Current activities in COSMO physics

(according to COSMO Science-Plan)

- Cloud microphysics: (in the course of common microphys. for COSMO/ICON)
  - ⊙ Revised explicit sedimentation scheme
  - ⊙ Improved determination of cloud-number concentration including aerosol activation ↔ fog
- Radiation: revised (so far one-way) cloud-radiation coupling ↔ fog
  - ⊙ Inclusion of falling hydrometeors in description of ice-cloud optical properties
  - ⊙ Determination and evaluation of sensitive parameters

so far **statistical saturation adjustment** only

- Turbulence(/ SGS Circulation): (in the course of common turbulence for COSMO/ICON)
  - ⊙ Extending (so far one-way) scale interaction between turbulent and non-turbulent SGS flow structures (Separated Turbulence Interacting with Circulations: STIC)
  - ⊙ Implementing (so far ad-hoc) empirical parameterization-extensions
  - ⊙ Introducing moist turbulence to Surface-Atmosphere Transfer (SAT)
  - ⊙ Investigation of possible “stability damping” in the current SAT-scheme

↔ fog

New explicit sedimentation-scheme (for the 2-moment microphysics)

Ulrich Blahak (DWD)

- **Explicit first order flux-form** advection scheme for **sedimentation of hydrometeors**
- In principle independent on Courant-number (in practice up to CFL ≈ 4)

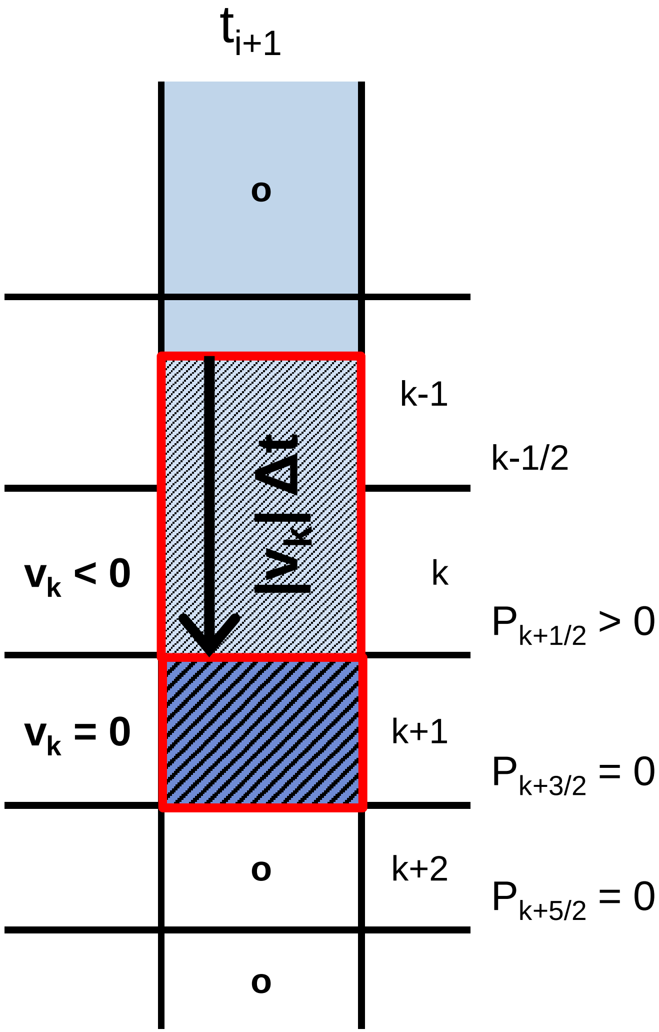
- Problem: unrealistic very high temporal peaks in the precipitation rate
  - vanishing for smaller time steps or by use of an implicit scheme

    (both currently too expensive, at least for the 2-moment scheme!)

➔ **Analysis** of the problem and **reformulation of the scheme**

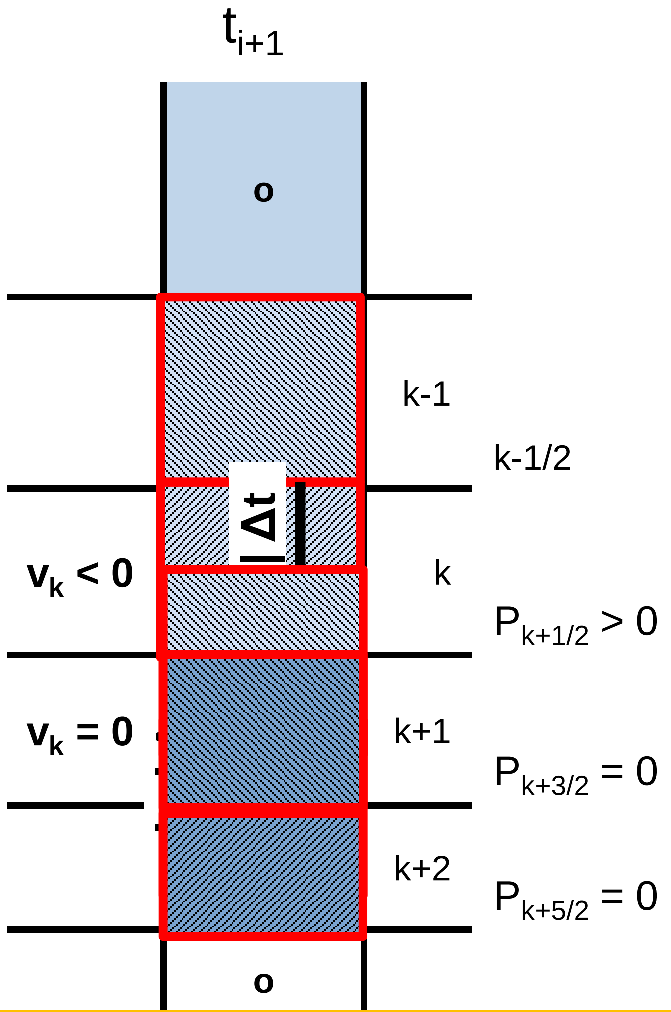
Comparison

Current method



Block „squeezed“ in box k+1 (self amplifying process)

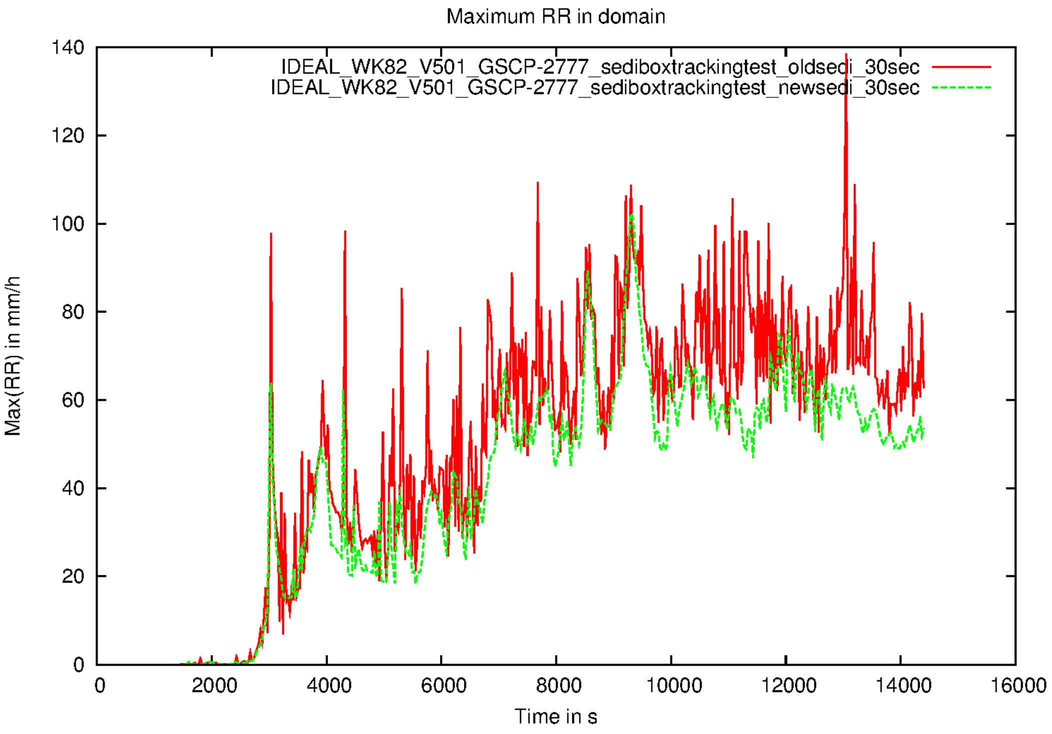
New method

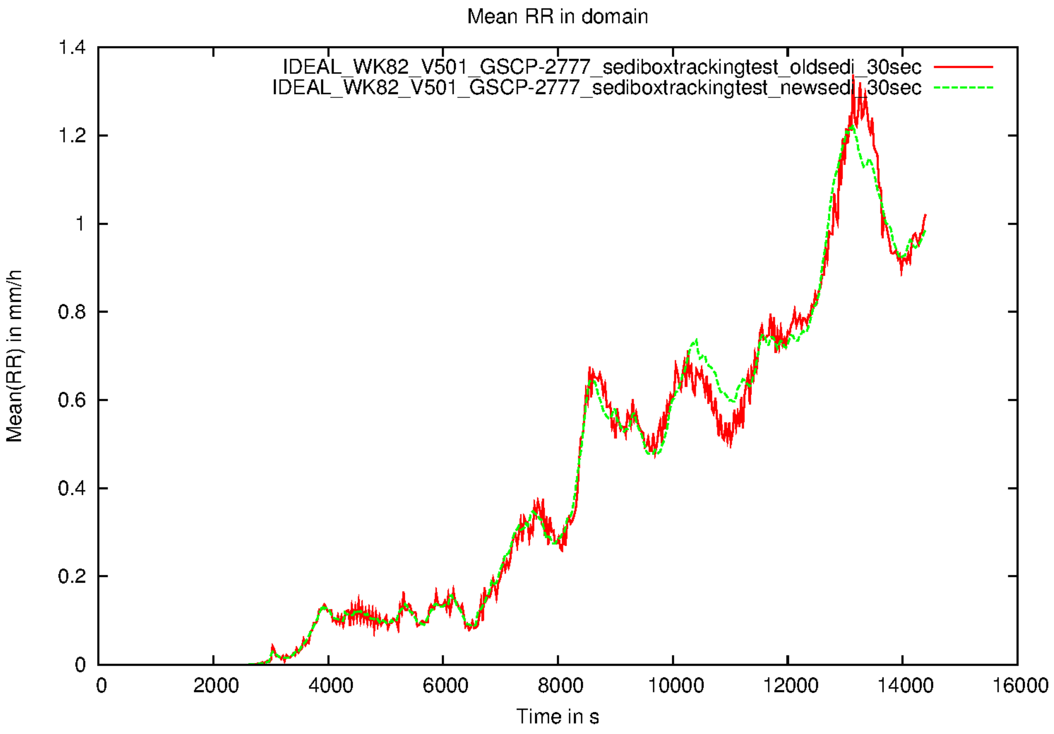


Each box moving at its own speed and contributes to P at all levels which it reaches/traverses during Δt

Comparison: idealized 3D supercell

- ➔ Weisman-Klemp supercell simulation (2-mom)


Maximum RR in domain


Mean RR in domain

Cloud Number Concentration N_{CCN} based on Tegen-climatology

Ulrich Blahak (DWD)

- Currently: constant N_{CCN} (in Kg^{-1}) for operational running 1-moment microphysics
- Tegen-climatology: (Tegen et al., 1997), unless **COSMO-ART** is running
  - o Optical thickness for 5 aerosol categories:
    - sea-salt, mineral dust, black carbon, organics
  - o Assumed spec. extinction coefficients
  - o Assumed mean particle radius and density
  - o Assumed exponential decrease within PBL

=> grid-column-integrated aerosol-mass per m^{-2}

=> aerosol number concentration N_{CN} in m^{-3}

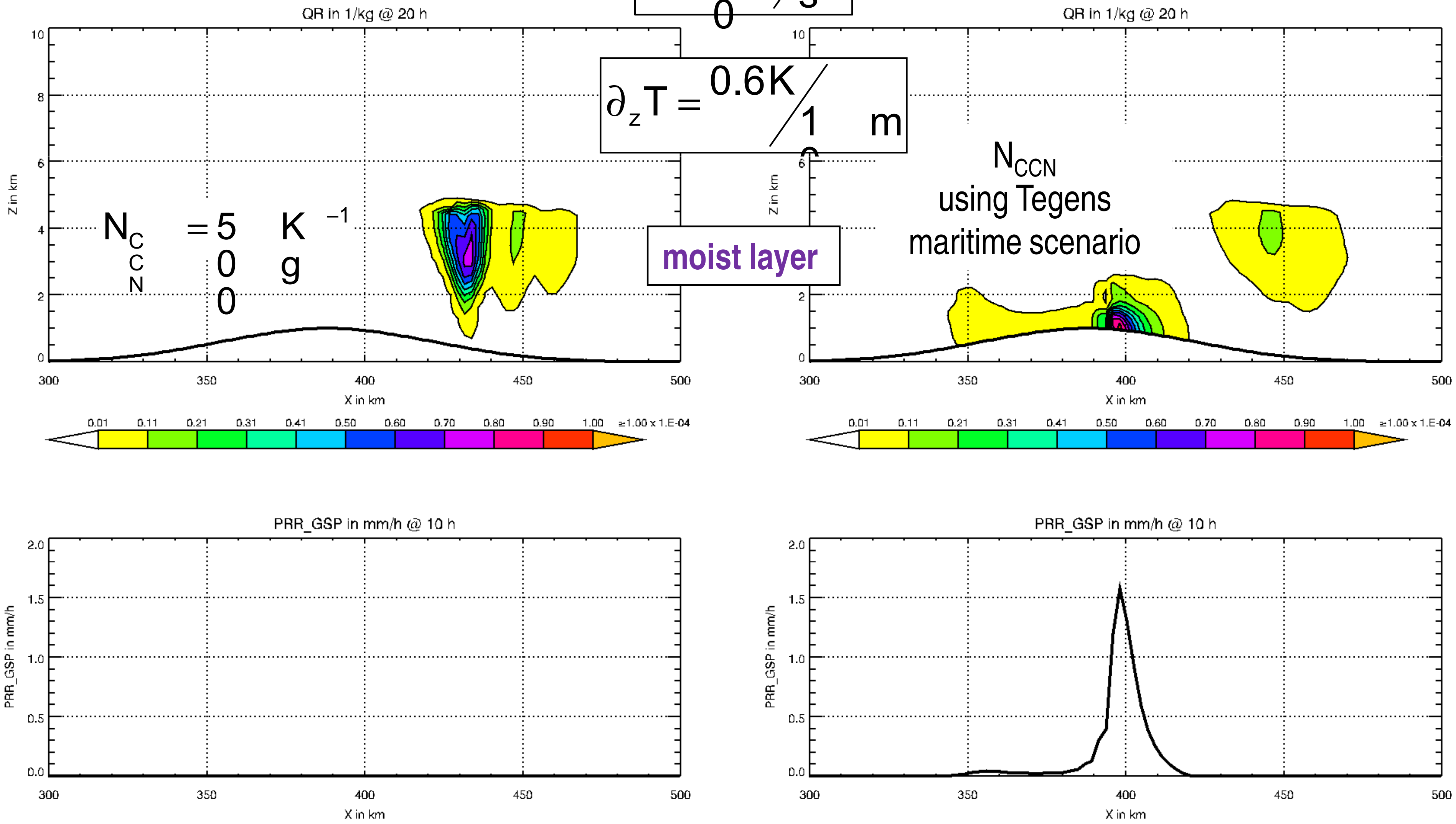
- Segal/Khain (2006) cloud-activation parameterization:
  - o aerosol number concentration N_{CN}
  - o cloud-base updraft speed

$$w_{cb} = w_{grid-scale} + \mathbf{0.7}\sqrt{\frac{TKE}{3} - \frac{c_{pd}}{g}\partial_t T\big|_{radiation}} \Rightarrow N_{CCN}(N_{CN}, w_{cb})$$

- Going to be used for new calculation of optical cloud properties (cloud effective radii)
- Should consistently be used for nucleation of cloud-water and -ice as well
- ➢ More realistic simulation of warm-rain process (so far corrected by unrealistic large constant N_{CCN})

Effect on pure orographic warm rain by idealized flow over a mountain

Control **Experiment**



$u = 10\ \mathrm{m/s}$

$\partial_z T = 0.6\mathrm{K}/100\ \mathrm{m}$

$N_{CCN} = 500\ \mathrm{Kg}^{-1}$

moist layer

N_{CCN} using Tegens maritime scenario

Revised parameterization of optical ice-cloud properties:

Ulrich Blahak (DWD), Harel Muskatel (IMS), Pavel Khain (IMS)

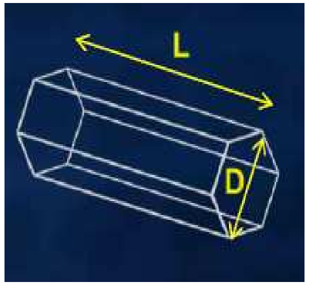
- In the COSMO radiation scheme (Ritter & Geleyn 1992)
  - **Optical properties** of ice-clouds are described **crudely** and don't **include precipitation products**

    extinction coeff. β_e , **single scattering albedo** ω ,
    asymmetry factor g , **delta-transmission factor f_d**
  - Effect of inhomogeneity is taken into account by means of a constant reduction factor **radqcfact=0.5** applied to the mass fractions.

➔ New parameterizations of **optical properties** based on idealized calculations according to **Fu**

- **Visible-bands**: **Ray-tracing** for randomly orientated hexagonal ice particles (Fu 2007)
- **IR-bands**: weighted average of **Mie-scattering** and related methods (Fu et al. 1998)
- **Optical properties** are treated as functions of **effective arguments**
  - **effective size** D_{ge}
  - **aspect ratio** **AR**

  and wave-length



- **Arguments** deduced from inherent assumptions in terms of **particle size distribution N(L)**, **mass size relation m(L)** and **particle shapes** (expressed by **L** and **D)**:
  - Suitable also for **complicated ice particles** (bullet rosettes, aggregates with rough surfaces, fractional crystals)
  - **Extending particle size range (5µm - 300 µm)** by using 7000 size-modified **Generalized Gamma-Distributions N(L)**
- **Fitting** the calculated relations between **optical properties** and **effective arguments**
  - In terms of **rational functions** using **spectral averaging** for **8 distinctive spectral bands**

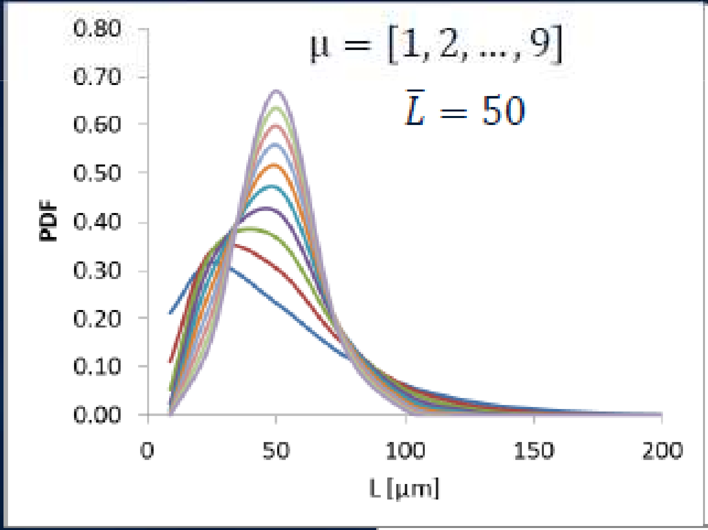
Generalized Gamma Distribution

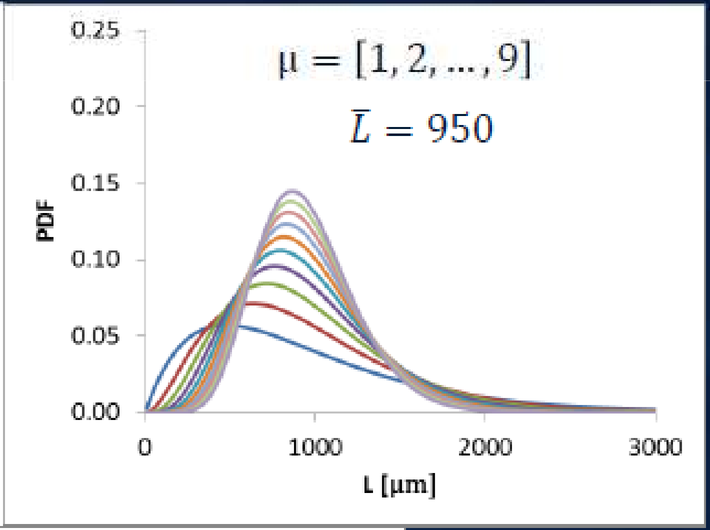
$$N(L) = N_0 L^{\mu} e^{-\lambda L^{\delta}}$$

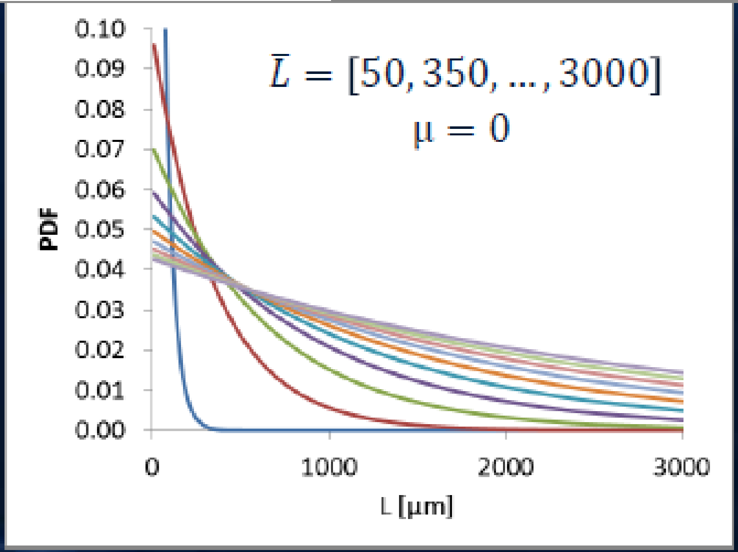
$$\mu = [0, 1, \dots, 14]\ ,\ \bar{L} = \frac{\mu+1}{\lambda} = [5\mu m, 3000\ \mu m],\ \ \delta = 1$$

total of 7000 distributions

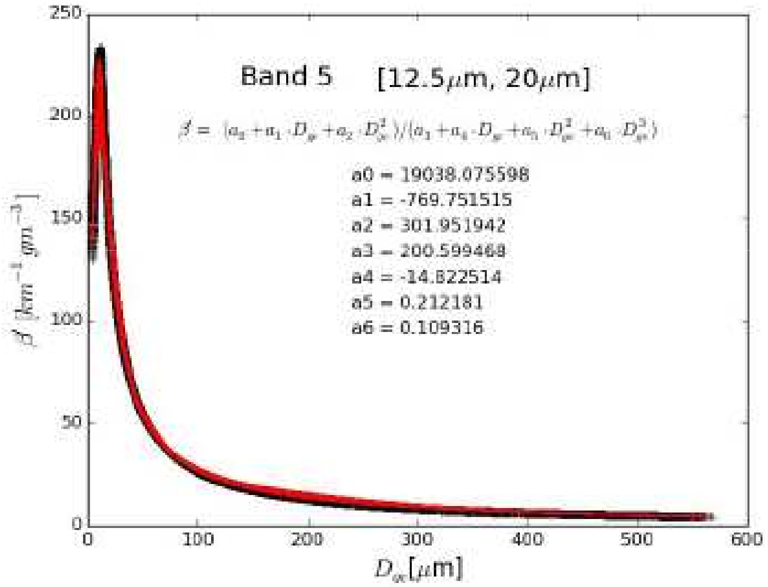
Examples:

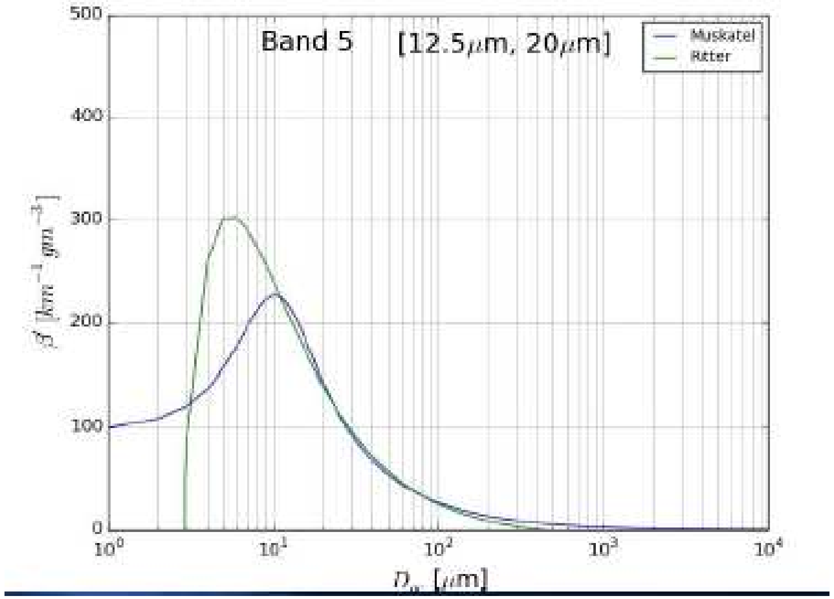




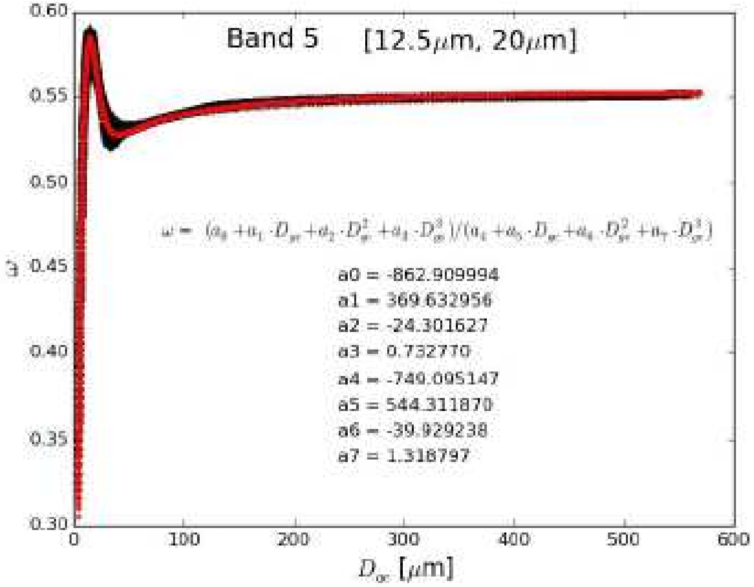


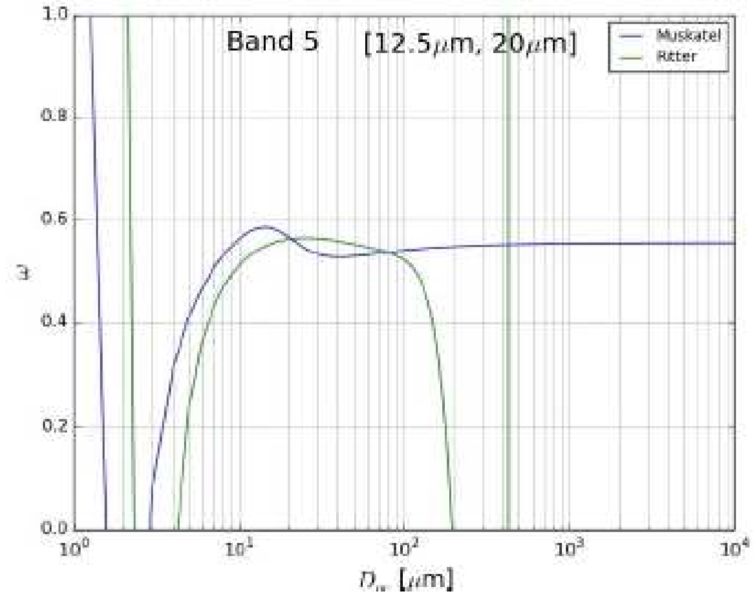
Fitting extinction coefficient $\beta_{ext}\left(D_{ge}\right)$:





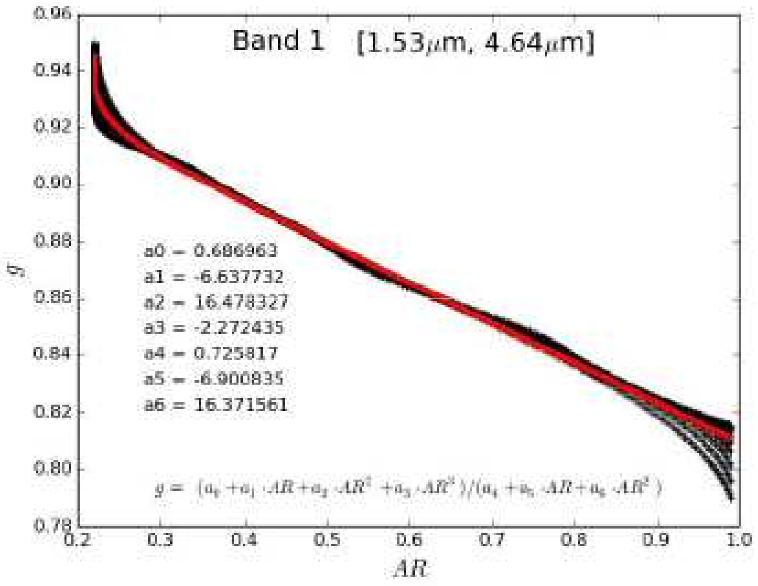
Fitting single scattering albedo $\omega\left(D_{ge}\right)$:

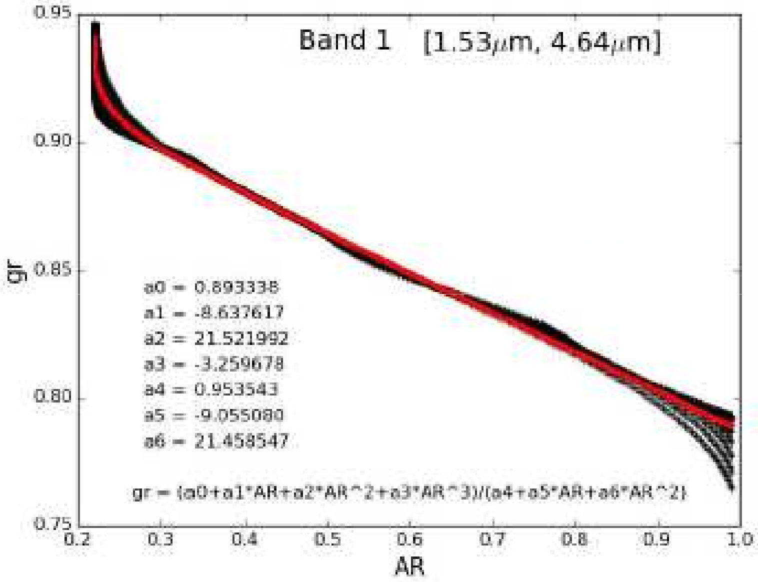




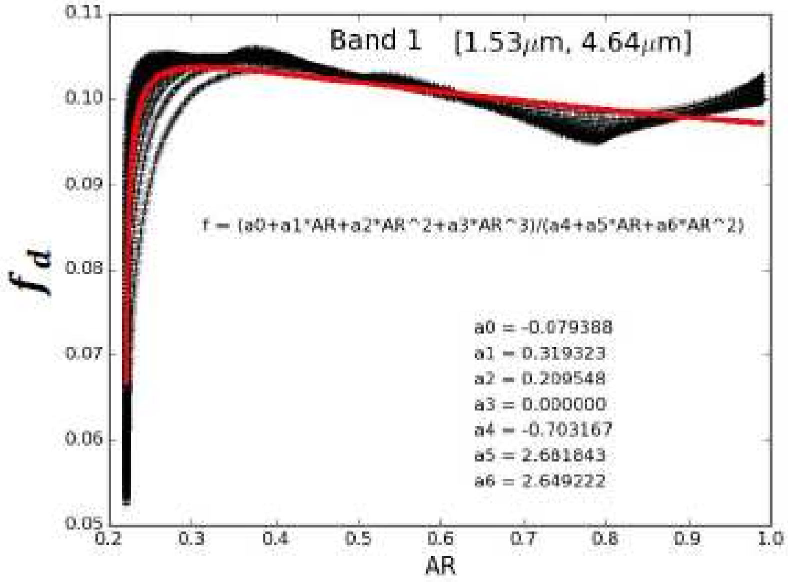
Fitting asymmetry-factor:

for smooth $g_s(A\quad)$ and rough $g_r(A\quad)$ surfaces





Fitting delta transmission-factor $f_d(A\quad)$



Problem: New radiation scheme depends on 30 parameters

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

➔ **Perform idealized COSMO simulations**

- **for many parameter combinations**
- **and special cloud types**

Cirrus	Stratus	Mixed phase	SGS Strato-cumulus	Shallow convective cumulus	Anvil of Cumulonimbus

➔ **Replace attenuation of radiation (in %) by an analytic function (quadratic form) of the parameters (meta-model):**

$$R\left(\underbrace{p_1, p_2, \cdots}\right)$$

scaled dimensionless parameters
ranging from -1 to 1

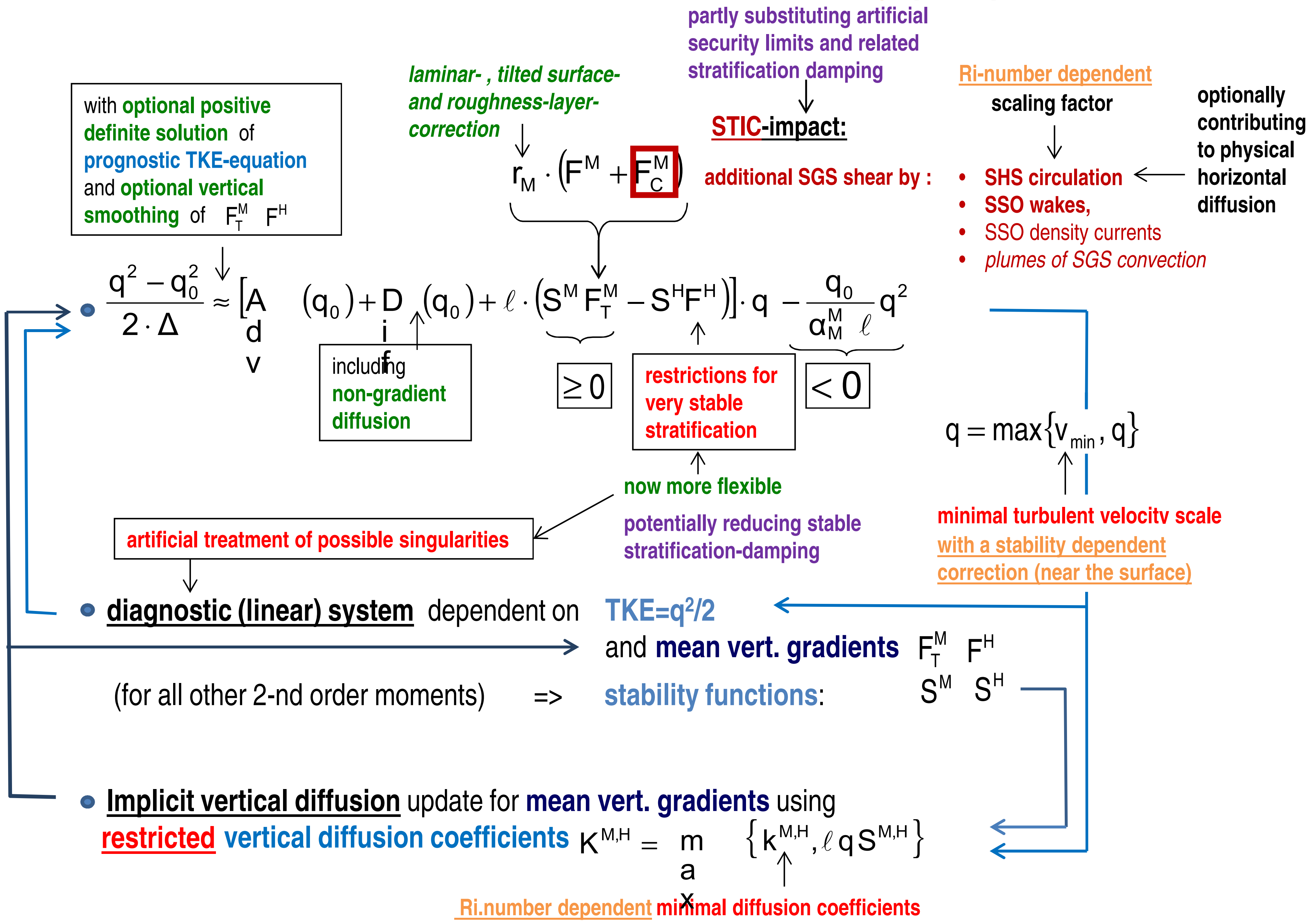
➔ **Calculate sensitivity of each parameter** p_i **:** $\partial_{p_i} R$

➔ **Treat most sensitive parameters as tuning-parameters to be evaluated by CALMO**

➔ **Evaluate the less sensitive parameters by "expert-tuning"**

The STIC-scheme including empirical parameterization extensions:

Matthias Raschendorfer, Günther Zängl (DWD)



with **optional positive definite solution** of **prognostic TKE-equation** and **optional vertical smoothing** of F_T^M F^H

laminar- , tilted surface- and roughness-layer-correction

$r_M \cdot (F^M + \boxed{F_C^M})$

partly substituting artificial security limits and related stratification damping

STIC-impact:

additional SGS shear by :

- **SHS circulation**
- **SSO wakes,**
- SSO density currents
- *plumes of SGS convection*

Ri-number dependent scaling factor

optionally contributing to physical horizontal diffusion

- $$\frac{q^2 - q_0^2}{2 \cdot \Delta} \approx \Big[A_{dv}(q_0) + D_{if}(q_0) + \ell \cdot \big(\underbrace{S^M F_T^M}_{\boxed{\geq 0}} - S^H F^H\big)\Big] \cdot q \; \underbrace{- \frac{q_0}{\alpha_M^M \, \ell} q^2}_{\boxed{< 0}}$$

including **non-gradient diffusion**

restrictions for very stable stratification

now more flexible

potentially reducing stable stratification-damping

artificial treatment of possible singularities

$q = \max\{v_{min}, q\}$

minimal turbulent velocity scale with a stability dependent correction (near the surface)

- **diagnostic (linear) system** dependent on **TKE=$q^2/2$** and **mean vert. gradients** F_T^M F^H

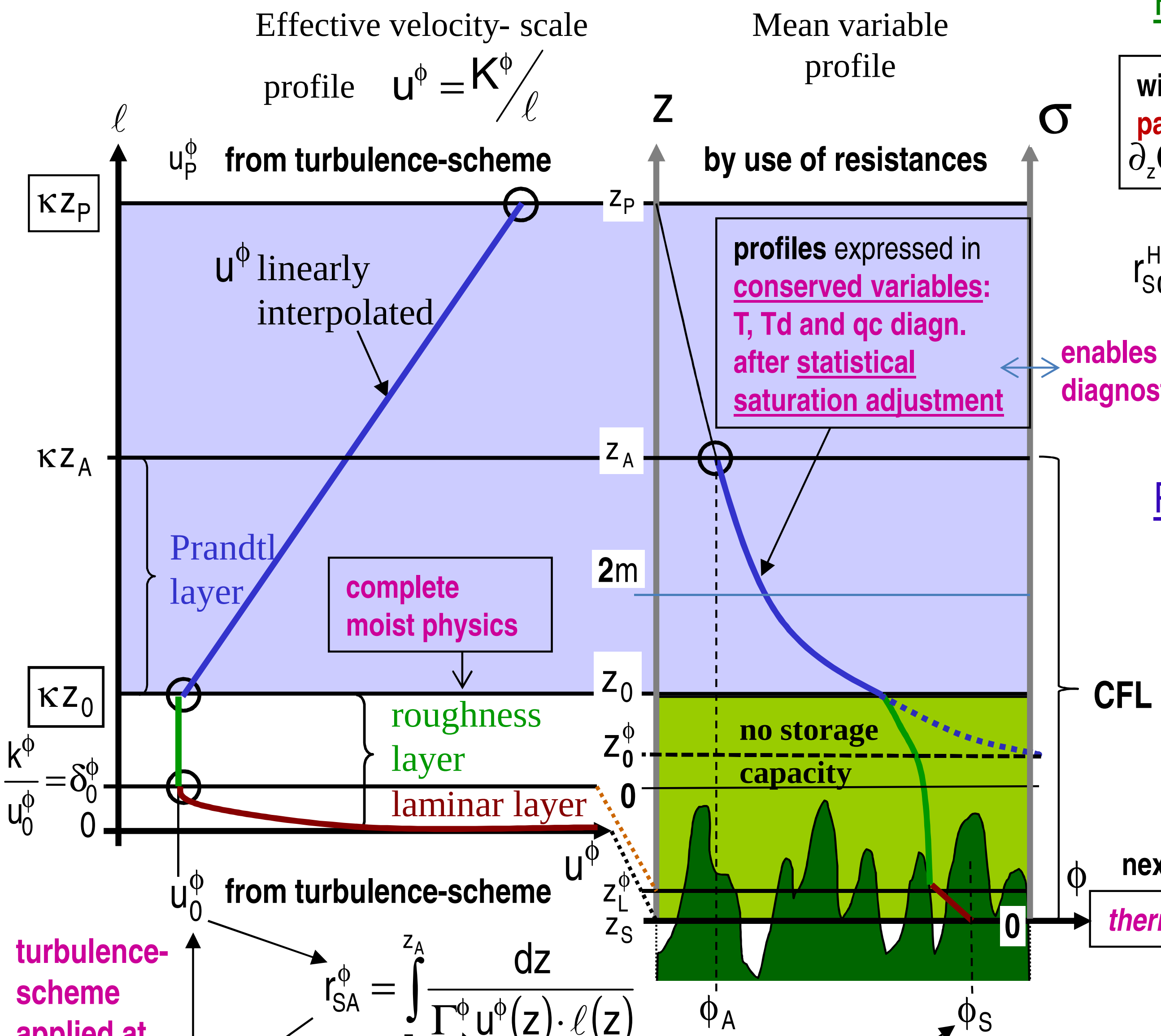
(for all other 2-nd order moments) => **stability functions:** S^M S^H

- **Implicit vertical diffusion** update for **mean vert. gradients** using **restricted vertical diffusion coefficients** $K^{M,H} = \max\{k^{M,H}, \ell q S^{M,H}\}$

Ri.number dependent minimal diffusion coefficients

The SAT-scheme with an explicit surface-level TKE-equation including moist physics:

Matthias Raschendorfer (DWD)



enables fog-diagnostics

next step:

thermally decouples cover layer (vegetation) ↔ **effects near surface fog initialization**

turbulence-scheme applied at level z = z_0

$$r_{SA}^\phi = \int_{z_S}^{z_A} \frac{dz}{\Gamma^\phi u^\phi(z) \cdot \ell(z)}$$

geometric roughness layer correction

$$\partial_z \phi_0 = \frac{\phi_A - \phi_S}{\kappa z_0 \, u_0^\phi \, r_{SA}^\phi}$$

with a zero-surface condition for qc ↔ **enables fog-deposition**

Roughness-layer resistance for scalars:

with a laminar scaling parameter dependent on $\partial_z \theta_0$ over see surfaces

with using u_0^ϕ as an lower interpolation node

$$r_{S0}^H = \frac{1}{\kappa S_0 \cdot u_0^H} \cdot \left(\lambda^H + \ln \frac{\kappa z_0 u_0^H}{k^H} \right) = \frac{1}{\kappa u_0^H} \cdot \ln \left[\frac{z_0}{z_0^H} \right]$$

effective geometric roughness- layer correction

substituted by explicit calculation of roughness-layer resistance for scalars

Prandtl-layer resistance:

stability-parameter of vertical profile-function

with using u_P^ϕ as an upper interpolation node

$$\gamma_s^\phi := \frac{z_0}{z_P - z_0} \left[\frac{u_P^\phi}{u_0^\phi} - 1 \right]$$

$$r_{0A}^\phi = \frac{1}{\kappa u_0^\phi \left(1 - \gamma_s^\phi\right)} \cdot \begin{cases} \ln\left(\frac{z_A}{z_0}\right) - \gamma_s^\phi \frac{z_A - z_0}{z_0} & , \gamma_s^\phi < 0 \quad \text{stable} \\ \ln\left[\frac{z_A}{z_0 + \gamma_s^\phi \cdot (z_A - z_0)}\right] & , \gamma_s^\phi \geq 0 \quad \text{unstable} \end{cases}$$

Testing potential stability damping:

Ines Cerenzia (ARPA-SIM), Matthias Raschendorfer (DWD)

- Application of component testing using COSMO-SC with the common turbulence-code and tower measurements:

  – 1-st hypothesis: Reducing the numerical security limits in the turbulence model and the specific SAT-code (based on the common code) can reduce the damping

  ➢ Only marginal effect (except minimal diffusion coefficients)

  – 2-nd hypothesis: Avoiding the upper interpolation node u_P^ϕ for the profile function can reduce the damping

  – Comparison with a modification by substituting the dimensionless P-Layer-resistance by the MO-stability function

$$\kappa u_0^\phi \cdot r_{0A}^\phi = \ln\left(\frac{z_A}{z_0}\right) - \underset{\uparrow}{\psi}\left(\frac{z_A}{L_{MO}}\right) \qquad L_{MO} := -\rho \frac{c_p}{g} \frac{u_*^3 \hat{\theta}_v}{S_{hfl}}$$

MO-stability-length

MO- semi-empirical integral-stability-function

➢ Considerably larger sensitivity of transfer-coefficients at stable stratification

  – Lower magnitude of surface fluxes

  – Stronger decrease of nocturnal T2m

Fluxes: sensitivity to observed stability

<u>Frequency of</u>

Friction velocity

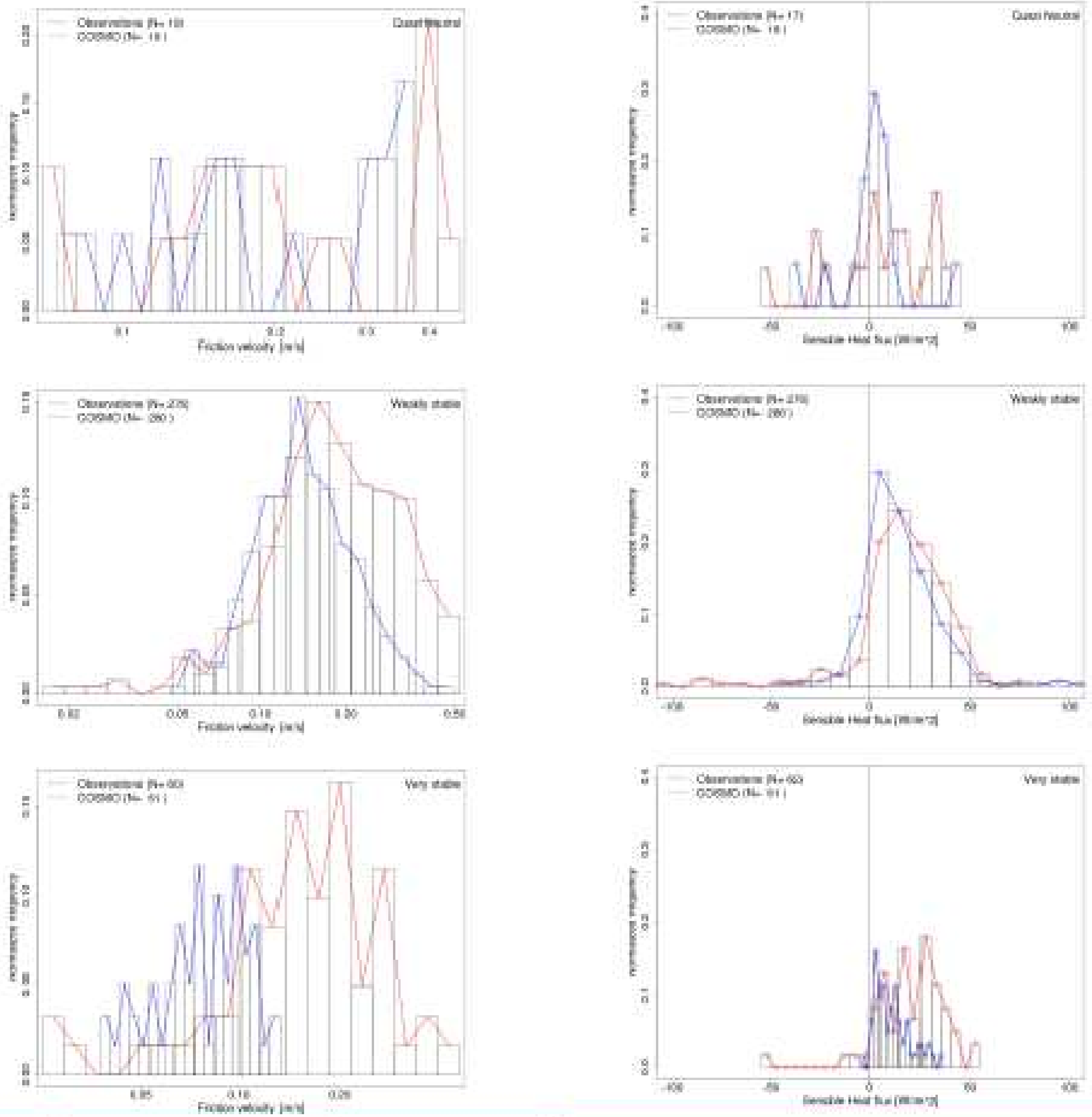
Sensible heat flux

Observations
COSMO

Quasi Neutral

Weakly Stable

Very Stable



Overestimation of surface fluxes

Stability damping seems to be active

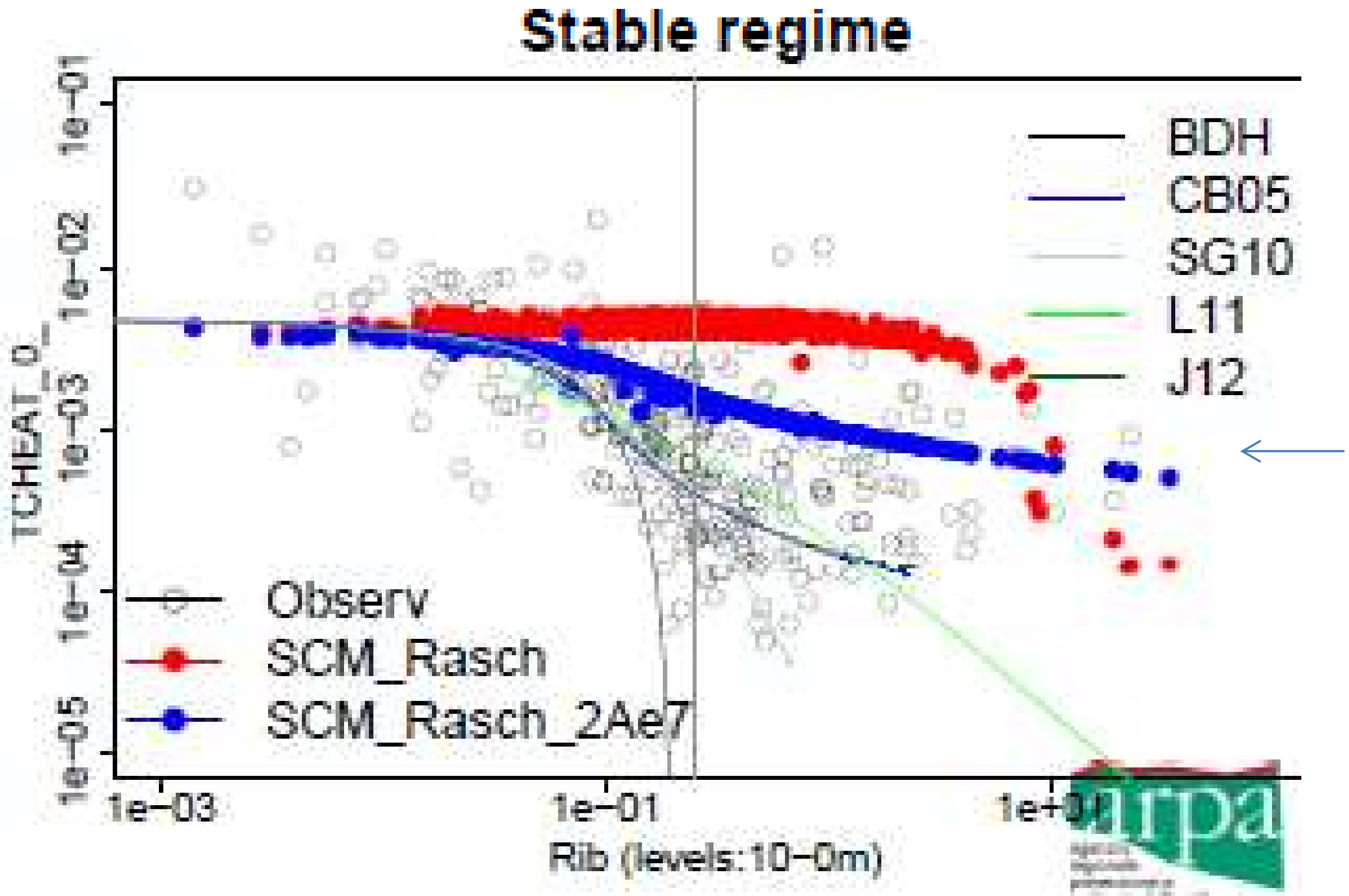
Notice:

Observations are <u>local</u> measurements

Simulations are <u>grid-box</u> representations

Transfer-coefficients:

- simulated by a SC-run with model levels at 2m and 10m height
- forced by measured T_2m, Td_2m, V_10m and T_s
- and derived directly from measurements



without using the upper node for the **profile function**

- **A first test-case based verification over Italy was rather indifferent, even though pointing in the right direction**

Promising general activity:

(still basic research, not yet implemented, not really started)

- Turbulence-Interaction with Micro-Phys. beyond pure saturation adjustment:
  - Consideration of turbulent statistics in MP

    Axel Seifert

  - Deriving missing correlations between model variables and MP-source-terms in 2-nd order budgets for turbulence

    Dimitrii Mironov, Axel Seifert
- Increasing the range of scales included to turbulence closure:
  - coherent structures with skewed distributions, TKESV

    Dimitrii Mironov, Ekatarina Maschulskaya
- Dealing with statistical parameterizations
  - substituting intended model-parameters to reduce systematic model errors

    staff from ICON or special projects at DWD (renewable energy)
- Developing stochastical parameterizations
  - simulating the not closed remaining stochastic discretization error

    Ekatarina Maschulskaya

Questions?

Fitting asymmetry-factors for smooth $g_s(A\ \ )$ **and rough** $g_r(A\ \ )$ **surfaces :**

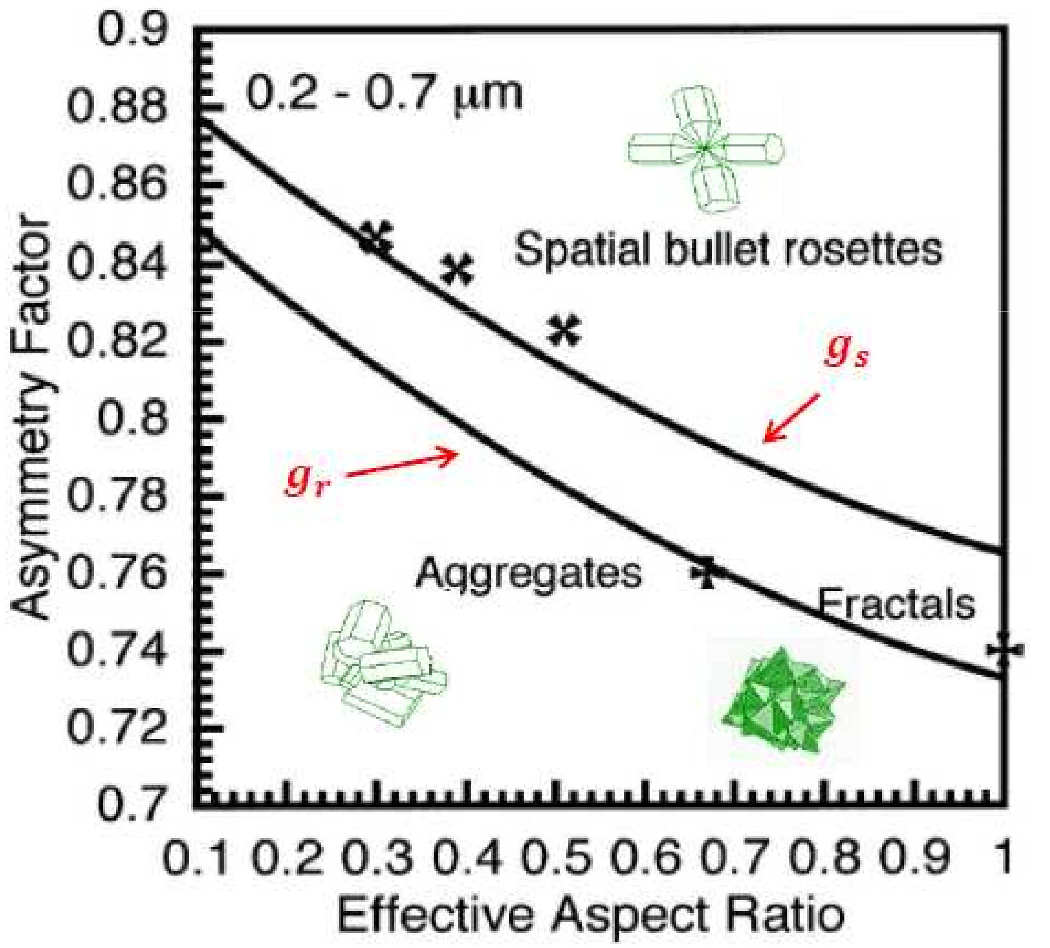
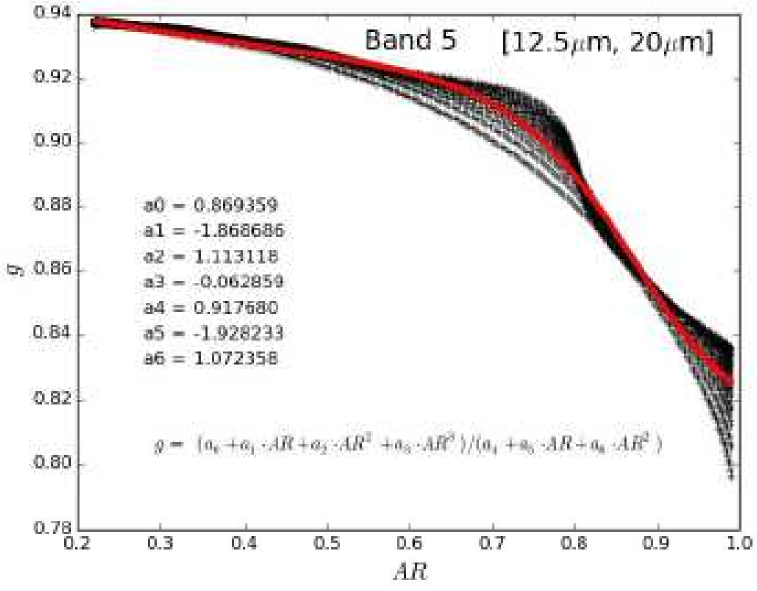


FIG. 7. Comparison of asymmetry factors based on the parameterization with those of spatial bullet rosettes with smooth surfaces, aggregates with rough surfaces, and fractal ice crystals in the visible.

Fu Q., J. Atm. Sci. V. 64, 4140-4150 (2007)

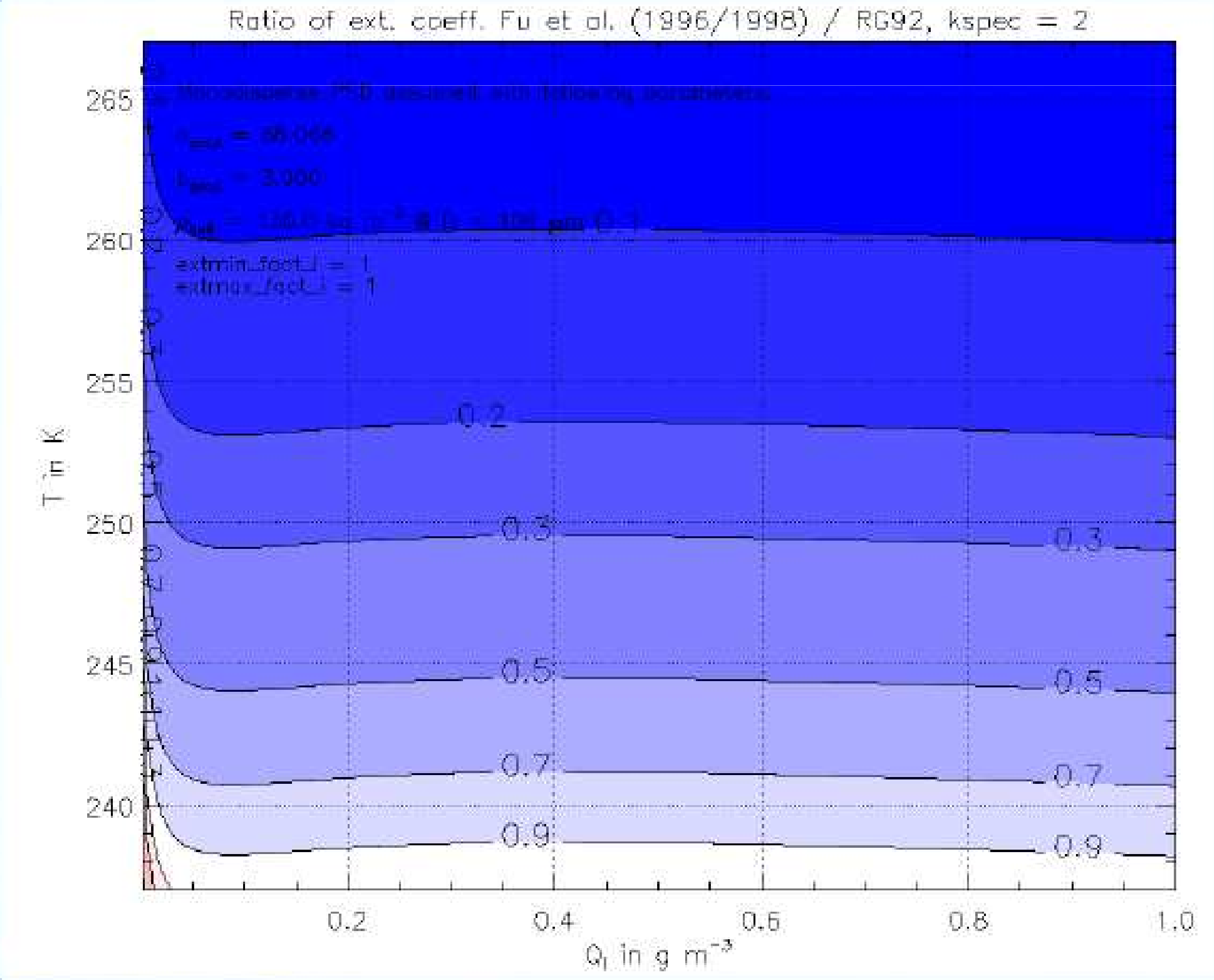
$g_s(A\ \ )$



Comparison to current RG92 (cloud ice)

If grid scale qi > 0: from cloud microphysics:

$$f(D) = \text{monodispers}$$
$$N_i(T) = a \exp(b(T_3 - T))$$
q_i prognostic
$$m_i = 130\,D^3 \quad \text{(SI-units)}$$

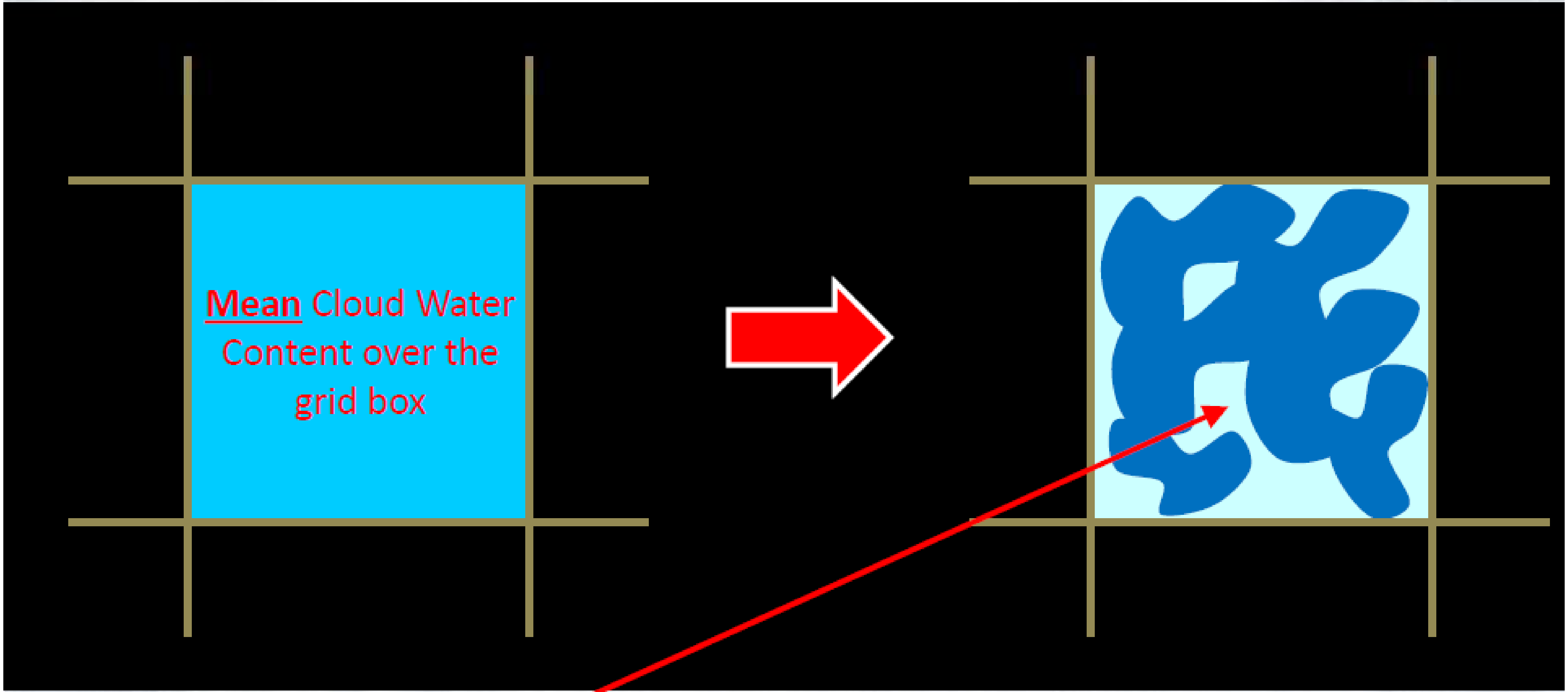


Spectral interval „2“
(visible range)

β_{ext} ratio new fits / RG92

1. Example: Subgrid-scale variability factor „radqcfact"

Assume: Microphysics → Cloud Water Content in a grid box



Higher radiation through "empty" areas → Effective CWC: **lower** → CWC → (radqcfact) X CWC