Radiation

Overview for ALARO-1 Working Days

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Abstract

- Generalities
- The RTE (Radiative Transfer Equation)
- ACRANEB – ‘economic’ radiation scheme
- New developments:
  - Refining of gaseous transmission functions
  - Correction for composite of gases
- Plans for the future

Generalities

- RTE is well known and theoretically it can be solved with infinite precision
- however, state of atmosphere is not known with sufficiently high precision
- furthermore, the exact integration of the RTE is very expensive and hence must be simplified
- in practice, parameterization of RT (Radiative Transfer) is only a problem of accuracy vs. cost of approximations

Radiative transfer equation

RTE – basic equation

$$\mu \frac{\partial I_\nu}{\partial \delta_\nu} = -I_\nu + (1-\omega_\nu) B_\nu + \frac{\omega}{4\pi}\left[S_\nu^0 e^{-\frac{\delta_\nu}{\mu_0}} P_\nu + \iint P_\nu I_\nu \, d\mu \, d\phi \right]$$

extinction | emission | scattering (parallel) | scattering (diffuse)

- resolution of RTE involves 4 integrals:
  - angular ***μ*, ϕ**
  - along the absorber paths $\boldsymbol{\delta_\nu}$
  - spectral ***ν***
  - vertical (in the model coordinate, classically)

RTE – 2-stream method

- Eddington's approximation – assumes horizontal isotropy in two half-spheres
- RT described by three fluxes: ***S*** for the solar parallel radiation, $\boldsymbol{F}^{\downarrow}$ diffuse downward radiation, $\boldsymbol{F}^{\uparrow}$ diffuse upward radiation
- after substitution $\boldsymbol{F^* = F - \pi B}$ where $\boldsymbol{\pi B}$ is black body flux of a given layer, one obtains

RTE – 2-stream method

$$\frac{\partial S}{\partial \delta} = -S / \mu_0$$

$$\frac{\partial F_*^{\downarrow}}{\partial \delta} = -\alpha_1 . F_*^{\downarrow} + \alpha_2 . F_*^{\uparrow} + \alpha_3(\mu_0) . S$$

$$\frac{\partial F_*^{\uparrow}}{\partial \delta} = -\alpha_2 . F_*^{\downarrow} + \alpha_1 . F_*^{\uparrow} - \alpha_4(\mu_0) . S$$

- after analytical integration one obtains the linear system for fluxes at the ***t***op and ***b***ottom of given layer

RTE – adding method

$$S(\tilde{0}) = \mu_0 . I_0 \quad F^{\downarrow}(\tilde{0}) = 0$$

$$\begin{vmatrix} S_b \\ F_{*b}^{\downarrow} \\ F_{*t}^{\uparrow} \end{vmatrix} = \begin{vmatrix} a_1 & 0 & 0 \\ a_2 & a_4 & a_5 \\ a_3 & a_5 & a_4 \end{vmatrix} . \begin{vmatrix} S_t \\ F_{*t}^{\downarrow} \\ F_{*b}^{\uparrow} \end{vmatrix}$$

$$F^{\uparrow}(\tilde{N}) = Al(\mu_0).S(\tilde{N}) + \overline{Al}.F^{\downarrow}(\tilde{N}) \quad F_*^{\uparrow}(\tilde{N}) = (1-\varepsilon).F_*^{\downarrow}(\tilde{N})$$

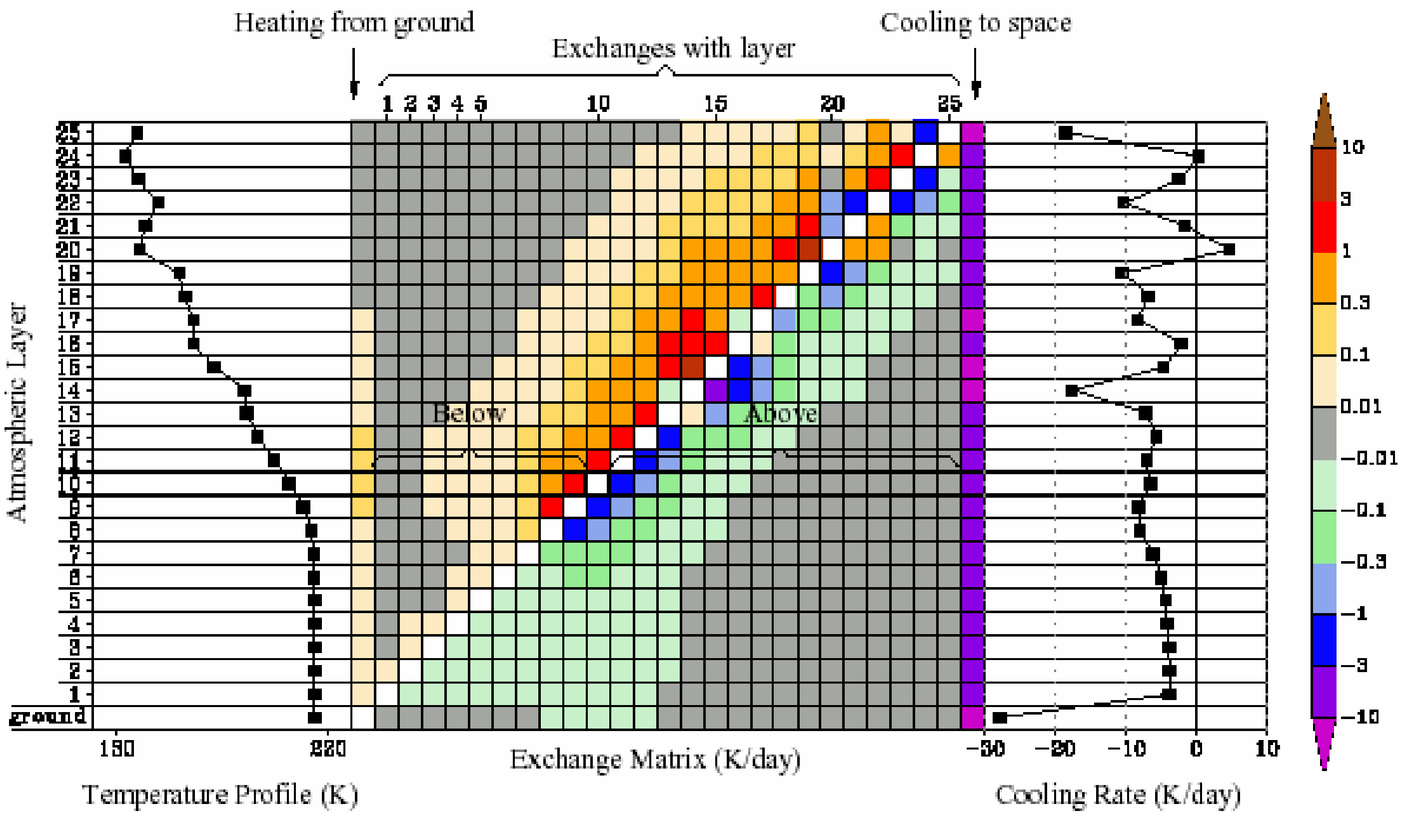
- the resulting linear system can be easily solved by Gaussian elimination-back-substitution provided that average optical properties are given for each layer

ACRANEB
'economic' radiation scheme

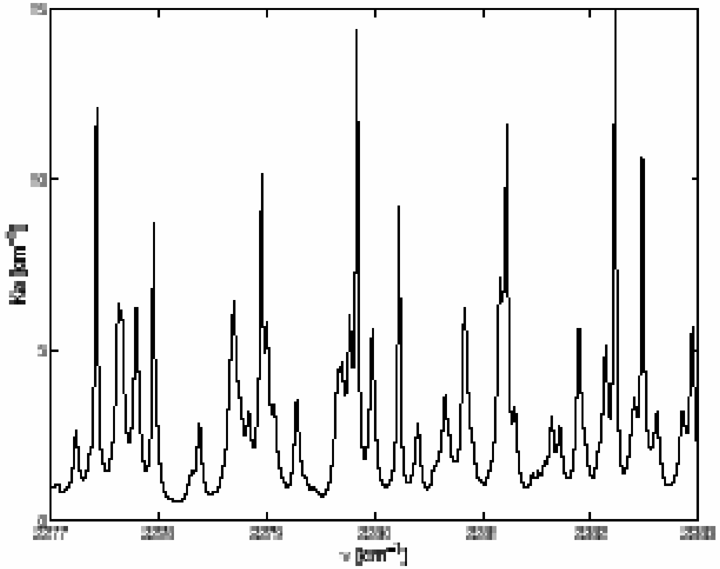
ACRANEB – basic elements

- δ-two-stream approximation of RTE + adding method
- using NER formulation for solving multi-source problem of thermal RT
- two spectral bands - solar [0.245 - 4.642 μm]
  - thermal [4.642 – 105.0 μm]
- three gases – H_2O, CO_2+, O_3
- Malkmus formula + Pade fits for evaluation of broad-band gaseous opt. depths (based on SPLIDACO database)
- using Voigt line profile to cope with high model levels
- max-random overlap hypothesis for treatment of cloudiness

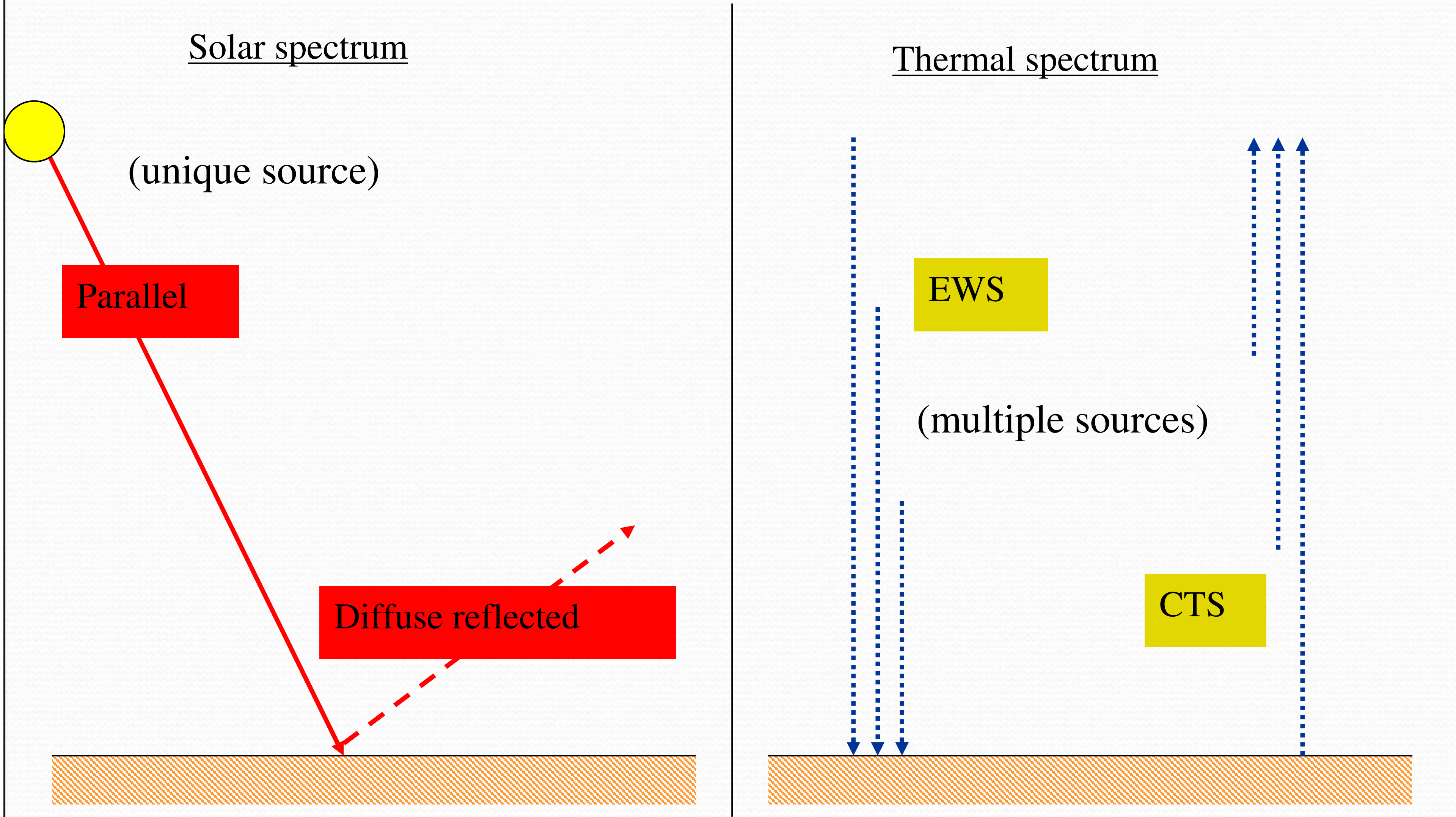
NE



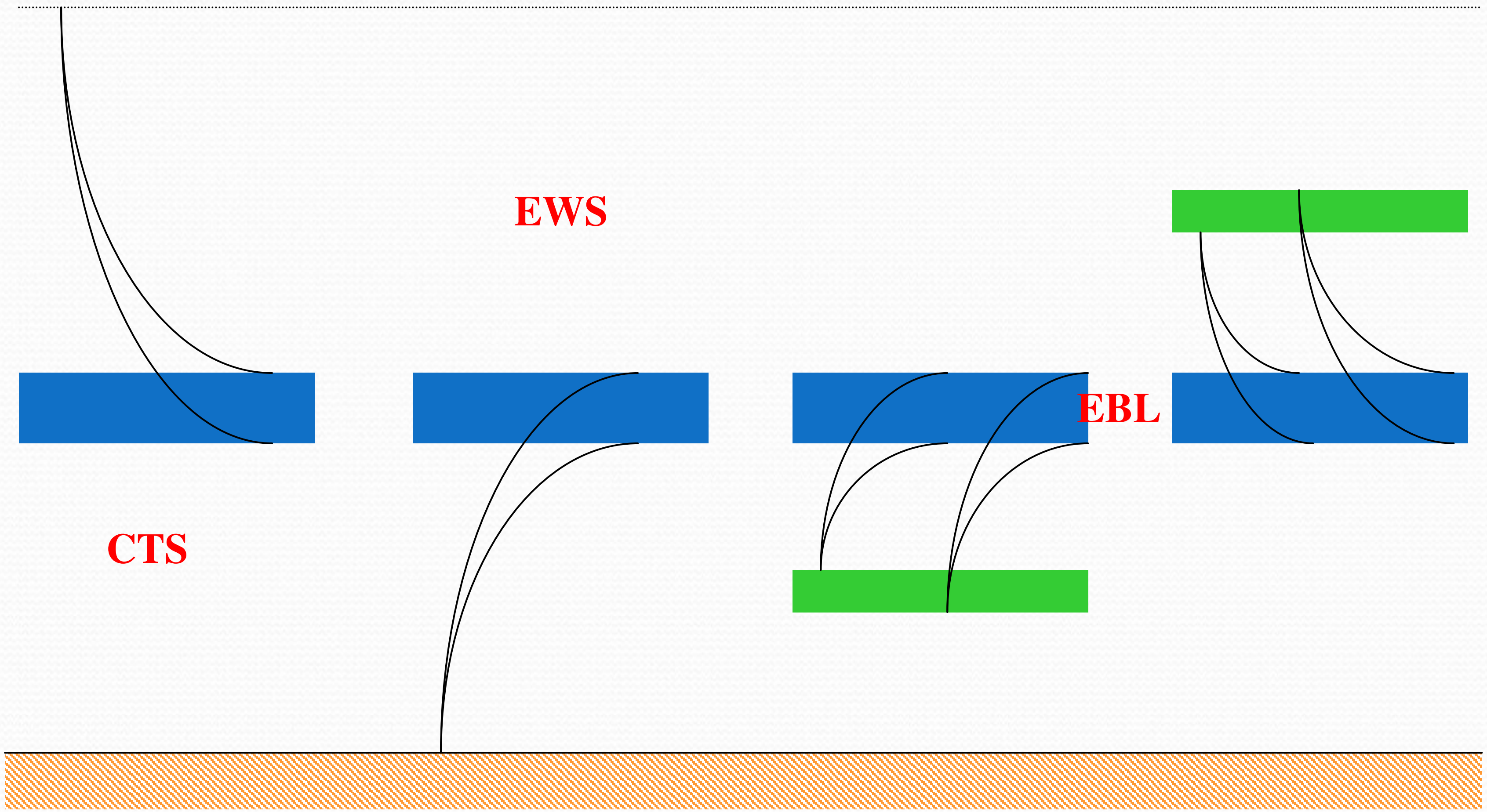
Heating from ground
Exchanges with layer
Cooling to space
1 2 3 4 5 10 15 20 25
Atmospheric Layer
ground
Below
Above
180
220
Exchange Matrix (K/day)
-30 -20 -10 0 10
Temperature Profile (K)
Cooling Rate (K/day)
10
3
1
0.3
0.1
0.01
-0.01
-0.1
-0.3
-1
-3
-10



Idealised optical paths



Decomposition of thermal radiative exchange terms in the absence of scattering



Method of idealised optical paths

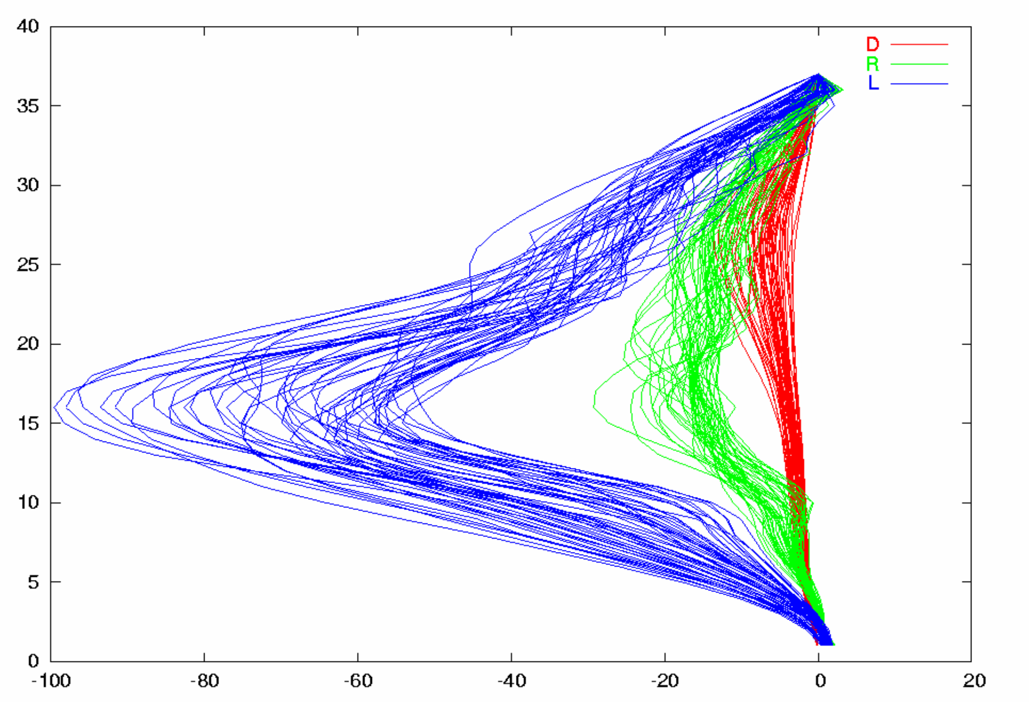
- One computes exactly the optical depths of gaseous absorption for every layer and one re-injects them as such in the two-stream + adding formalism, together with the ‘grey body’ effects.
- For the thermal part, the CTS and EWS computations rely on obvious direct optical paths.
- There remains, like always, the ‘CPU barrier’ for the EBL calculations.
- For the EBL part, the dominating term is the one corresponding to exchanges between immediately adjacent layers

NER

- In the following, one will work with three different profiles:
  - ***ΠB = 1*** at the ground and everywhere in the atmosphere => allows to suppress all other exchanges than 'cooling to space' (CTS) – Profile A
  - ***ΠB = 1*** at the ground et ***ΠB = 0*** everywhere in the atmosphere => allows to suppress all other exchanges than 'exchange with surface' (EWS) – Profile B
  - The one corresponding to the physical truth => it mixes CTS, EWS with the 'exchanges between layers' (EBL) – Profile C

Method of idealised optical paths

- The central idea is to ‘bracket’ the true result for EBL between min. exchange (wither surface or space) and max. exchange (with adjacent layer).



Method

- One gets now the following algorithm:
  - One does a calculation [I] with profile A and δ_{CTS}
  - One does a calculation [II] with profile B and δ_{EWS}
  - On does three calculations [III, IV, V] with profiles A, B & C and $\delta_{EBL}= \delta_{min}$
  - One does three calculations [VI, VII, VIII] with profiles A, B & C and $\delta_{EBL} = \delta_{max}$
- After multiplying the results (except 'V' and 'VIII') by the relevant ΠB values, one recombines:

  [I] + [II] – α.([III]+[IV]-[V]) - (1-α).([VI]+[VII]-[VIII])
- α is calibrated from model statistics as a function of gradient of potential temperature and of altitude

Refining of gaseous transmission functions

Refining of gaseous transmission functions

- motivation:
  - known problem of overestimation of cooling rates in lower troposphere leading to geopotential stretching around 700hPa
- strategy:
  - revision of the fitting procedure
  - verify if we can reproduce old fits
  - use RRTM's transmission functions as a database for new fits
  - verify assumption of independency of single gaseous contributions upon the total optical depth

Refining of gaseous transmission functions

- method of computation:
  - using Malkmus band model for evaluation of equivalent scale width ***w***

$$w = W / \delta_{lines} = \frac{2a}{b}\frac{q_r}{q_n}\left(\sqrt{1+4b\frac{q_n^2}{q_r}}-1\right)+cq_r$$

a – weak line parameter

b – strong line parameter

c – continuum parameter

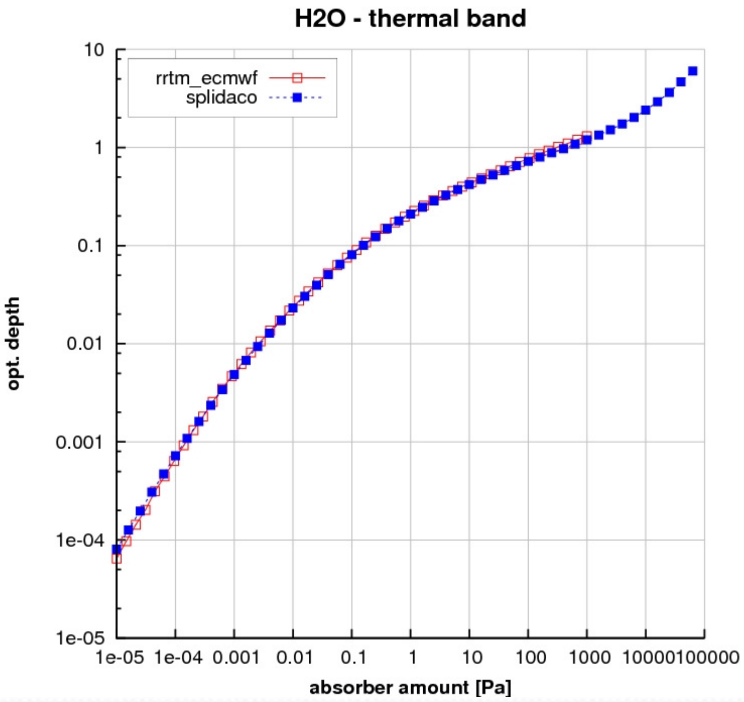
$\boldsymbol{q_r}$, $\boldsymbol{q_n}$ - reduced (by *T* and *p* factors) and unreduced absorber amounts

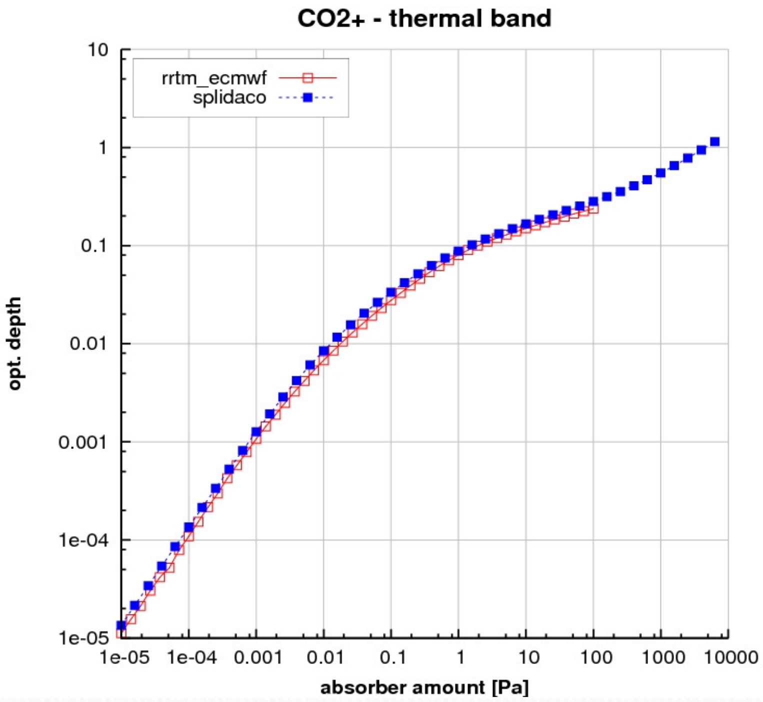
Refining of gaseous transmission functions

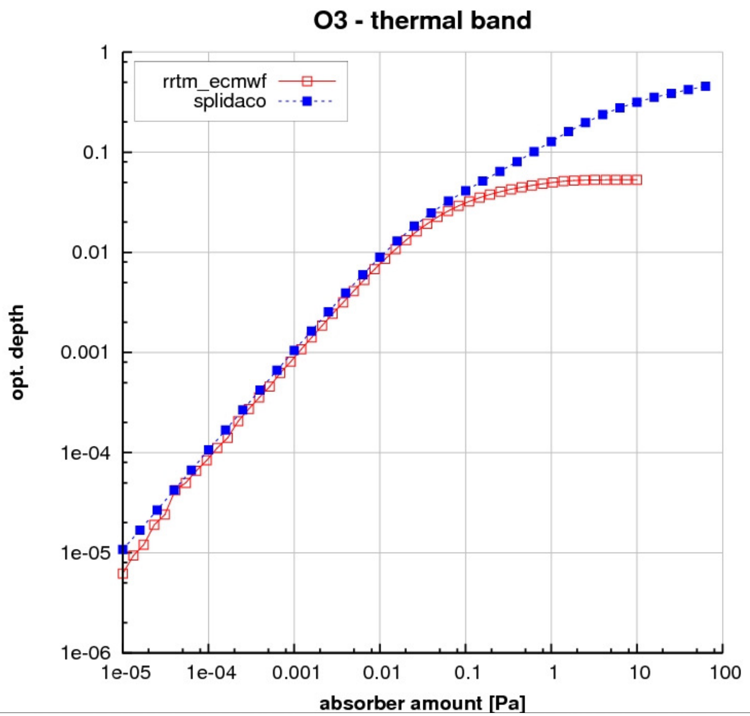
- due to non-linear dependence, optical depth $\boldsymbol{\delta}$ is expressed as a function of $\boldsymbol{w}$ in a form of Pade approximant

$$\delta_g = \frac{P(w)}{Q(w)} = w \frac{1 + \sum p_n w^n}{1 + \sum q_m w^m}$$

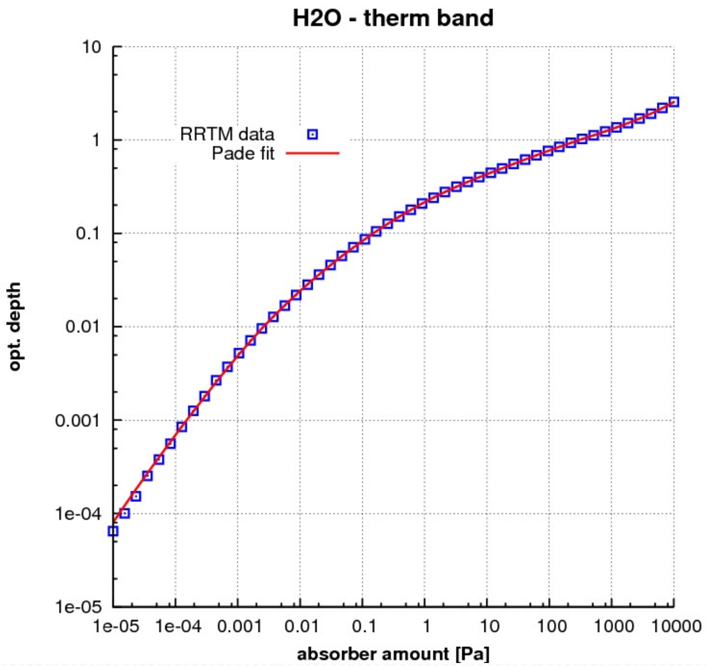
- subtleties:
  - all polynomial coefficients must be non-negative in order to ensure monotonicity and to prevent numerical instabilities

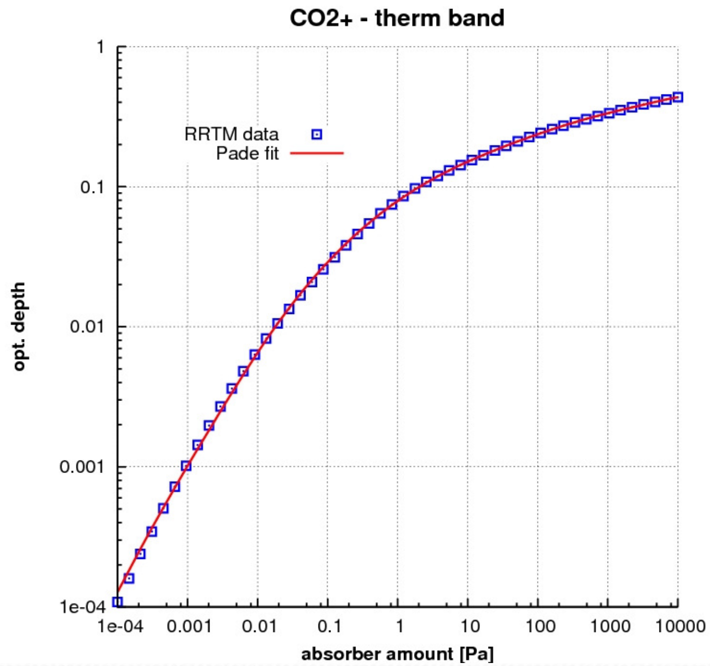


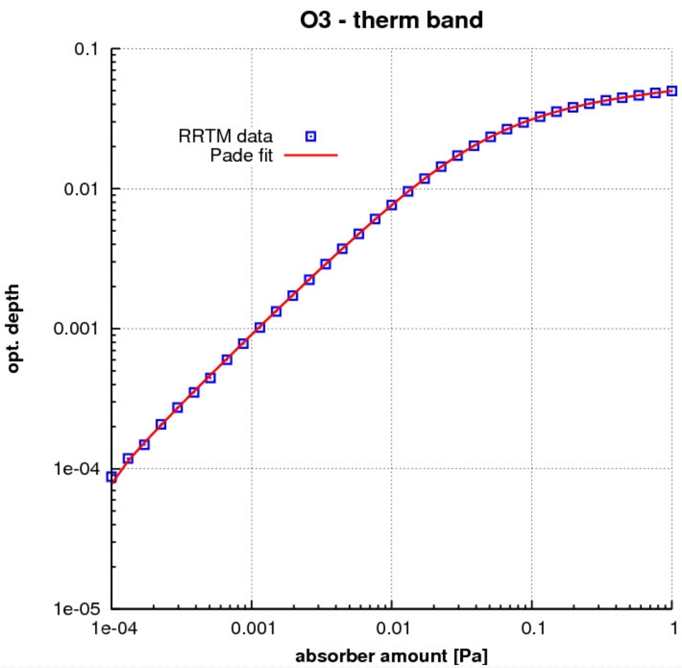




red – RRTM
blue – spidaco
(old fits)





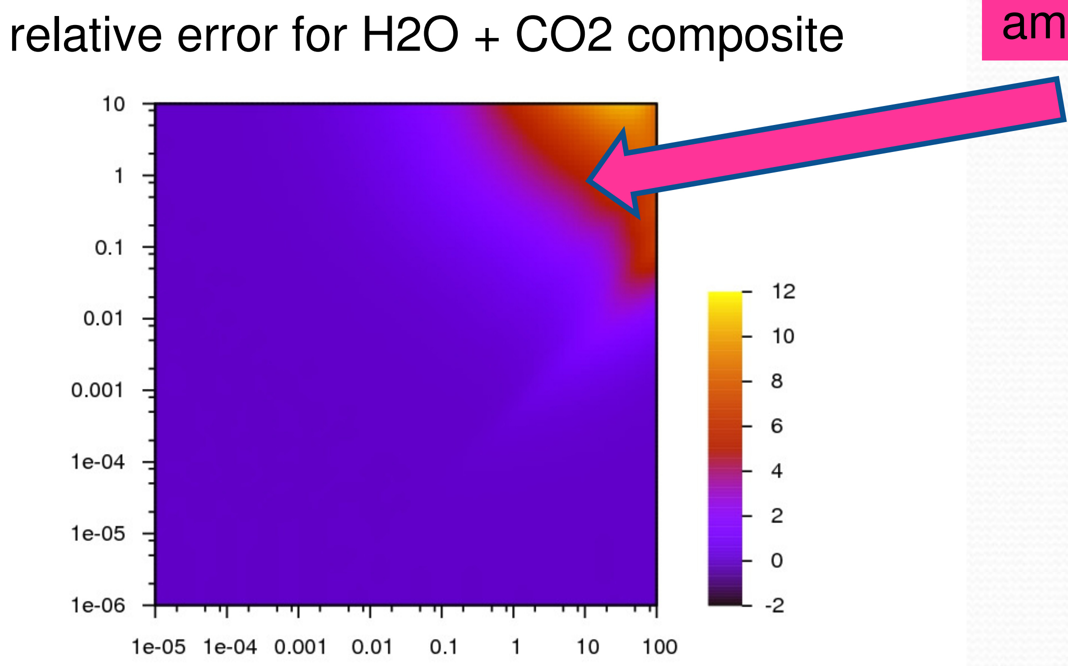


red – RRTM
blue – Pade fit

Correction for composite of gases

- assumption: sum of individual gaseous contributions to the total opt. depth is equivalent to the total optical depth of their composite

NOT valid for higher absorber amounts



Correction for composite of gases

- proposed solution:

$$\boldsymbol{\delta_{tot}} = \boldsymbol{\delta_1 + \delta_2 + \delta_3} + \boldsymbol{X_{12}} + \boldsymbol{X_{13}} + \boldsymbol{X_{23}} + \ldots \ (?)$$

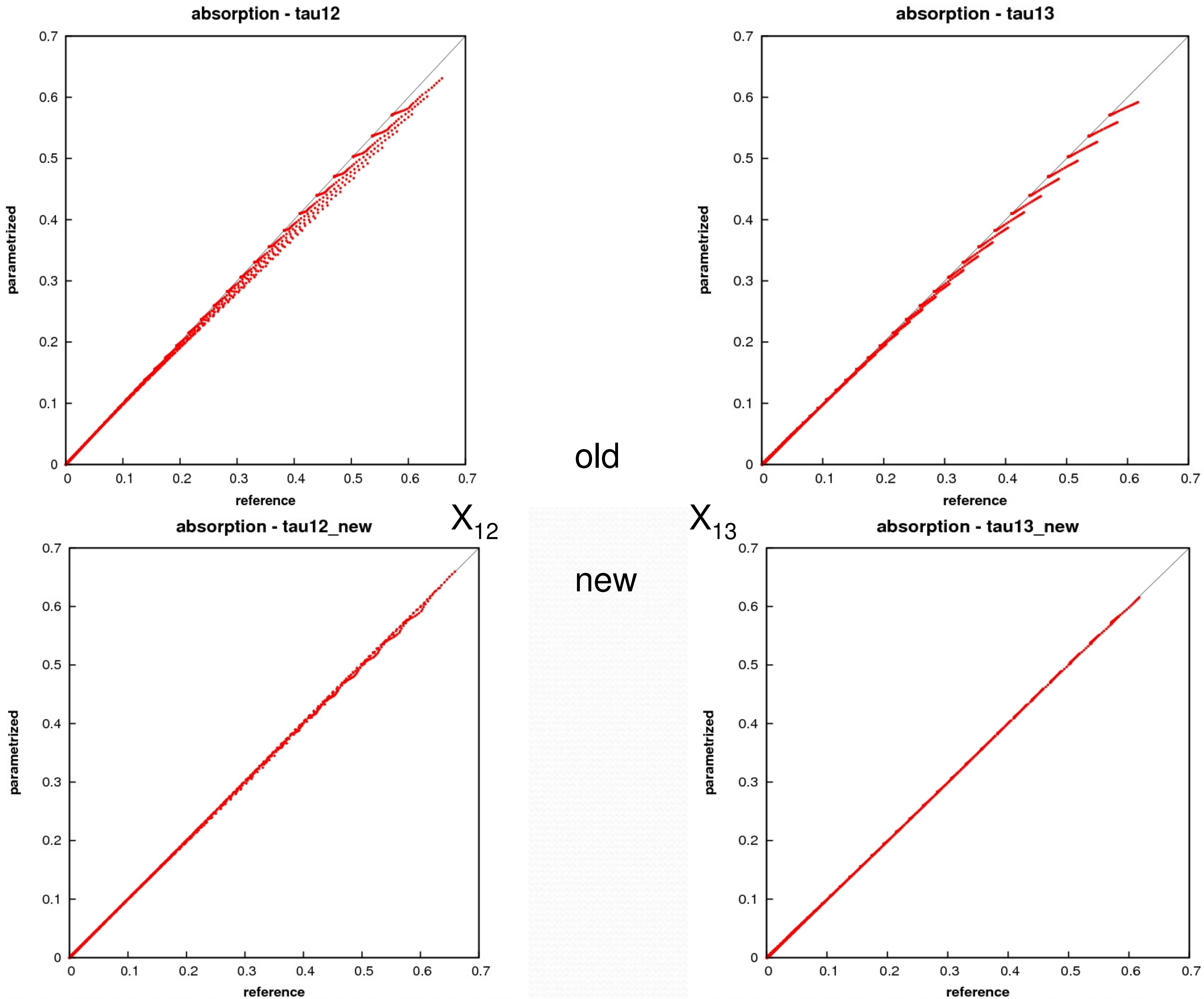
current solution | new correction terms

$\boldsymbol{X_{ij}} = \boldsymbol{\delta_{ij}} - (\boldsymbol{\delta_i} + \boldsymbol{\delta_j})$ … 'double-composite' correction

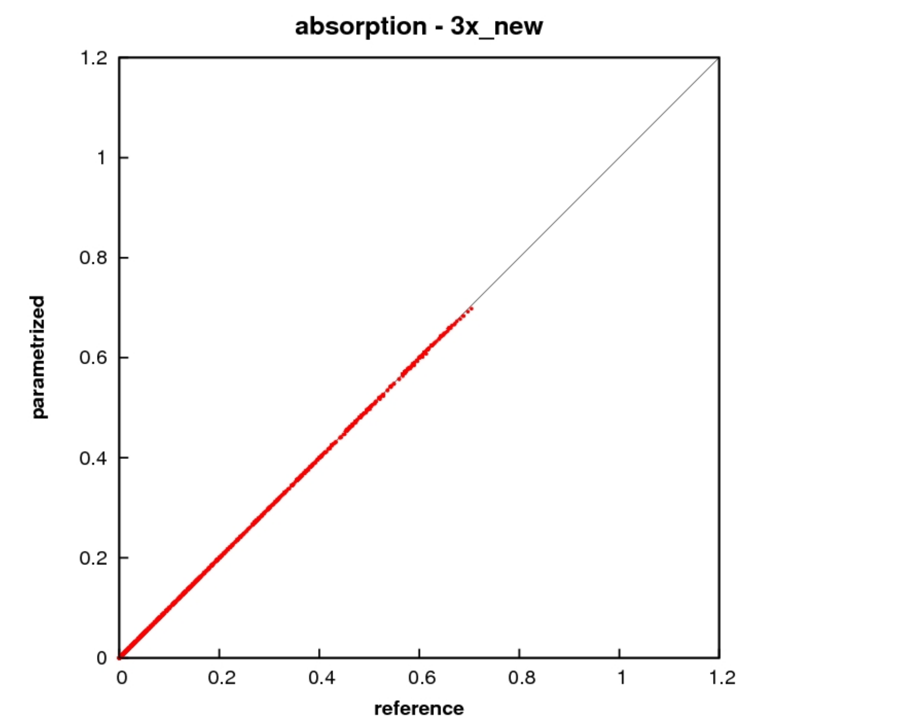
$$X_{ij} = \sqrt{a \frac{u_i}{(u_i + b)} \frac{u_j}{(u_j + c)}}$$

u – *absorber amount*

a, b, c – fitting coeff.

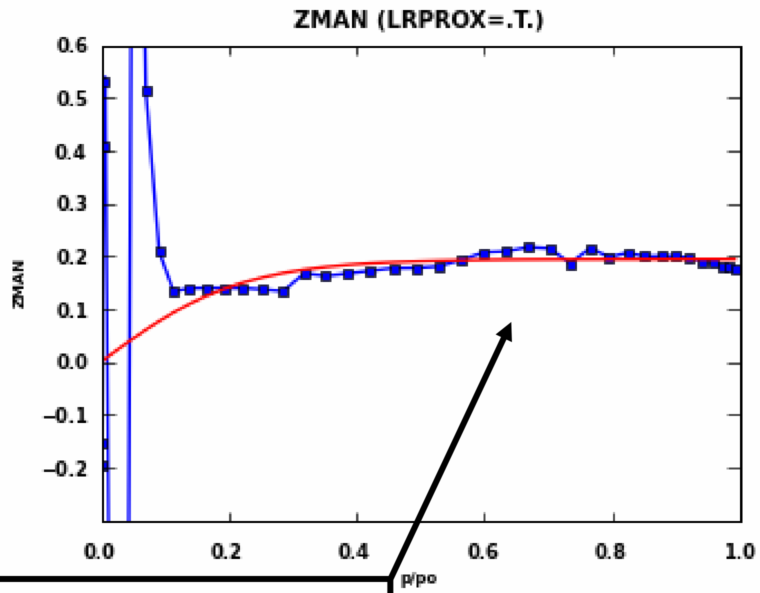

absorption - tau12
absorption - tau13
absorption - tau12_new
absorption - tau13_new
parametrized
reference
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
old
new
X12
X13

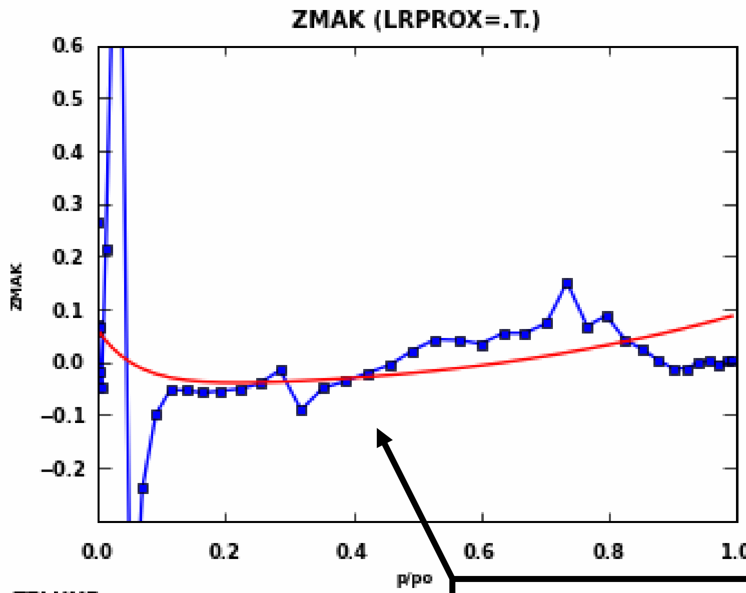
Composite of gases



- absorption of composite of all three gases after applying corrections X_{12}, X_{13}, X_{23}
- additional higher order correction term X_{123} not necessary

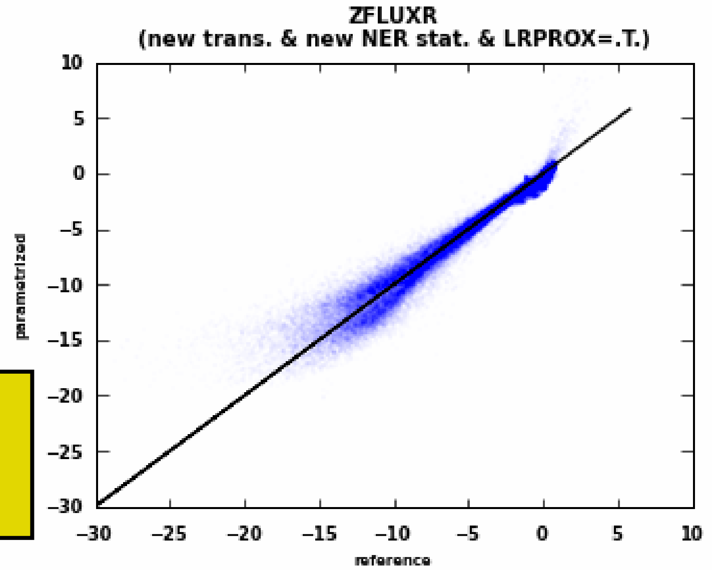
The strategy of parameterising α: dispersion diagram for total fluxes





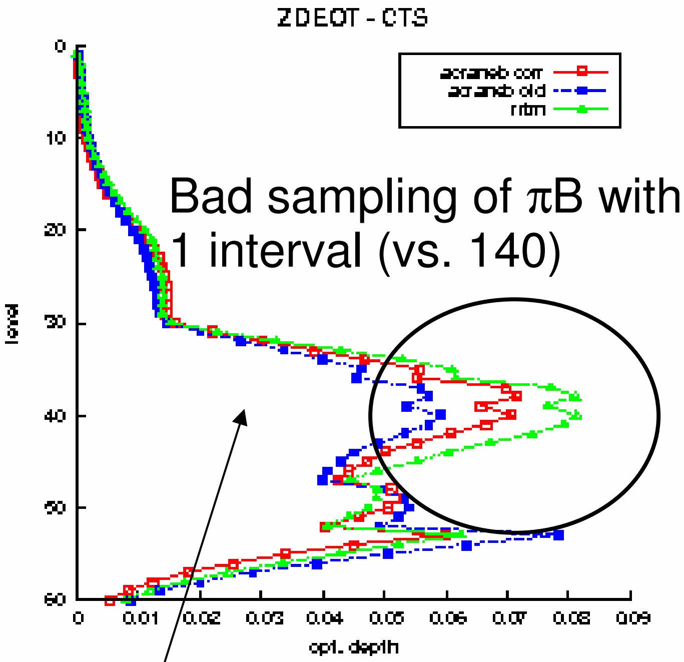
α dependency on pressure

α dependency on vertical gradient of potential temperature

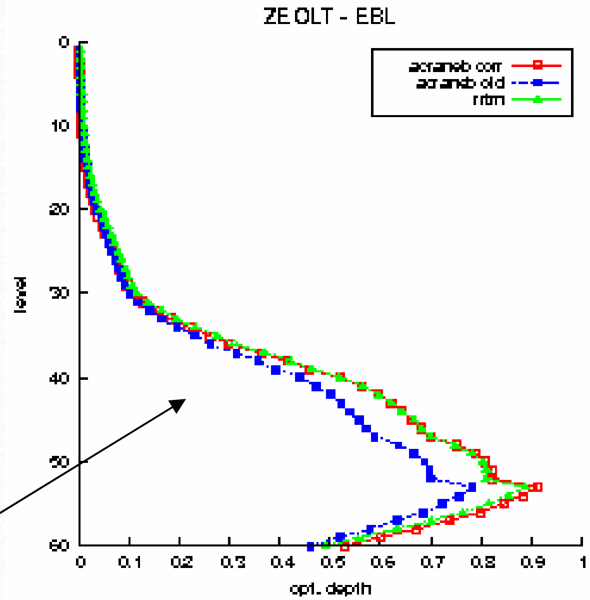


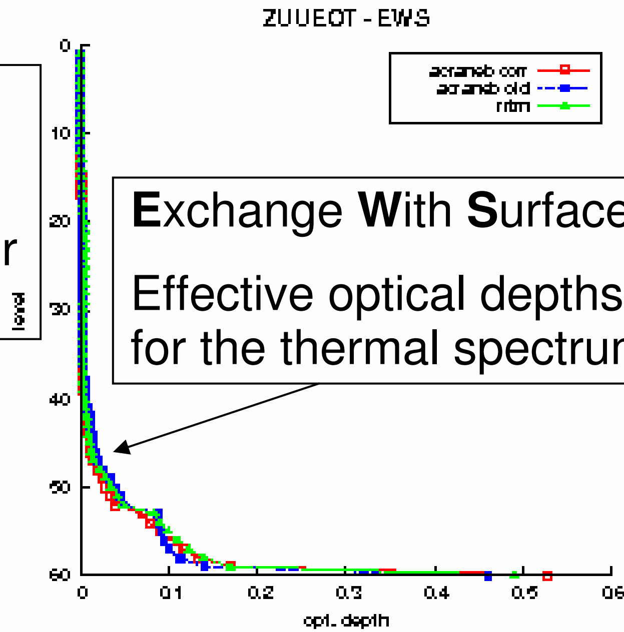
Scatter diagram for EBL fluxes

Path to better transmission functions



Bad sampling of πB with 1 interval (vs. 140)





Cooling **T**o **S**pace

Effective optical depths for the thermal spectrum

Exchange **B**etween (adjacent) **L**ayers

Effective optical depths for the thermal spectrum

Exchange **W**ith **S**urface

Effective optical depths for the thermal spectrum

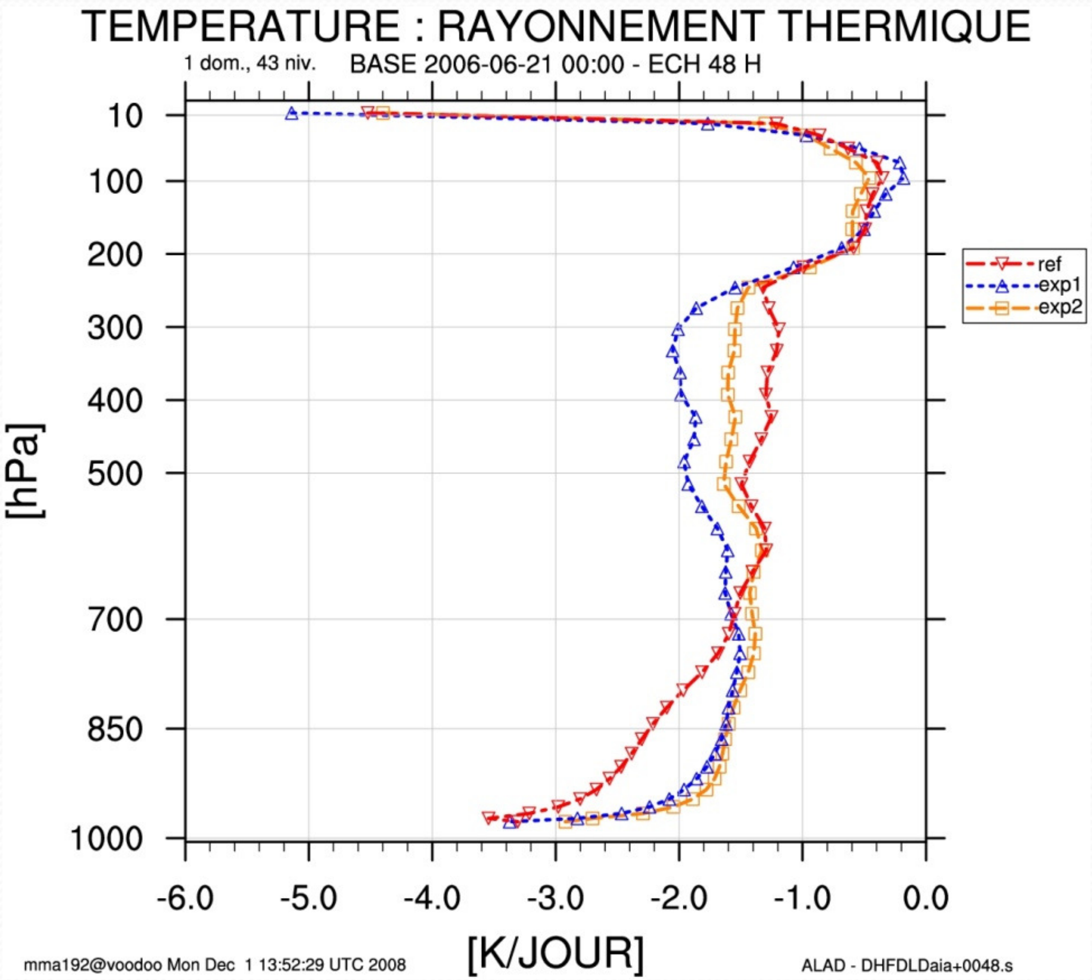
RRTM (reference)

Old ACRANEB

New ACRANEB

Improvement due to a better fit and to some spectral overlap specific accounting

DDH Inter-comparison with RRTM



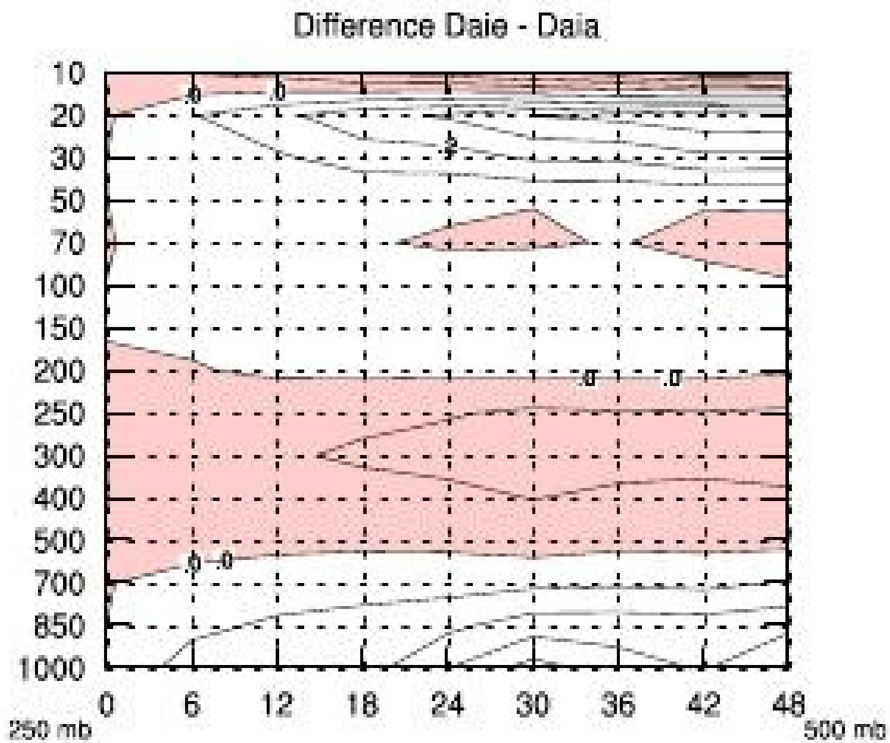
red – reference fits

blue – RRTM

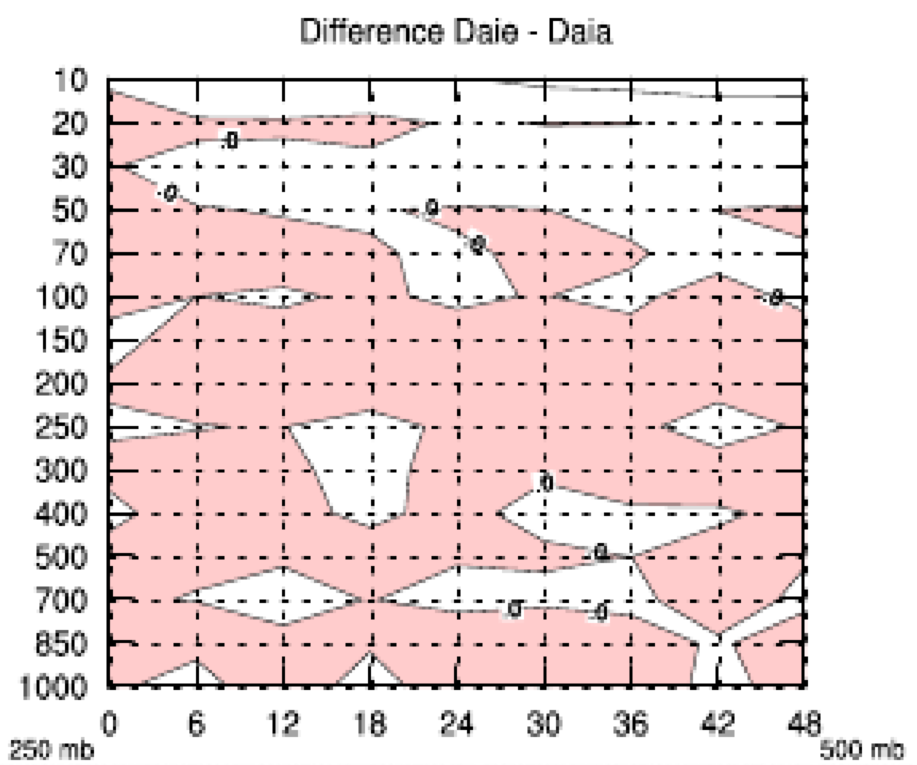
yellow – new fits

Verification of scores

Period 20080501…20080510



bias



STDE

Conclusion

- After refining transmission functions and applying correction for composite of gases we obtained results not far from the ones of RRTM
- One can see that there is room for a compromise between 1 and 140 spectral intervals!

Plans for the future

Plans for the future

- Refit the NER 'α' statistical coefficients with the new transmission functions (DONE)
- also review the solar gaseous transmission functions
- introduce climatology for aerosols' optical properties (DONE)
- development of a time intermittent scheme:
  - principle of constant gaseous opt. depths within ***N*** integration time steps
  - clear-sky fluxes at the beginning of each updating period are exact
  - interaction with clouds can be recomputed in every time step (without excessive CPU burden)