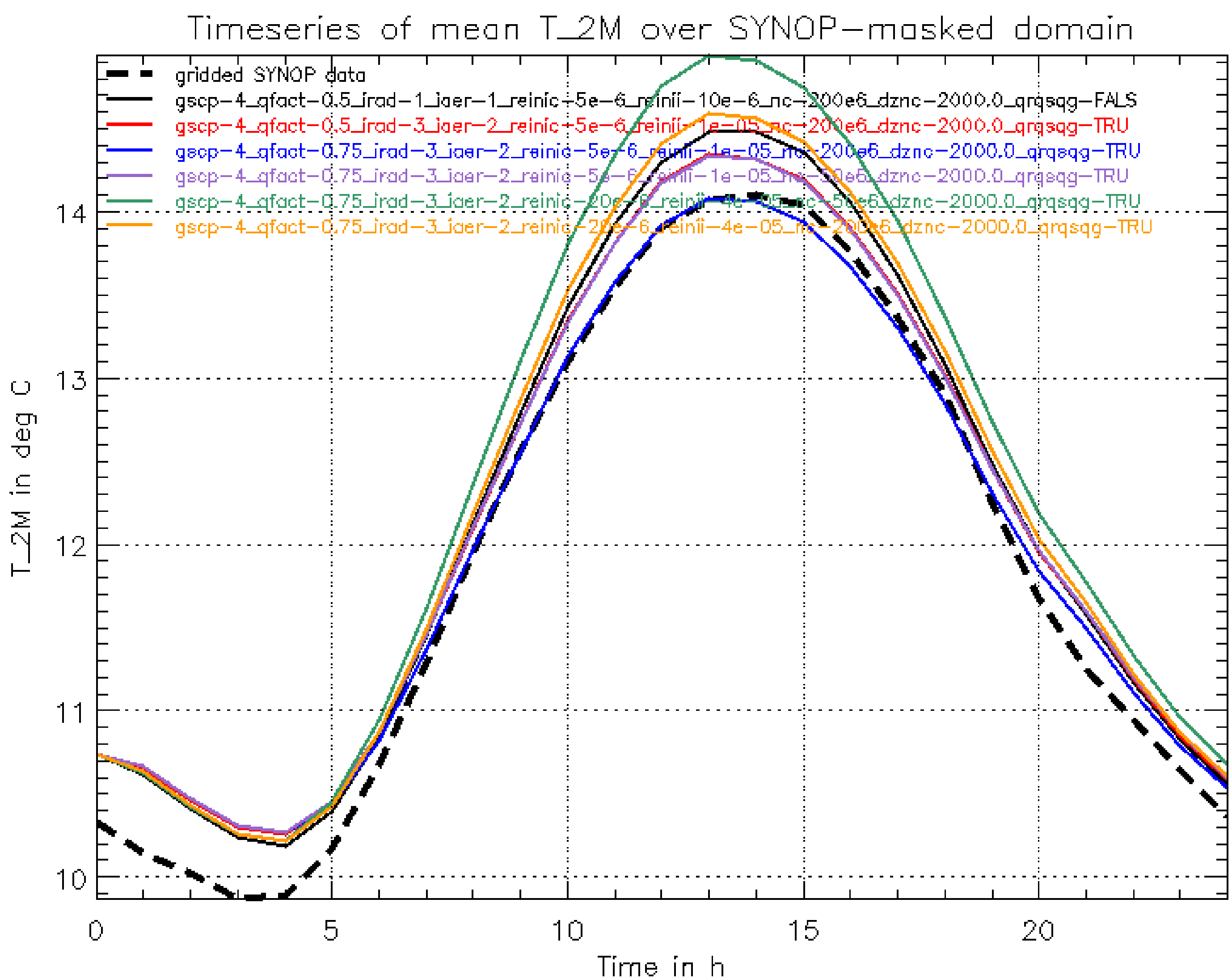

Control

+ qs, qr, qg,
n_{c0} = 200e6,
R_e for SGS water clouds = 5 μm,
new Tegen aerosols

+ incr. k to 0.75

+ decr. n_{c0} to 50e6

+ incr. R_e for SGS water clouds to 20 μm

+ incr. n_{c0} to 200e6 again

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Case study: 1.6.2013 (C-DE)

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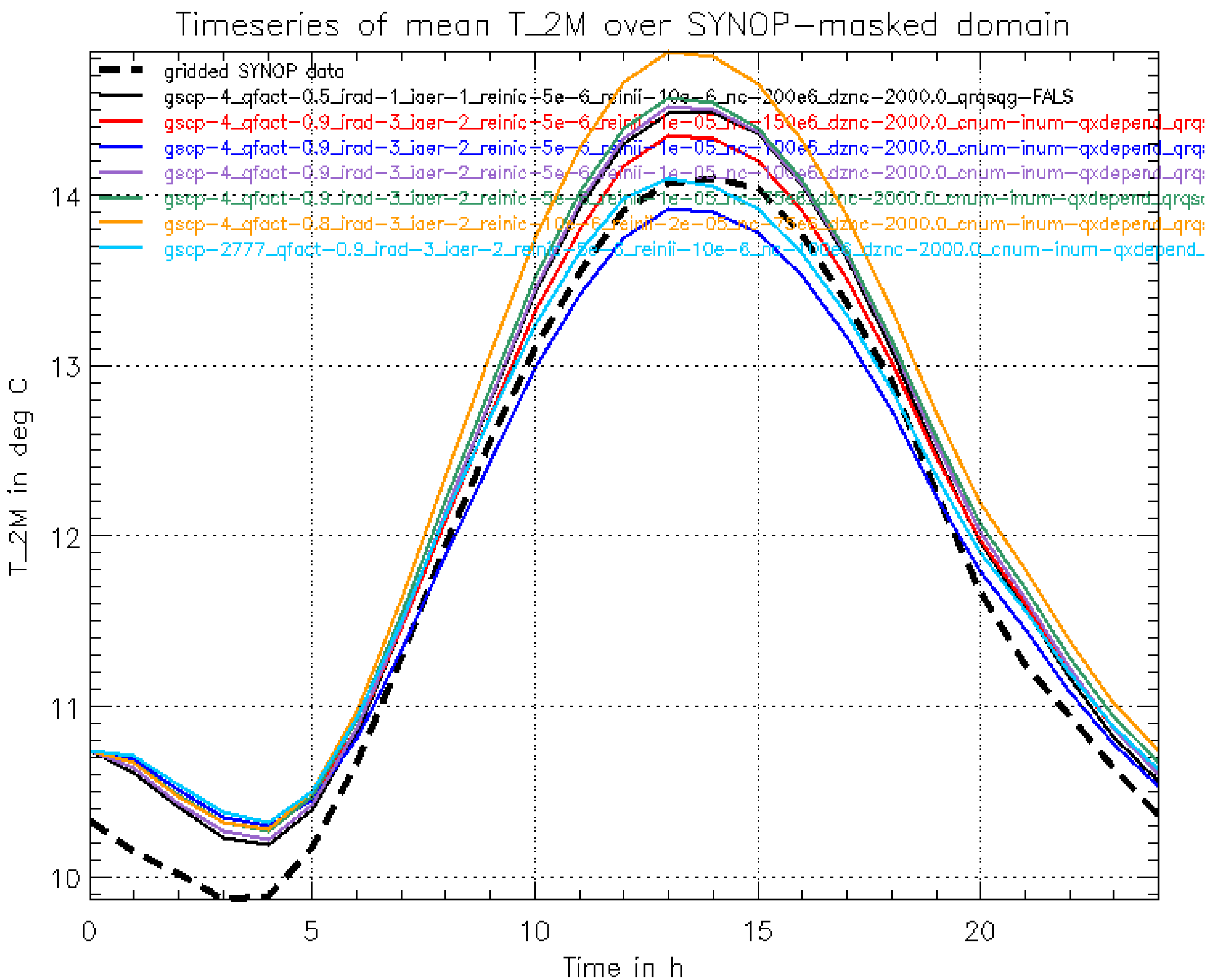

Control

„optimal tuning“ at k=0.9

+ doubling LWC and IWC of SGS clouds

+ halfing LWC and IWC of SGS clouds

+ halfing n_{c0}

+ halfing n_{c0} and doubling Re of SGS water clouds

2-moment scheme

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Summary of the method

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- ➔ Implemented Re based parameterizations of the optical properties of cloud droplets and cloud ice from literature
- ➔ Extrapolation of these parameterizations for the larger Re of snow, graupel and rain with the help of a large size approximation
- ➔ N_{c0} of cloud droplets is new tuning parameter
- ➔ Subgrid variability factor k for grid scale clouds investigated. Previous value 0.5 too low. Treated as new tuning parameter.
- ➔ Uncertain properties of SGS clouds are treated as tuning parameters
- ➔ Some other minor new tuning parameters
- ➔ Next step has to be a considerable reduction of tuning parameters!

Conclusions

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➔ Changes in cloud radiation coupling can lead to big changes of T_2M and possibly other model variables. This gives us a pretty big handle on the model!

➔ Sensitivities: The implemented R_e-parameterisations make the ice clouds optically thinner in the visible and infrared, therefore increased shortwave heating and longwave cooling in the presence of clouds. Including qs/qg and increasing factor k both counteract this, the clouds get optically thicker at all wavelengths, so Tmax during day is reduced.

➔ However, entire model currently tuned to the previous method of cloud radiation coupling (SGS cloud diagnostics, ...). Therefore, to uncover possible beneficial effects of the presented new method requires extensive re-tuning of the model!

➔ We are in the middle of this process, but will perhaps take a long time!

➔ Changes in the cloud microphysics scheme now also have a more direct influence on the radiation!

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List of namelist parameters

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lrad_incl_qrqsqg*	PHYCTL	to include QS, QG, QR or not
iradpar_cloud*	PHYCTL	1=beta,omega,g of RG92, 2=new R_e based values
lrad_use_largesizeapprox	PHYCTL	to use large-size-approx. for QS,QG,QR or clip at 70 µm
itype_aerosol*	PHYCTL	1=old climat., 2=Tegen
icloud_num_type_rad (not fully yet)	PHYCTL	1=const. N_{cloud}, 2=derive from Tegen
radqcfact*	TUNING	k-factor for QC, QR **(, QG, QH!) repr. more variable cloud types**
radqifact*	TUNING	k-factor for QI, QS, ~~QG (, QH~~**) repr. more stratiform cloud types**
rad_arearat_ls_i (f_trans)	TUNING	shadowed area fract. of cloud ice for large size approx (LS)
rad_arearat_ls_s	TUNING	shadowed area fract. of cloud ice for large size approx (LS)
rad_arearat_ls_g	TUNING	
rad_arearat_ls_h	TUNING	
rhobulk_ls_ini_i (not very important)	TUNING	for large-size-approx: value of rho_{bulk} for subgrid scale ice clouds
reff_ini_c (sensitive!)	TUNING	Re for SGS water clouds (if icloud_num_type_rad=1)
reff_ini_i (unnecessary!)	TUNING	initial value for Re of ice clouds. Gets overwritten everywhere
cloud_num_rad	TUNING	N_{c0} for gridscale cloud drops if icloud_num_type_rad=1
zref_cloud_num_rad	TUNING	height of constant N_{c0} layer close to the ground „-“
dz_oe_cloud_num_rad	TUNING	1/e height of expon. decrease above „-“

*** “Master switches“ are in red**

List of namelist parameters

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➔ tqc_thresh_rad*	TUNING	maximum allowed TQC for radiation
➔ tqi_thresh_rad*	TUNING	if model values are higher, reduction
➔ tqs_thresh_rad*	TUNING	of the profiles by a corresp. factor
➔ rhos_n0shigh_rad	TUNING	3 parameters for reduction of N0s (intercept of snow PSD)
➔ rhos_n0slow_rad	TUNING	as function of QS in a linear ramp-down function
➔ n0s_low_rad	TUNING	
➔ rhoc_nchigh_rad	TUNING	3 parameters for reduction of QNC as function of QC
➔ rhoc_nclow_rad	TUNING	in a linear ramp-down function
➔ ncfact_low_rad	TUNING	Just for grid scale cloud water!
➔ rhoi_nihigh_rad	TUNING	similar 3 parameters for reduction of QNI as function of QI
➔ rhoi_nilow_rad	TUNING	Just for grid scale cloud ice!
➔ nifact_low_rad	TUNING	
➔ qvsatfact_sgscl_rad*	TUNING	„zsexfac“, but gets further multiplied by radqx_fact; default: 0.01 to reproduce 0.005, given that radqc_fact=0.5

*** “Master switches“ are in red**

Outlook: new PT $(RC)^2$

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- „Revised Cloud Radiative Coupling“
- Is presented to the STC right now
- Intended as preparation for a larger community tuning exercise (new PP next year), then based on new radiation scheme RRTM (common COSMO-ICON library)
- Work in the PT does however not rely on RRTM, because we are concerned with the input to the radiation scheme and it‘s sensitivities, not the scheme itself!
- Collaboration with colleagues from IMS (Pavel Khain, Harel Muscatel)

Work packages for Priority Task

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- **Priority Task (RC)² (2014 – 2015)**
  - Upgrade test code to the newest COSMO version **(→ UB)**
  - Getting familiar with the COSMO radiation scheme and with UB's test code together with the changes/ extentions contained herein **(→ PK, HM)**
  - Further revision of optical properties of ice hydrometeors (single scat. alb., asym. param.) based on a new parameterization of Fu et al. (2007) **(→ UB, HM)**
    (UB has visited Quiang Fu in Hamburg and initiated collaboration)
  - Review/ revise treatment of subgrid scale clouds in radiation **(→ PK, HM)**
    - E.g., decoupling of CLC diagnostic and radiation tuning; SGS clouds consistent to turbulence scheme?
  - Reduce number of tuning parameters **(→ PK, HM, UB)**
    - 1) Find insensitive parameters by case studies and set to constant values.
    - 2) Physically based closures. Examples:
      - Replace parameter *cloud_num* (number conc. of cloud drops) by a climatology. UB has developed a method for a similar parameter in the microphysics, based on Tegen et al. (1997) and Segal & Khain (2006), but not implemented in the radiation so far.
      - Replace *radqc_fact* by a PDF-based closure. Would be a new development and not clear if possible.
  - Case studies for different weather situations and different climates
  - Possible co-operation with a group from CLM-community for studies in longterm climate mode?
  - Participants: **UB (Ulrich Blahak), PK (Pavel Khain), HM (Harel Muskatel)**
  - Tentative PT leader: **UB**

Work packages for next year's Priority Project

- **Priority Project (2015-2017), first idea on working title: *$T^2(RC)^2$ - Testing and Tuning of Revised Cloud Radiation Coupling***
  - Coupling of RRTM to COSMO (Common physics library) + Transfer of new cloud radiation coupling methods to RRTM interface
  - Extensive testing, model tuning and evaluation in different climates necessary!
    - Would be ideal for a collaborative COSMO effort (different model setups, different climates)
    - Needs help from people from different COSMO countries
    - Liase with PP CALMO for automatic tuning, after expert tuning has revealed the most sensitive tuning parameters?
  - Estimated duration: 2 years
  - Tentative PP leader: tbd (Marco is ready to take the lead in case no one else wants to do it)

Scattering databases for snow/ice hydrometeors

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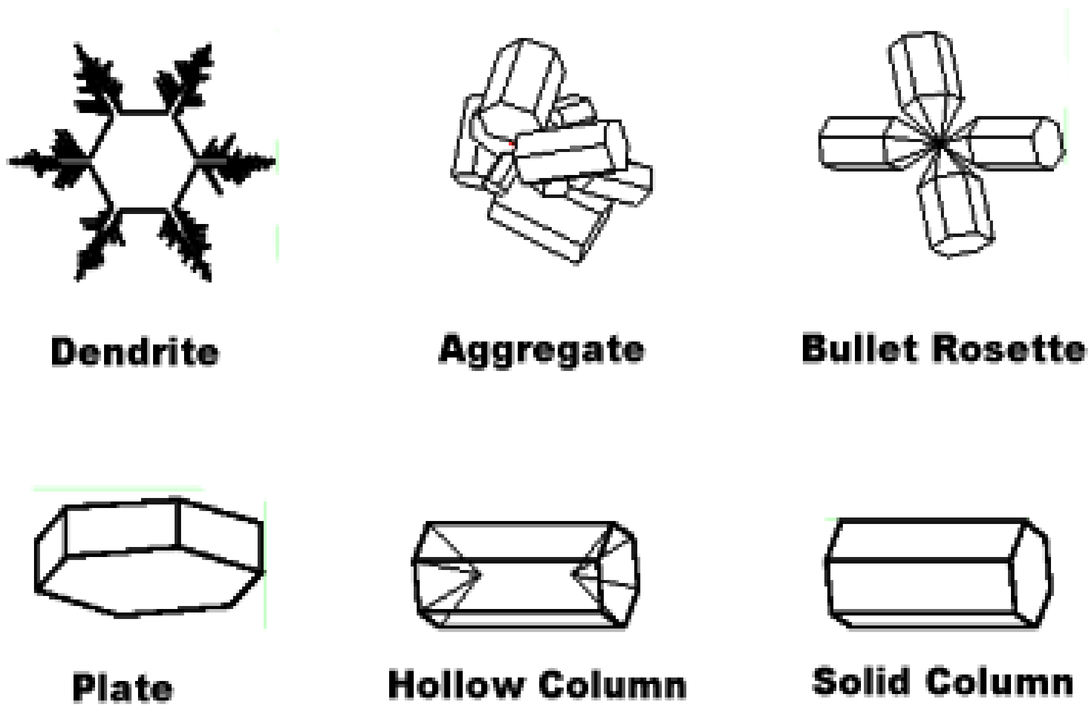
Key et al., 2002: **shortwave radiation**, different habits, but only up to Reff = 0.085 mm!



Gridded T_2M from synop station data (COSMO-DE)

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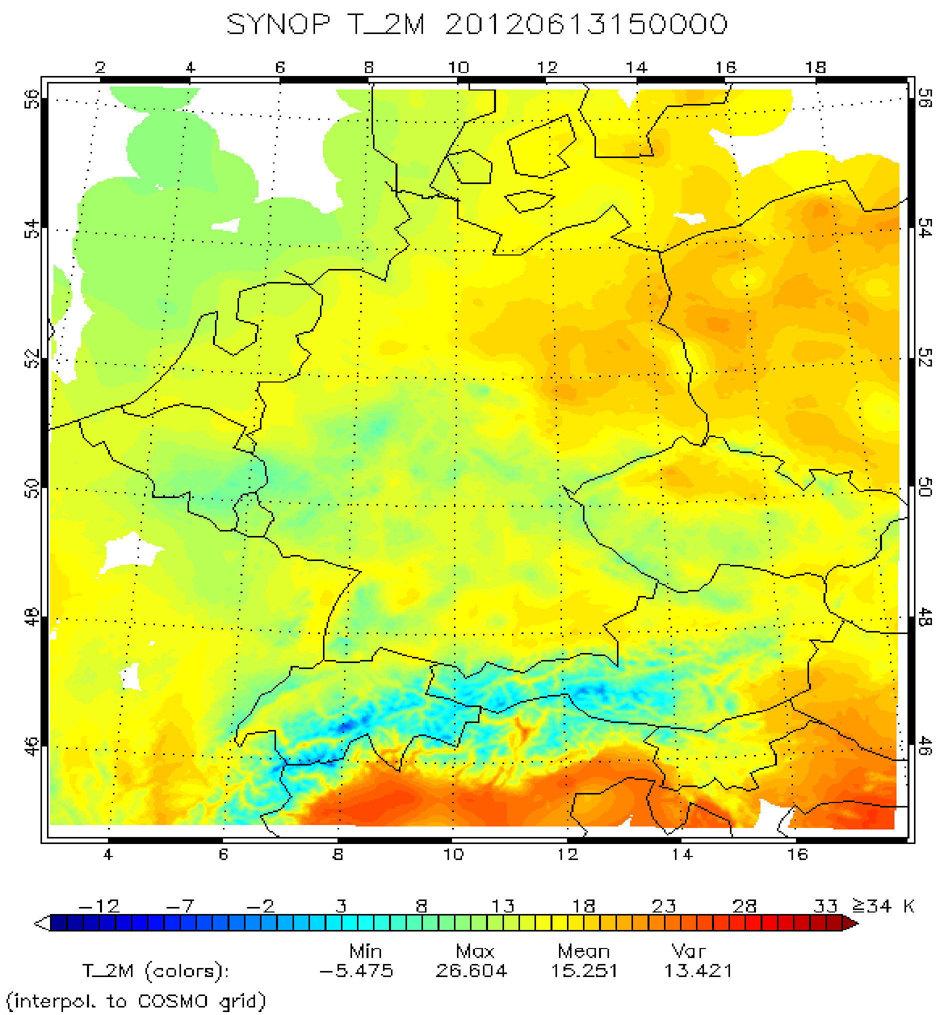


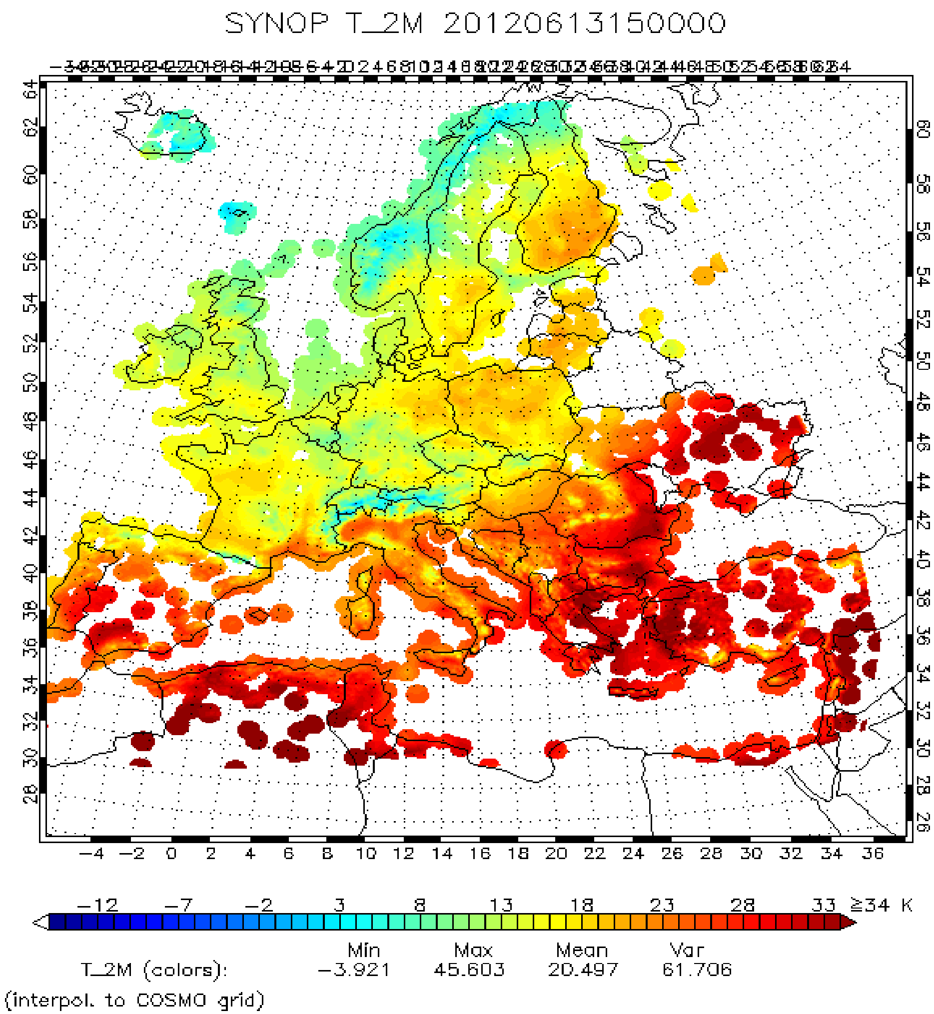
Voronoi-interpolation, based on triangulation.

Height correction to model surface height using standard atmosphere gradient.

„Distance filter“:
Max. distance from the next synop station 70 km.

⇨ Synop data on the model grid, suitable for computing, e.g., bias and rms.

Gridded T_2M from synop station data (COSMO-EU)



Voronoi-interpolation, based on triangulation.

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