New parameterization of cloud optical properties for ALARO-0

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Motivation

- current ACRANEB scheme uses (among the others) following two approximations for cloud treatment:
  - coefficients k^{abs}, k^{scat} and asymmetry factor g do not depend on cloud water content
  - only mean saturation effect is taken into account

- these approximations lead to some known deficiencies, e.g. too small surface insolation in cloudy case caused by too opaque clouds in solar band

Objectives

- develop simple and cheap cloud scheme which could be plugged into ACRANEB, where:
  - quantities k^{abs}, k^{scat} and g depend on cloud water content
  - coefficients k^{abs}, k^{scat} are further modified by saturation effect, taking into account optical properties and geometry of cloud layers above/below current layer

- design the scheme flexibly, so that it can be adjusted to more spectral bands when needed

Saturation effect

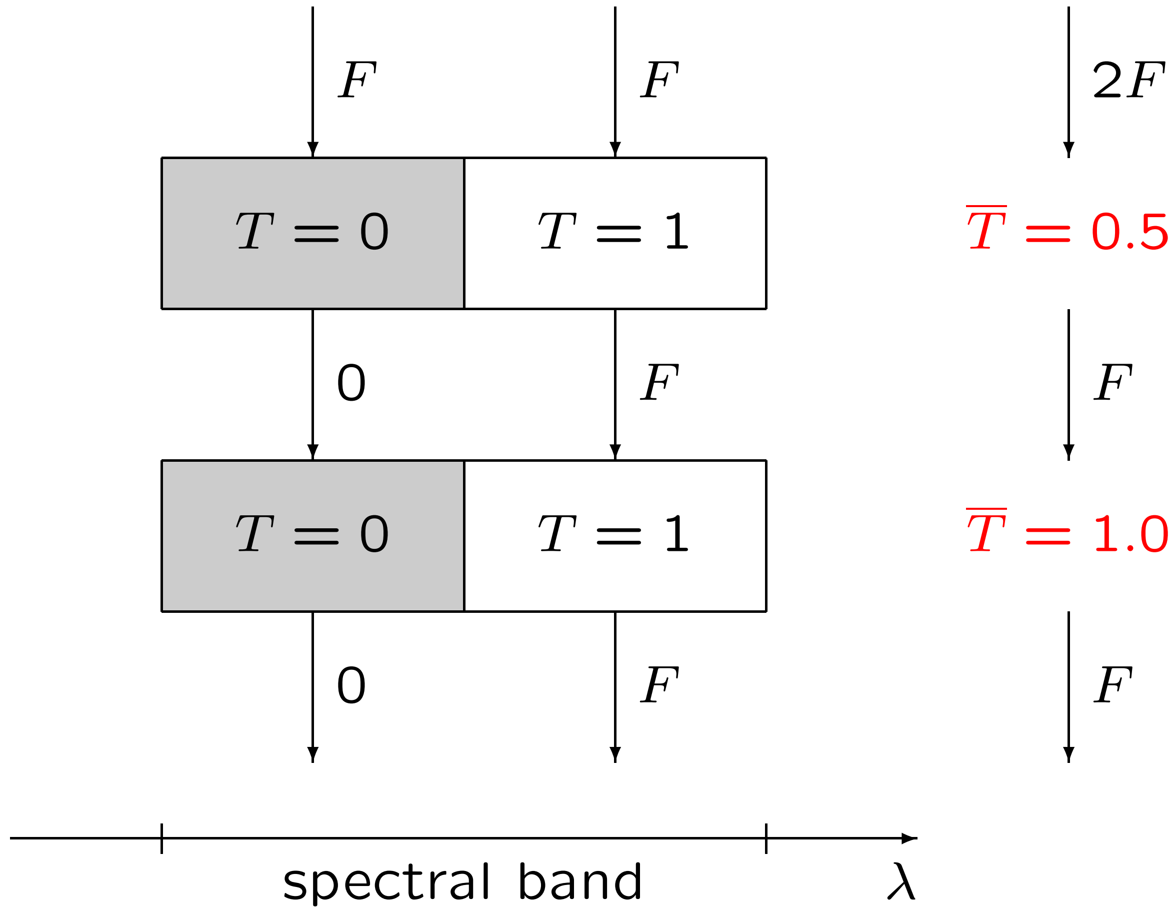
Narrow spectral bands:

- dependency of coefficients k^{abs}, k^{scat} on wavelength is weak within bands $\Rightarrow$ clouds can be treated as grey bodies
- broadband coefficients k^{abs}, k^{scat} do not depend on spectral composition of incoming radiation

Wide spectral bands (e.g. solar and thermal, as in ACRANEB):

- grey body approximation no longer fully valid for clouds
- broadband coefficients k^{abs}, k^{scat} depend on spectral composition of incoming radiation
- spectral composition of incoming radiation is influenced by layers above/below $\Rightarrow$ saturation effect is non-local

Illustration of saturation effect (1)



- two identical layers, only absorption assumed
- in broadband, bottom layer appears to be more transparent

Illustration of saturation effect (2)

- two adjacent layers (1 and 2), only absorption assumed
- monochromatic transmission function for composed layer $1+2$:

$$T_{12}^{\lambda} = T_1^{\lambda} \cdot T_2^{\lambda}$$

- broadband transmission function for composed layer $1+2$:

$$\overline{T}_{12} = \overline{T_1 \cdot T_2} \neq \overline{T}_1 \cdot \overline{T}_2$$

- when transmission functions T_1^{λ} and T_2^{λ} are positively correlated in given spectral band, composed layer appears to be more transparent than it should be according to broadband values $\overline{T}_1$, $\overline{T}_2$:

$$\overline{T}_{12} > \overline{T}_1 \cdot \overline{T}_2$$

Problems with saturation effect

- broadband approach uses only spectrally integrated fluxes
- broadband optical coefficients depend on many non-local and/or unresolved details: optical properties of other layers, cloud geometry, direction and spectral composition of fluxes entering the atmosphere (solar band) or emitted by surface and atmosphere (thermal band)
- because of efficiency, parameterization of saturation effect must be relatively simple

Strategy (1)

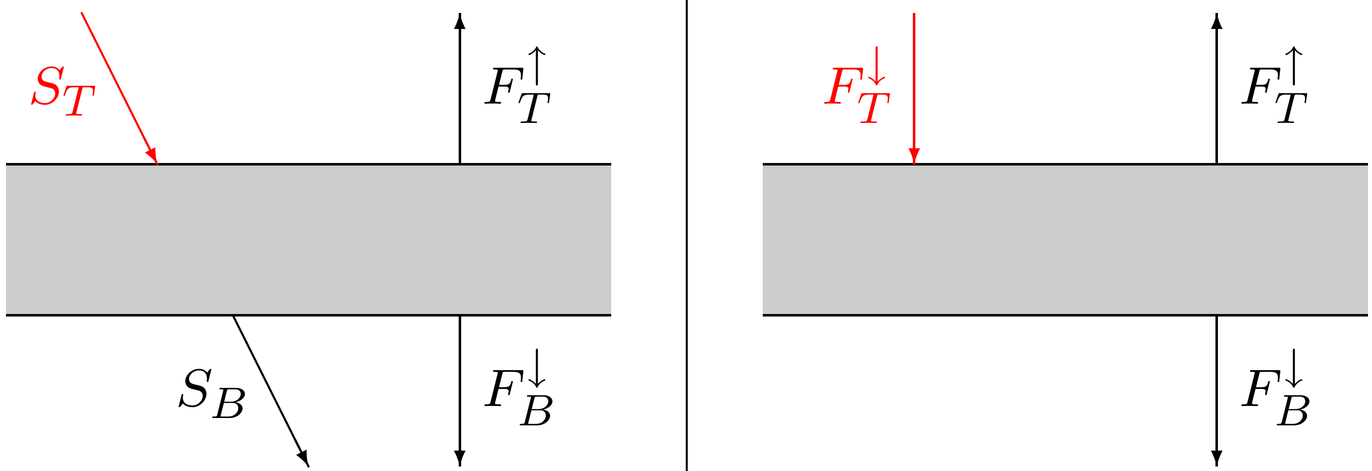
- new scheme was developed and tested in idealized framework:
  - multi-layer delta-two stream radiative transfer model
  - only clouds taken into account, gases and aerosols ignored
  - cloud geometry with random overlaps or maximum overlaps between adjacent layers
  - atmosphere illuminated from one side by direct flux (solar band) or diffuse flux (thermal band), reflected and transmitted fluxes evaluated

- cloud properties derived from experimental sample of spectral data for 7 liquid and 16 ice cloud types

- monochromatic computations used as reference, composition of incident flux is either solar spectrum at TOA (solar band) or blackbody radiation with $T = 255.8\,\mathrm{K}$ (thermal band)

Strategy (2)

solar band | thermal band



Solar band:

$$T = (S_B + F_B^\downarrow)/S_T$$
$$R = F_T^\uparrow/S_T$$

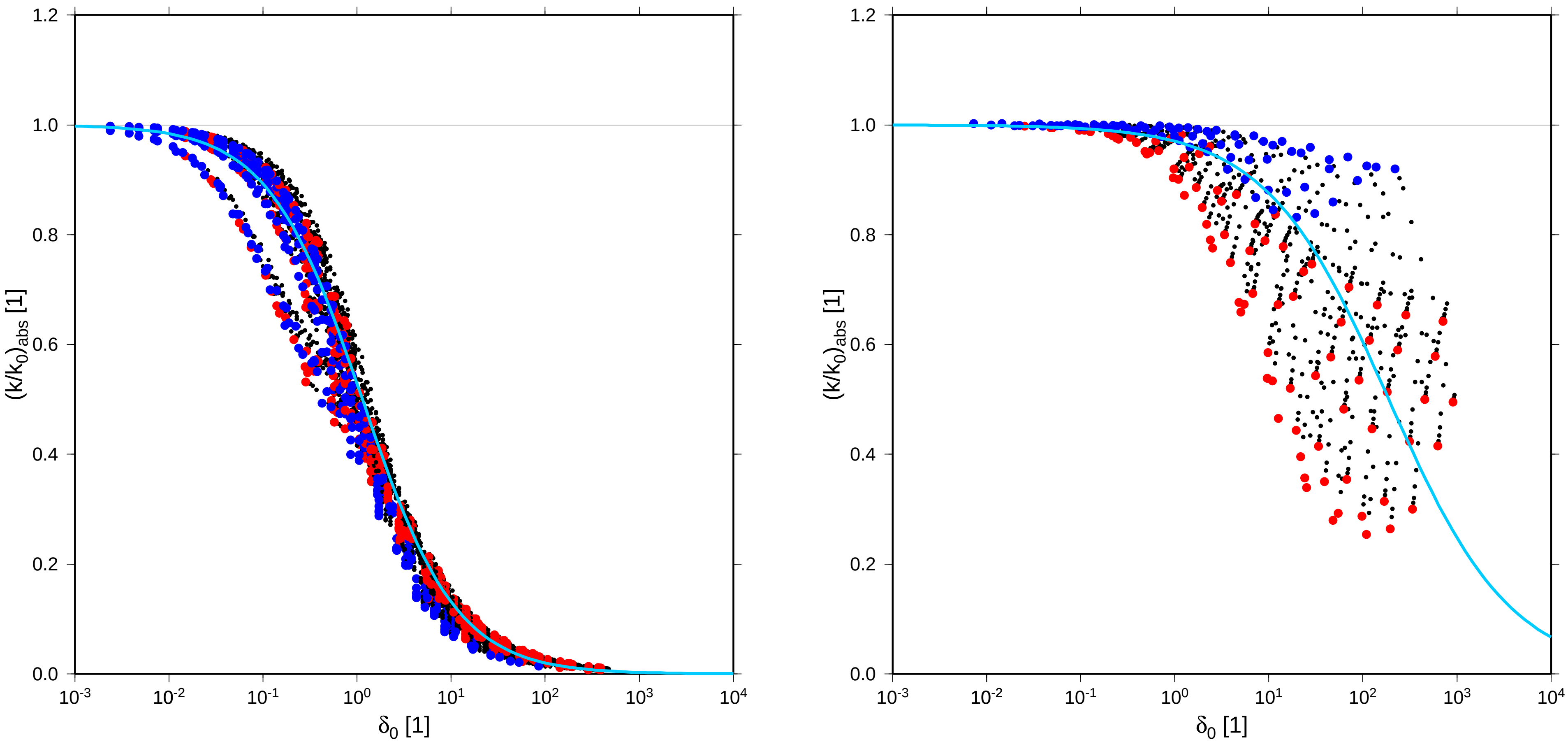
Thermal band:

$$T = F_B^\downarrow/F_T^\downarrow$$
$$R = F_T^\uparrow/F_T^\downarrow$$

- averaged results of monochromatic simulations provide saturated broadband transmittance T and reflectance R
- broadband values k^{abs}, k^{scat} giving the same T and R are sought (broadband asymmetry factor g is not subject to spectral-type saturation)

Saturation factor $c^{\text{abs}} = k^{\text{abs}}/k_0^{\text{abs}}$ fitted on sample of homogeneous clouds

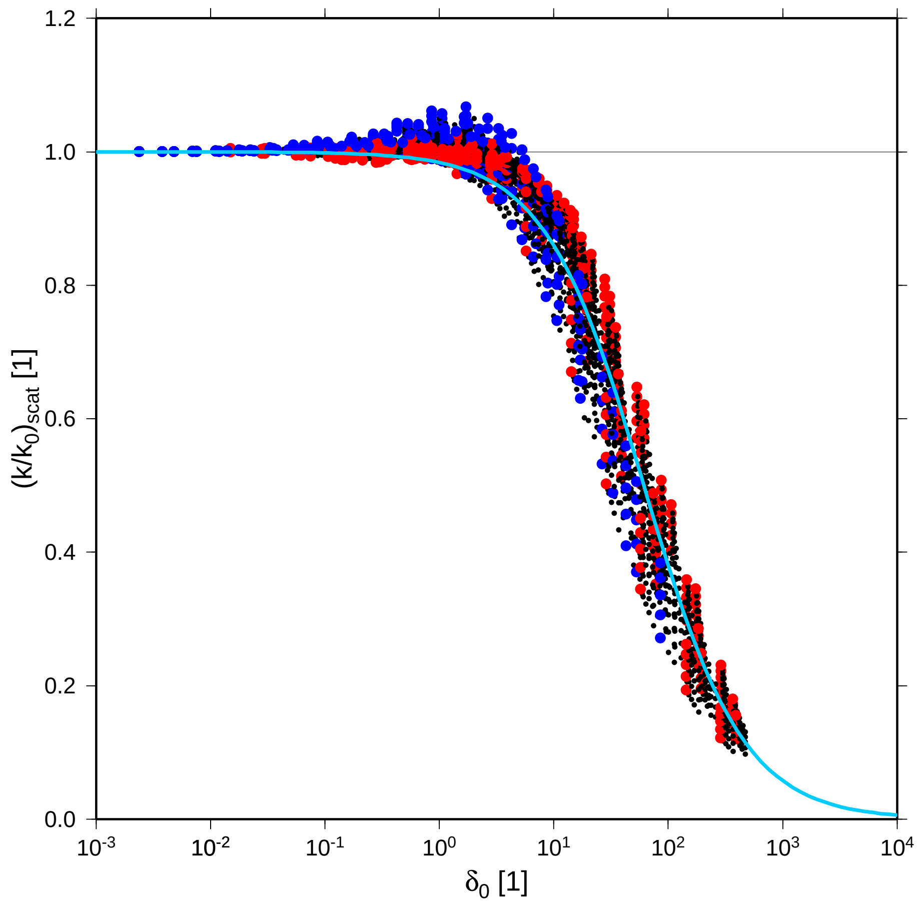
solar band $(\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9)$ | thermal band



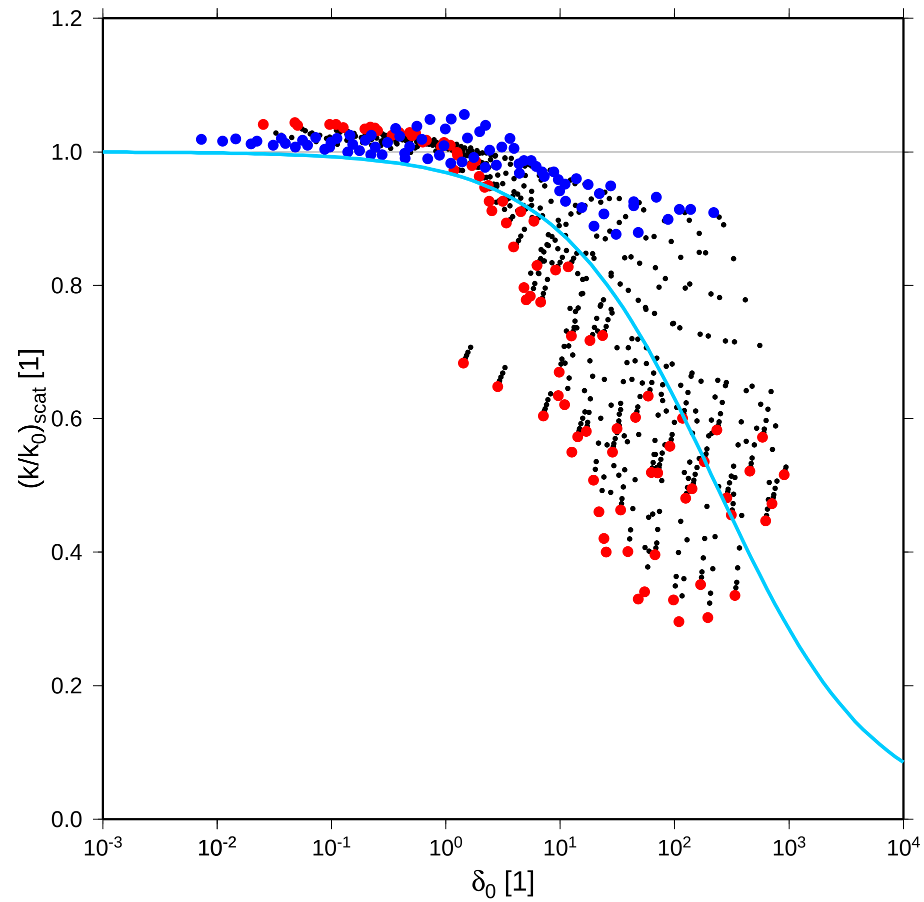
red – liquid clouds, blue – ice clouds, black – mixed clouds

Saturation factor $c^{\text{scat}} = k^{\text{scat}}/k_0^{\text{scat}}$ fitted on sample of homogeneous clouds

solar band
$(\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9)$



thermal band



red – liquid clouds, blue – ice clouds, black – mixed clouds

Outline of the new scheme

- for layer j, unsaturated broadband values k_{0j}^{abs}, k_{0j}^{scat} and g_j are determined by Pade fits (dependency on liquid/ice water content)

- coefficients k_{0j}^{abs}, k_{0j}^{scat} are further reduced by saturation factors c_j^{abs}, c_j^{scat} given by simple fits:

$$c(\delta_{0j}^{\text{eff}}) = \frac{1}{1 + \left(\delta_{0j}^{\text{eff}}/\delta_0^{\text{crit}}\right)^{\mu}} \qquad \delta_0^{\text{crit}} > 0 \qquad 0 < \mu \leq 1$$

- effective optical depth δ_{0j}^{eff} depends on layer unsaturated optical depths δ_{0k} and cloud fractions n_k:

$$\delta_{0j}^{\text{eff}} = \delta_{0j} + \sum_{k \neq j} f(n_j, n_k)\, \delta_{0k} \qquad 0 \leq f \leq 1$$

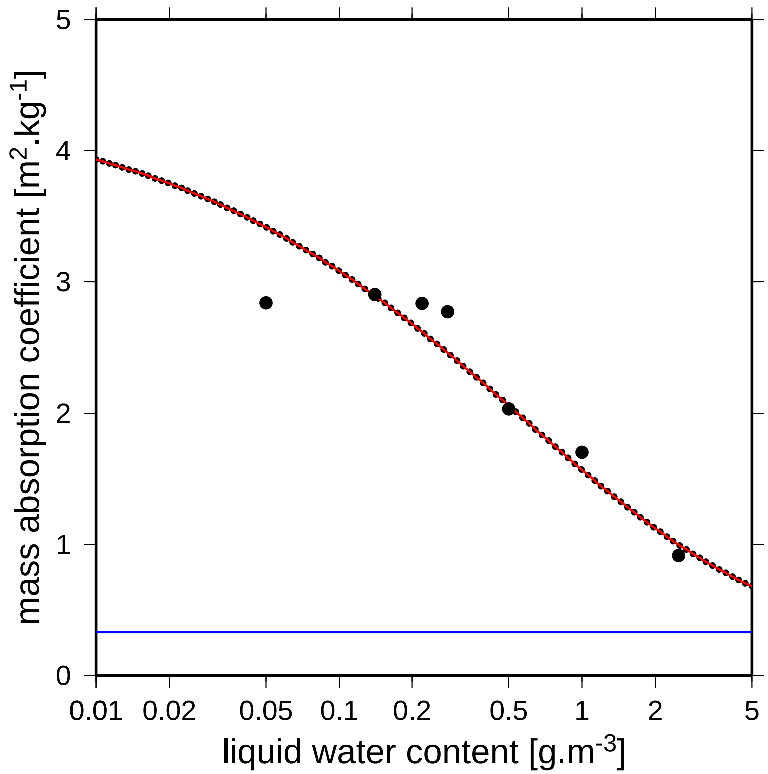
random overlaps: $f(n_j, n_k) = (n_k)^p$

maximum overlaps: $f(n_j, n_k) = [\min(1, n_k/n_j)]^p$

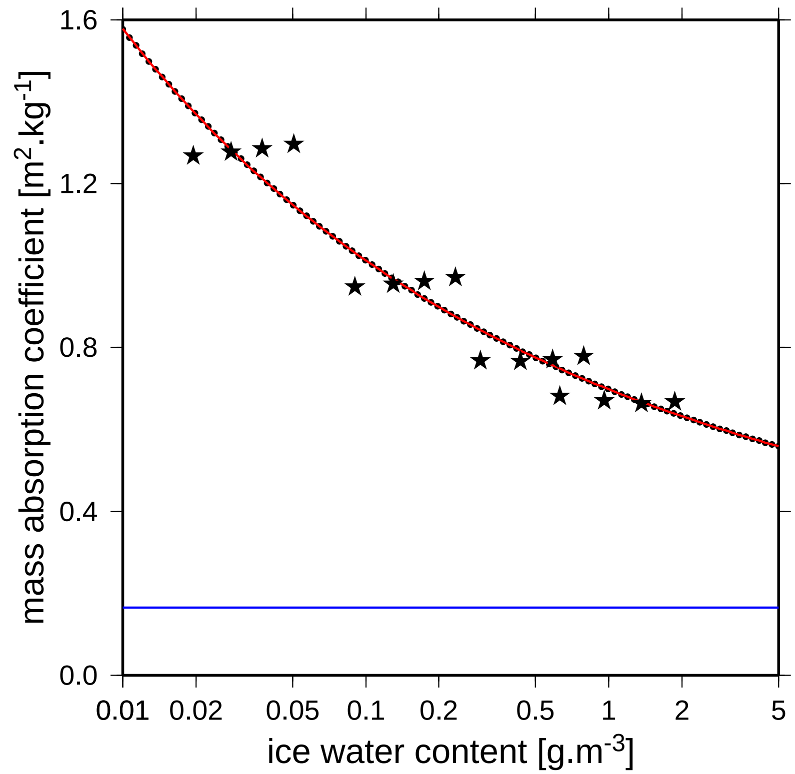
(currently $p = 8$)

Dependency of unsaturated coefficient k_0^{abs} on cloud water content (solar band)

liquid clouds



ice clouds



●/⋆ broadband values for individual cloud types

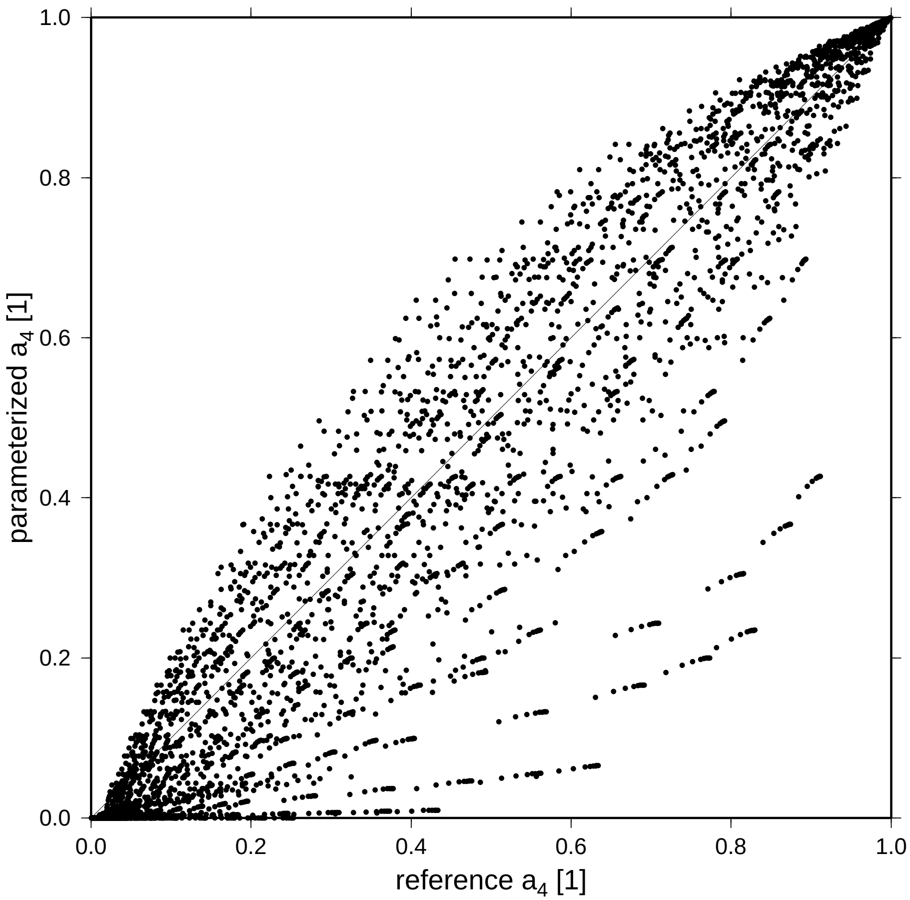
Pade approximant used in new scheme

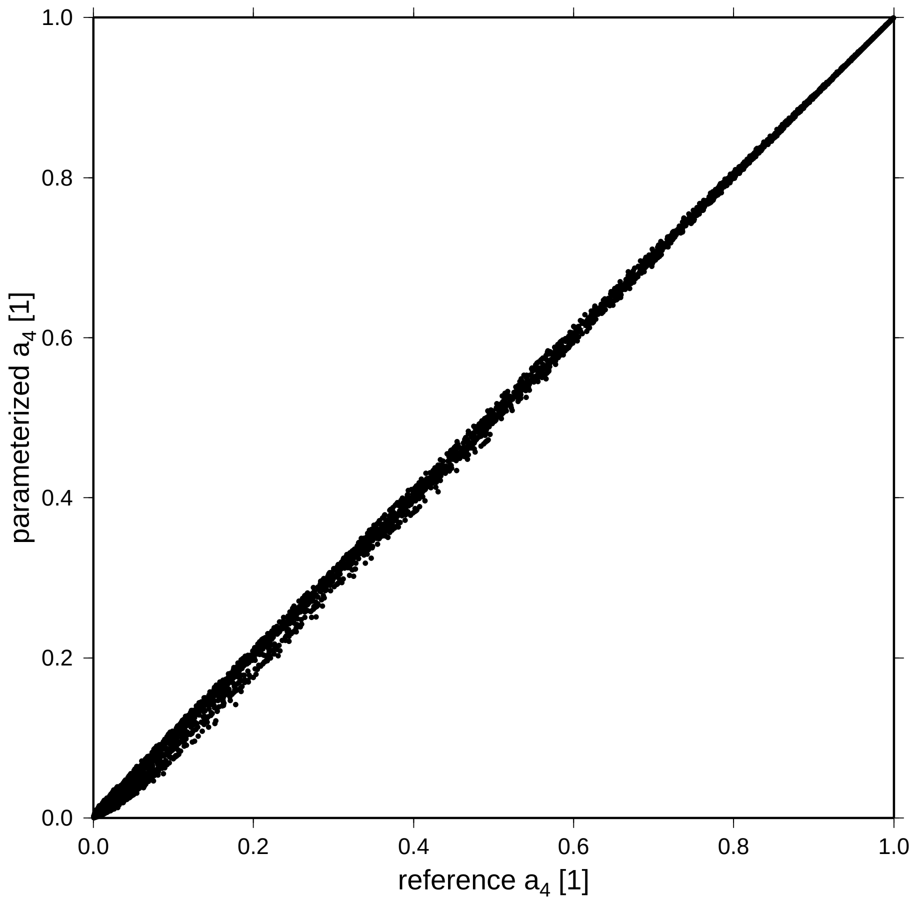
current ACRANEB setting (accounting also for mean saturation)

Parameterized versus reference total transmittance T, sample of homogeneous clouds (solar band, $\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9$)

current scheme

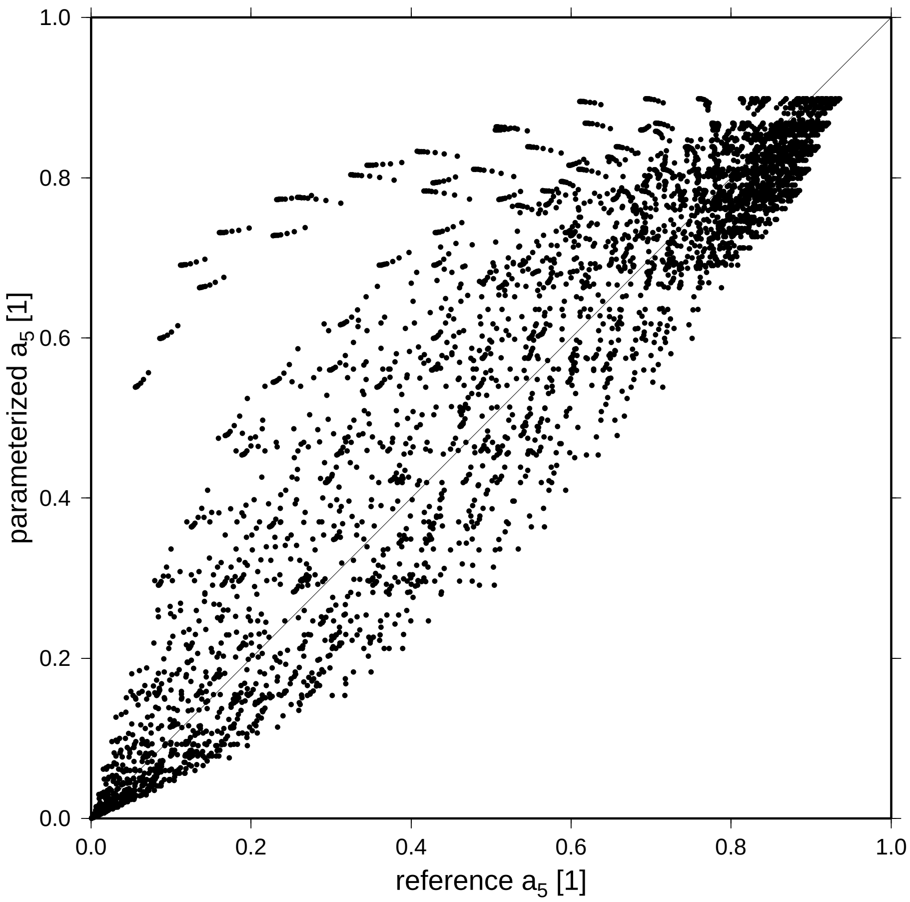
new scheme



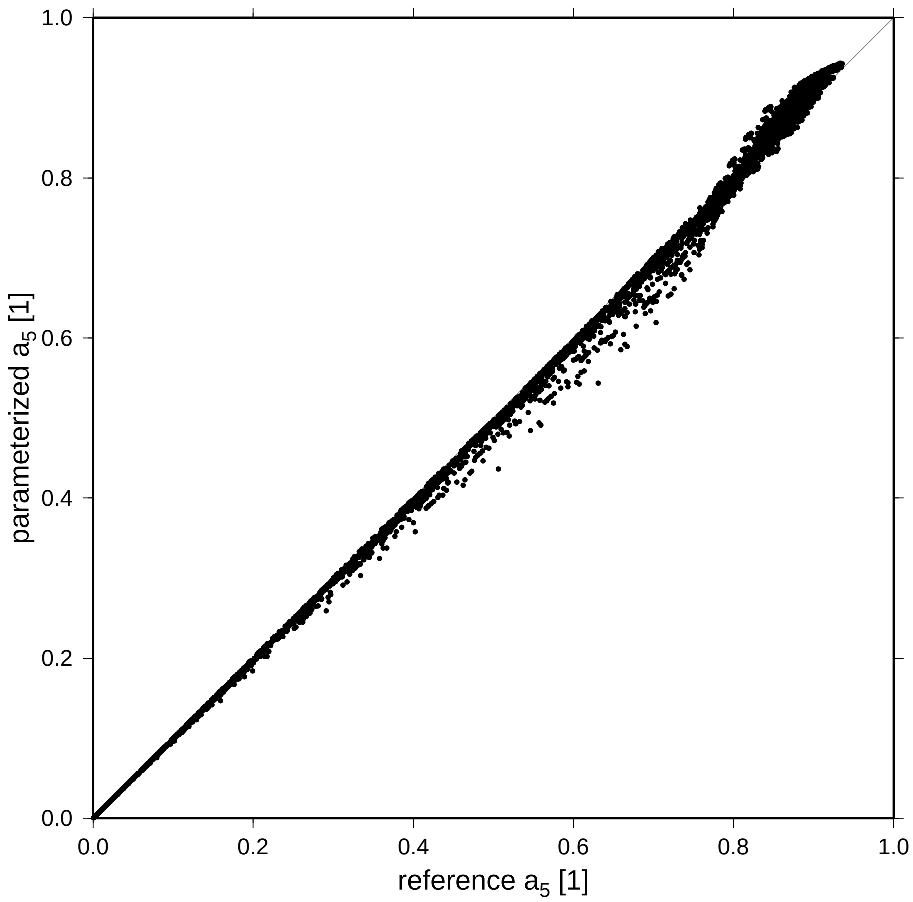


Parameterized versus reference total reflectance R, sample of homogeneous clouds (solar band, $\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9$)

current scheme

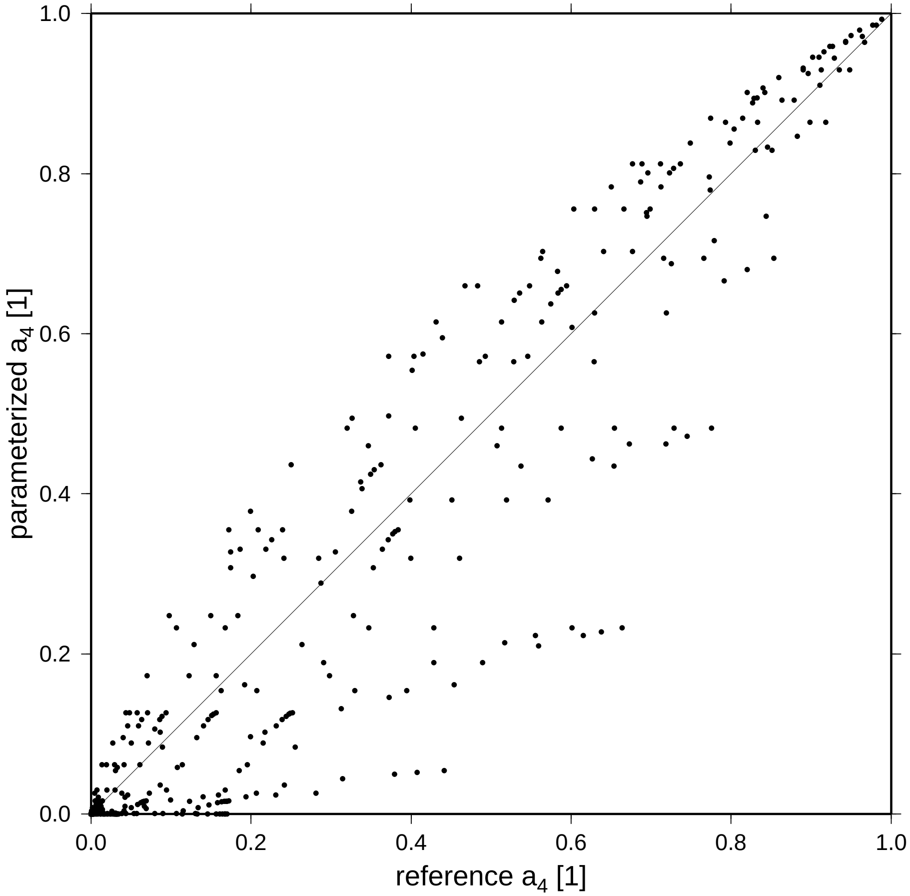


new scheme

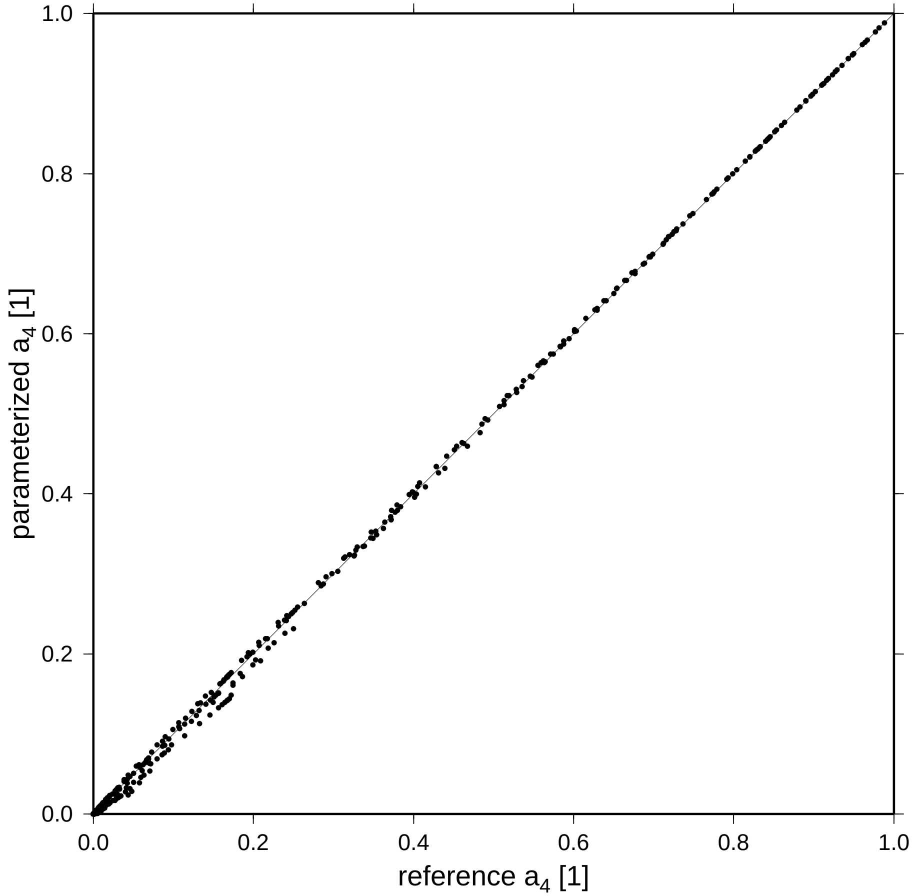


Parameterized versus reference total transmittance T, sample of homogeneous clouds (thermal band)

current scheme

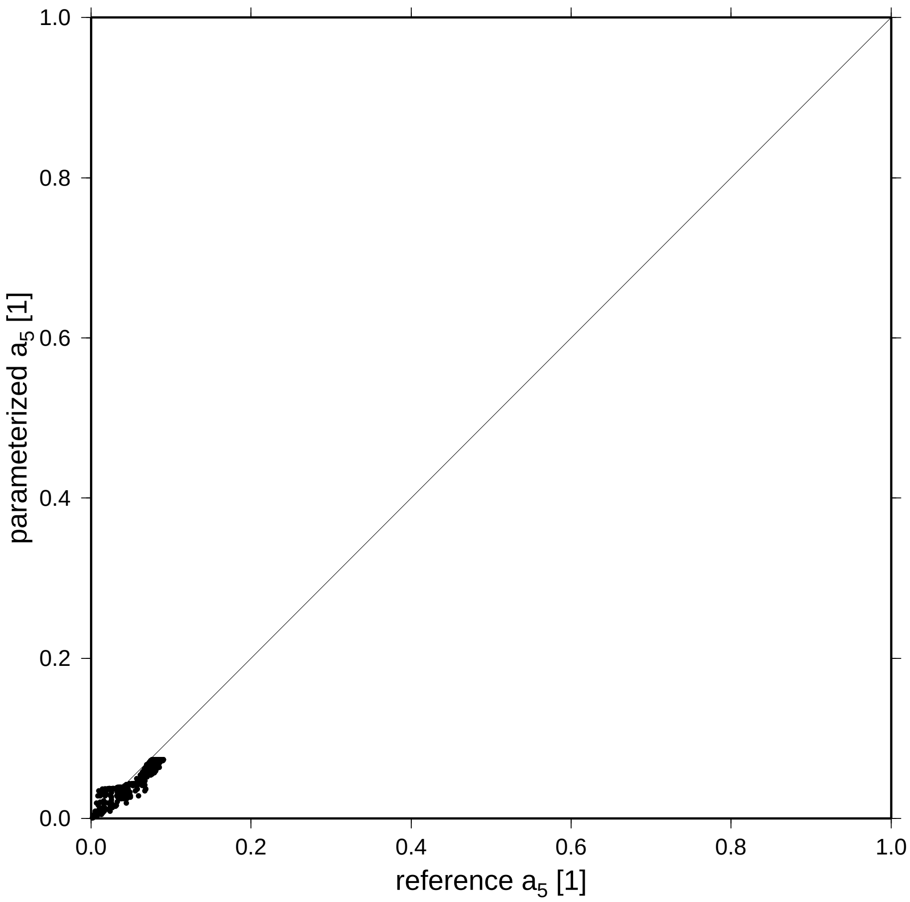


new scheme

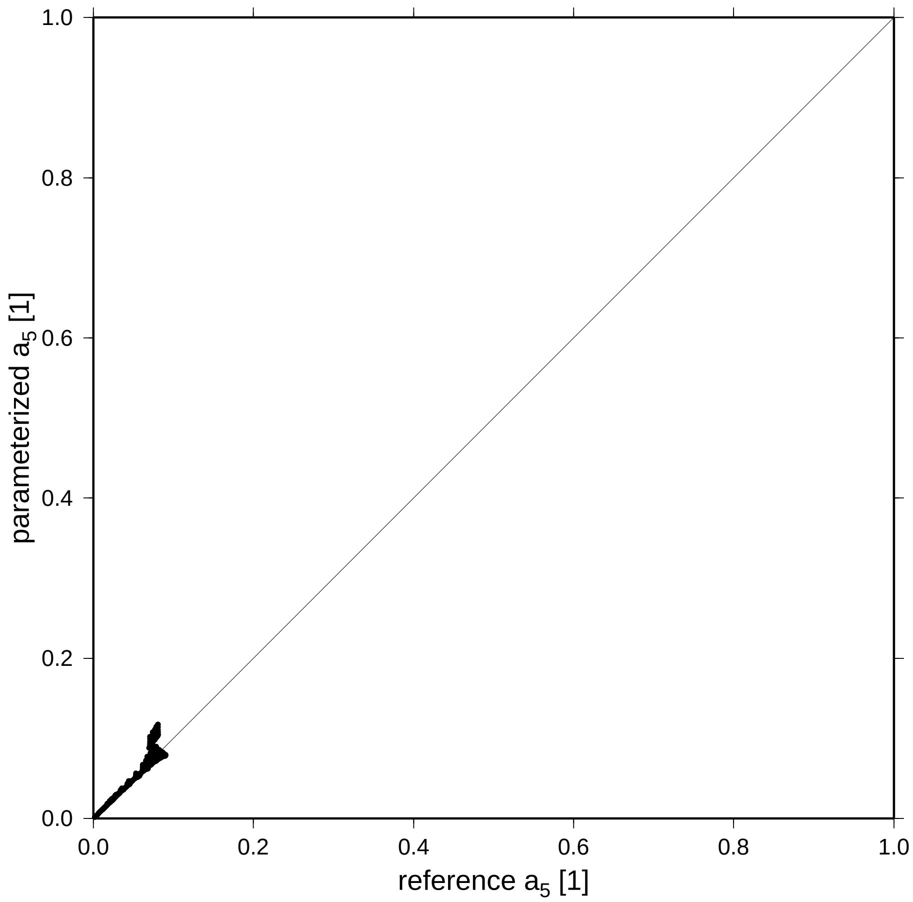


Parameterized versus reference total reflectance R,
sample of homogeneous clouds
(thermal band)

current scheme

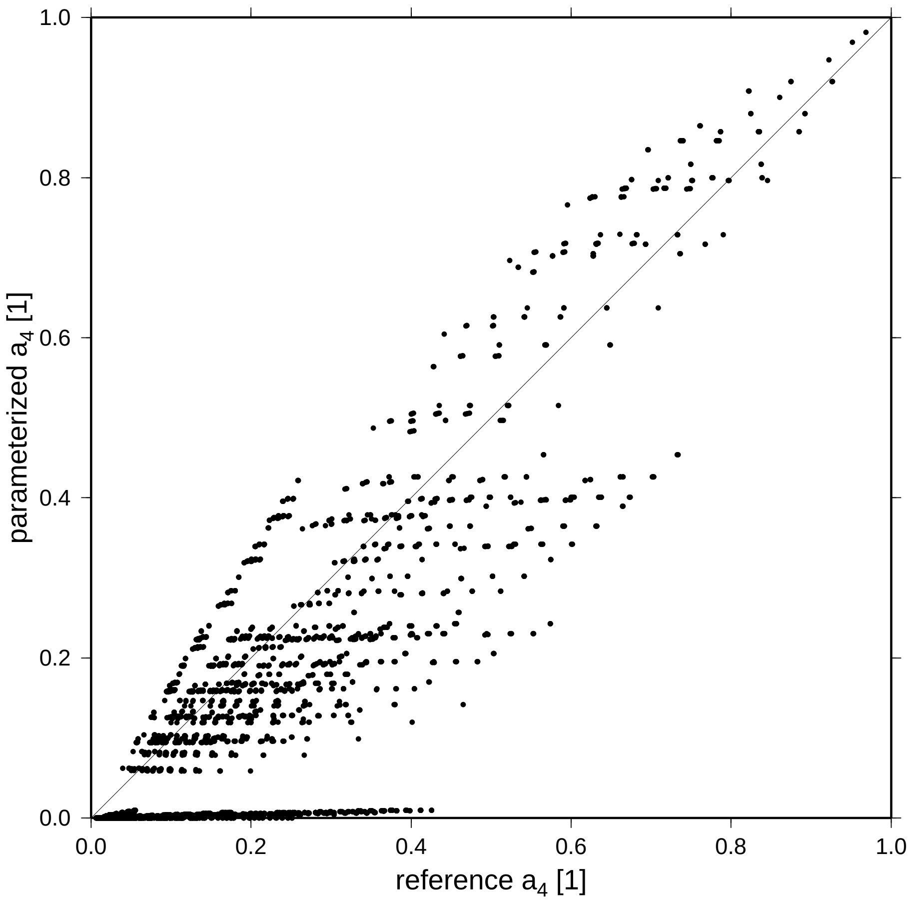


new scheme

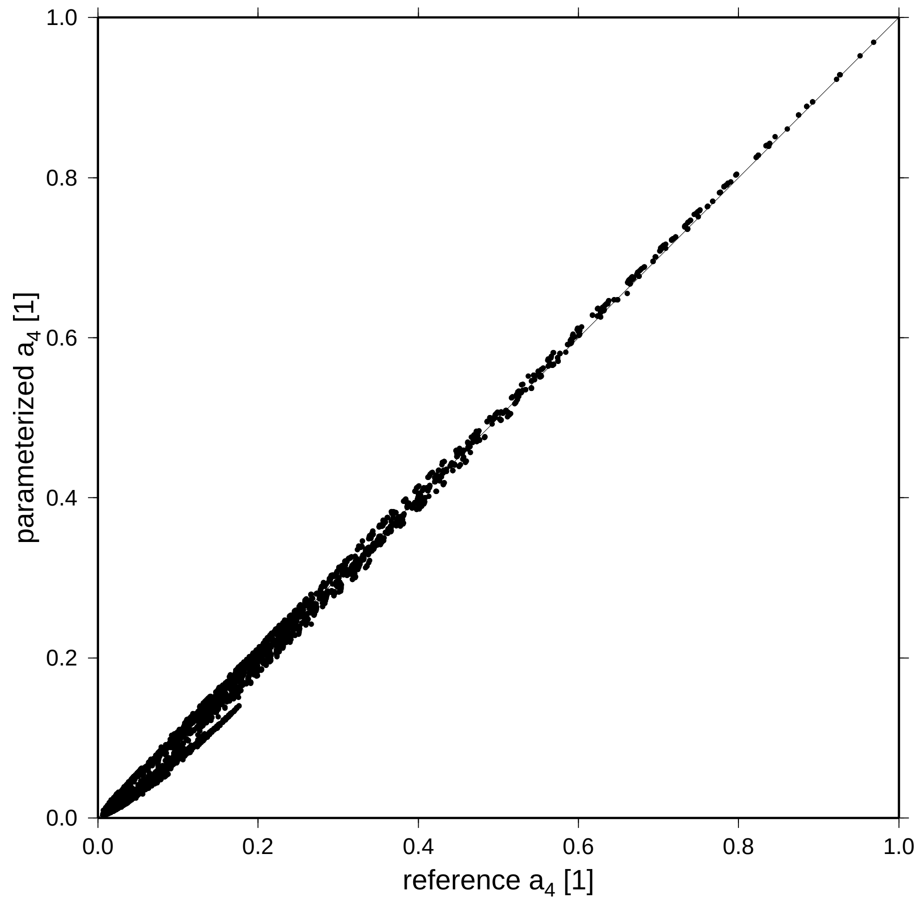


Parameterized versus reference total transmittance T, sample of non-homogeneous 3-layer clouds (solar band, $\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9$)

current scheme

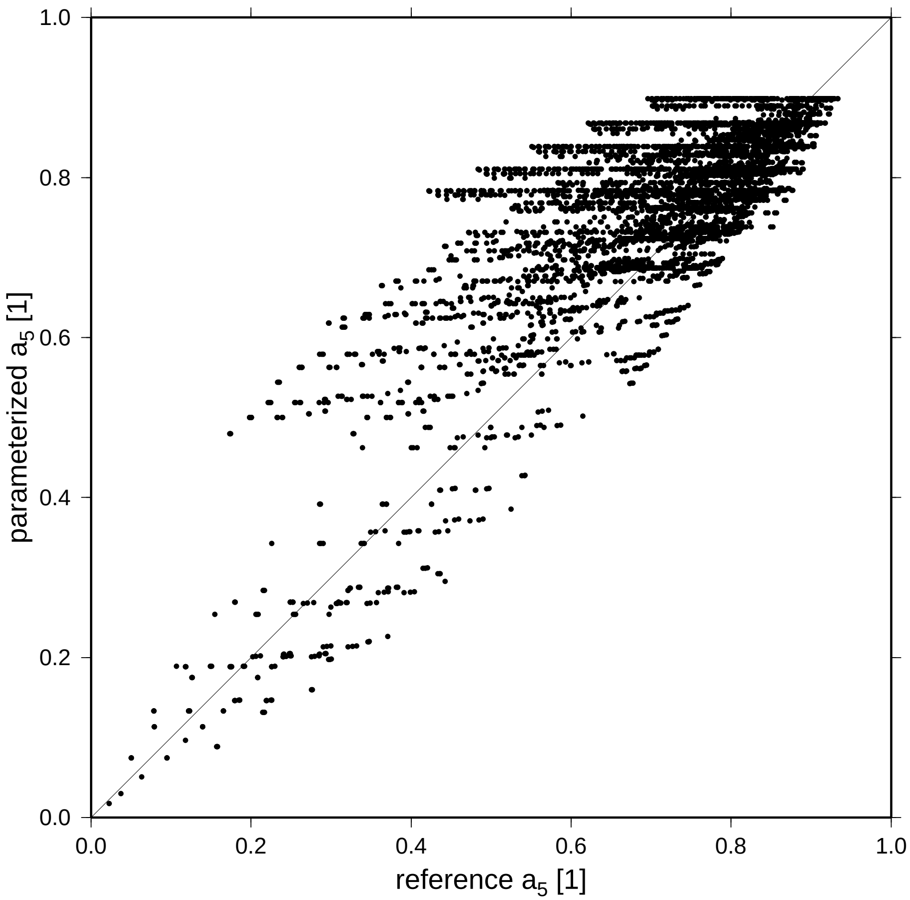


new scheme

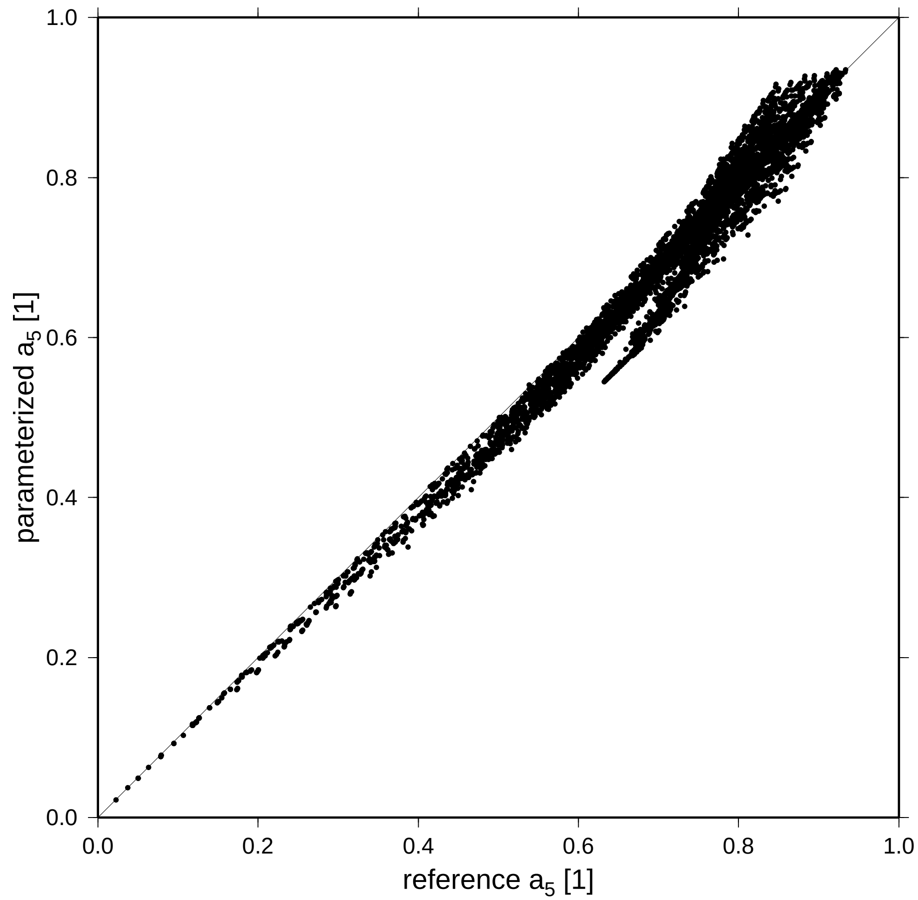


Parameterized versus reference total reflectance R, sample of non-homogeneous 3-layer clouds (solar band, $\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9$)

current scheme

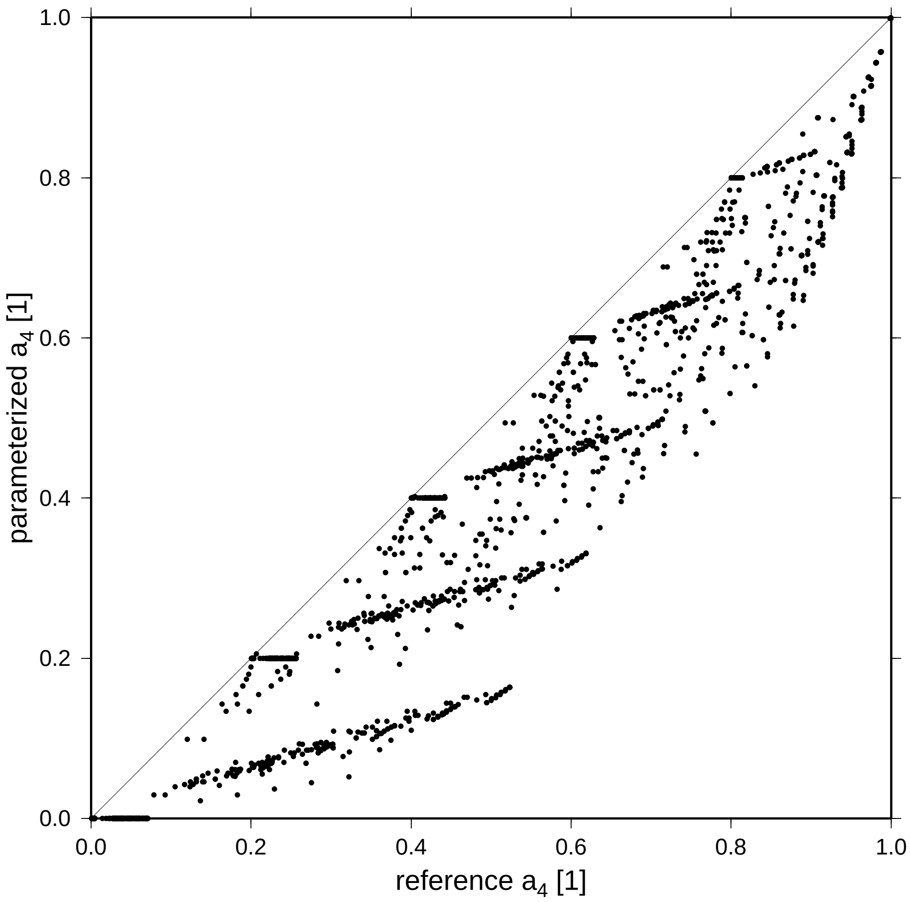


new scheme

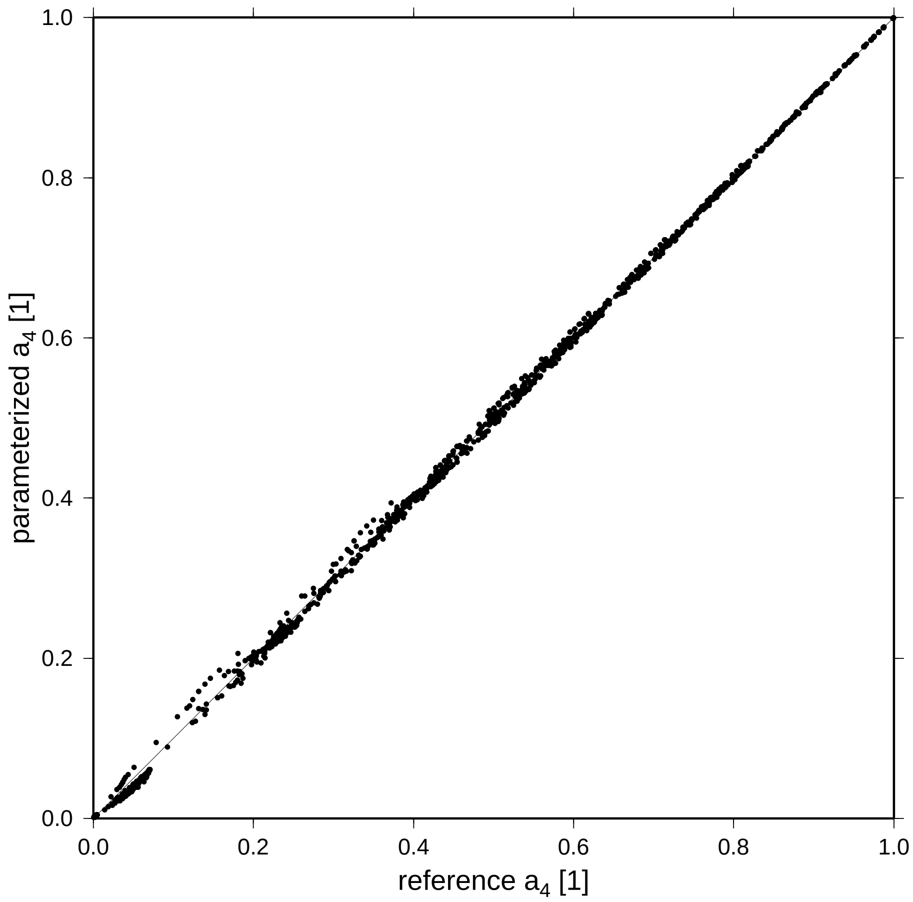


Parameterized versus reference total transmittance T,
sample of 2-layer clouds with maximum overlaps
(solar band, $\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9$)

current scheme

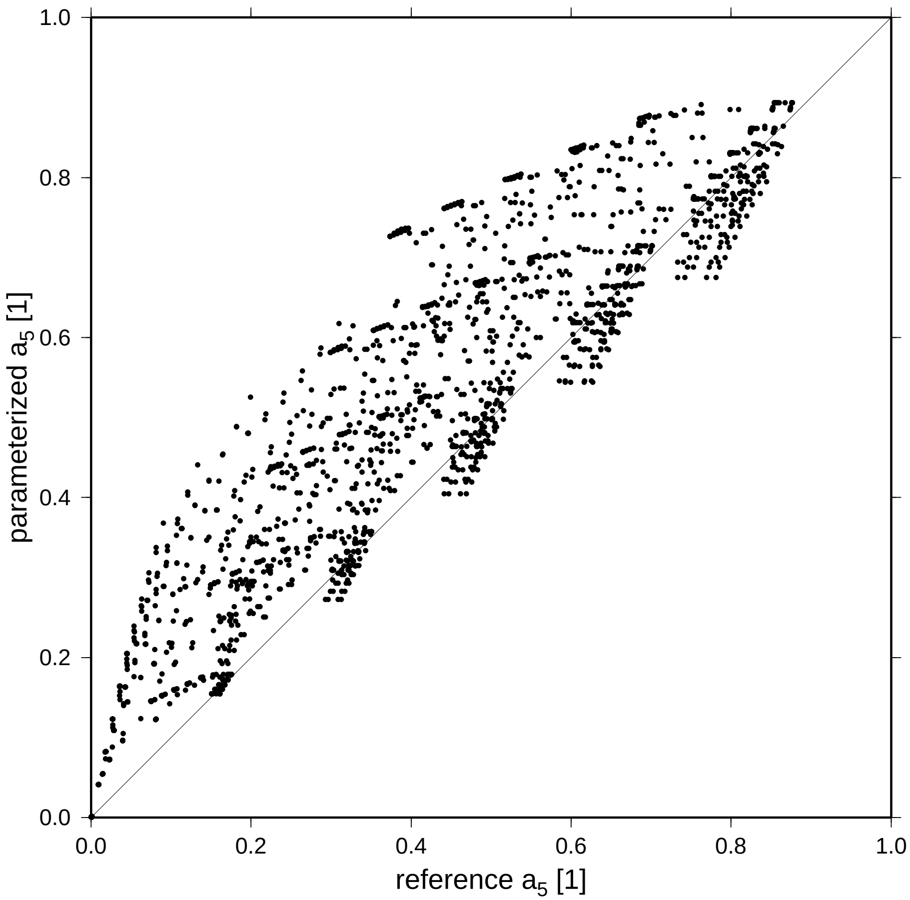


new scheme

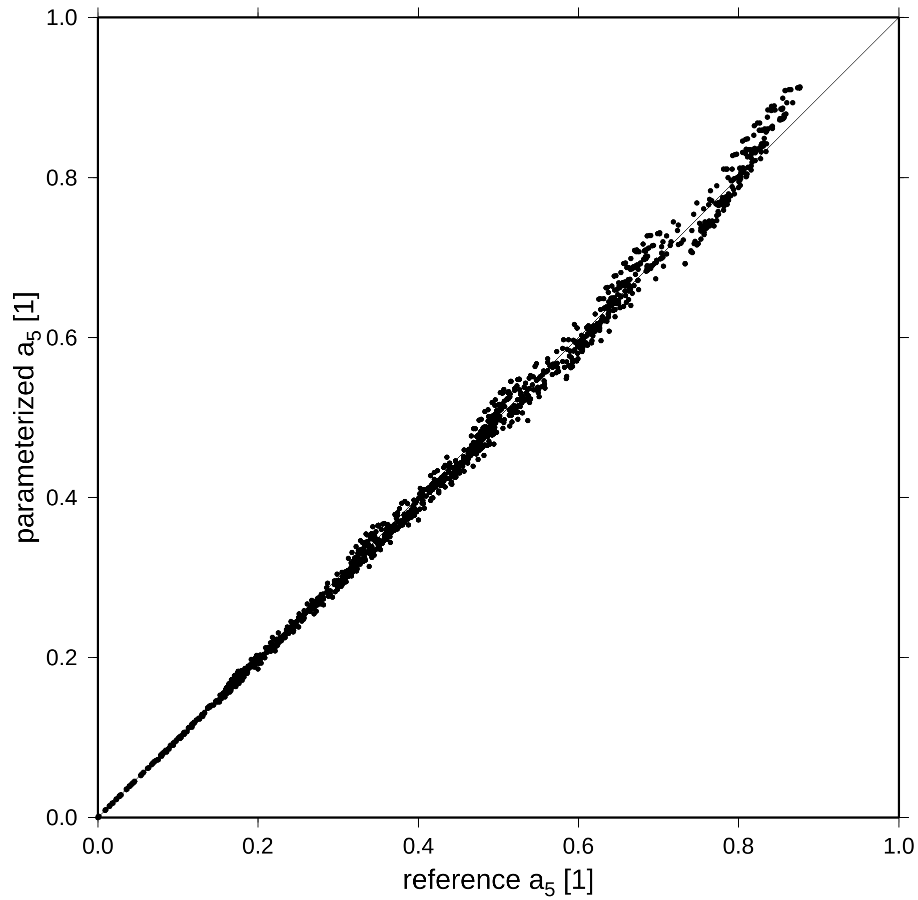


Parameterized versus reference total reflectance R, sample of 2-layer clouds with maximum overlaps (solar band, $\mu_0 = 0.1, 0.3, 0.5, 0.7, 0.9$)

current scheme



new scheme



Implementation in ALADIN

- new cloud scheme was coded in cycle 29t2, preliminary version is now phased with other ALARO-0 developments

- computation of cloud optical properties is done in new subroutine AC_CLOUD_MODEL called from ACRANEB

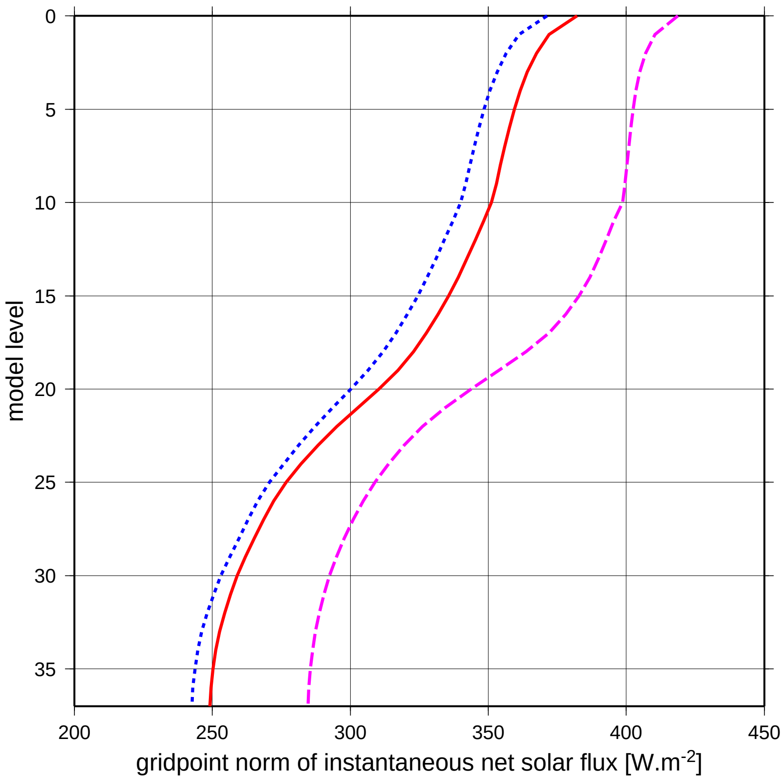
- new scheme is activated by logical key LCLSATUR in namelist &NAMPHY

- technical validation showed total CPU increase about 15 %, after code optimizations it was reduced to 8 % which is still too much

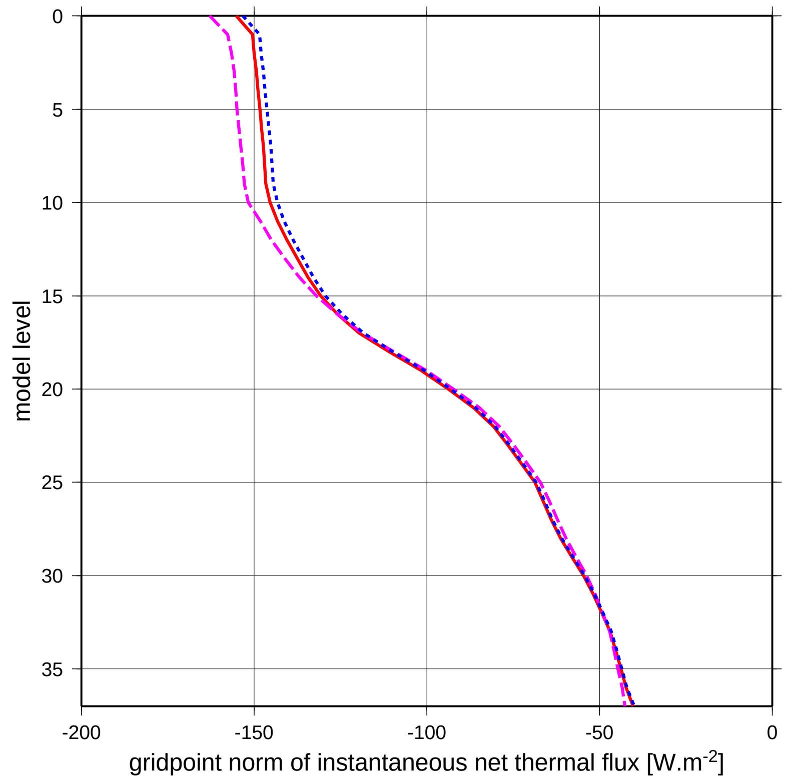
- comparison of radiative fluxes with FMR15 reference was a bad surprise

Vertical profile of net radiative flux averaged over model domain (instantaneous value at noon, positive downward)

solar band



thermal band



ACRANEB

ACRANEB + AC_CLOUD_MODEL

FMR15

Problem and its possible causes

- new scheme further reduces already underestimated net solar flux (by about 3 %)
- since it was tuned in idealized framework, it puts in question reference monochromatic computations representing the “truth”
- problem might arise due to oversimplified reference (neglecting of gases and aerosols, restricting to diffuse fluxes*, assuming zero surface albedo)
- investigations made so far indicate that all these simplifications are acceptable
- main suspicion now falls on delta-two stream approximation used in reference monochromatic computations (could it be improved, or do we need some more sophisticated scheme?)

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* only in original version, presented results were obtained including direct solar flux

Summary

- new cloud scheme was developed and implemented in cycle 29t2
- experiments in idealized framework show its superiority over current ACRANEB
- however, real case tests indicate slight amplification of known deficiencies
- problem is under investigation, likely cause being imperfectness of idealized reference leading to biased tunings