# New gaseous transmissions in ACRANEB

(presented by J. Mašek)

ALARO-1 Brainstorming

Prague, 6.–7.3.2013

# Introduction

- in ALARO-1 Working Days (Ljubljana, June 2012) it seemed that the only remaining problem concerns $H_2O$ e-type continuum
- development of single column versions for both SPLIDACO reference and ACRANEB2 scheme enabled extensive testing and comparison with published results for ICRCCM benchmark cases
- it showed that there are still far more problems in thermal band, some of them being fundamental
- ICRCCM reference in solar band is missing, still the situation is simpler here in the absence of clouds

# Problems (• – mostly cured, ◦ – to be cured)

◦ fitting reference (thermal $H_2O$ and its e-type continuum, $CO_2$+ composition, solar $O_3$)

• double temperature dependency of broadband thermal transmissions

• accuracy of individual gaseous fits

• parameterization of non-random gaseous overlaps (sufficiency of pair overlaps, accuracy)

• broadband Voigt treatment

◦ NER bracketing technique and statistical model

◦ issues to be addressed before publication (spectral overlap between gases and clouds, reliable fitting reference for gases, comparisons with clouds and aerosols present)

# General remarks concerning presented results

- used radiative transfer models (from GFDL and GLA line by line models we have only publicly available results):

  ACRANEB – old ALADIN/ALARO radiation scheme (currently operational)
  ACRANEB2 – new ALADIN/ALARO radiation scheme
  SPLIDACO – narrowband reference based on emissivity type computation (thermal band only)
  ACRANEB2/SPLIDACO – narrowband reference based on NER scheme in thermal band
  GFDL – LBL model of NOAA Geophysical Fluid Dynamics Laboratory
  GLA – LBL model of NASA Goddard Laboratory for Atmospheres

- all ACRANEB, ACRANEB2 and ACRANEB2/SPLIDACO thermal computations are done in LRAUTOEV mode, i.e. without using statistical model, evaluating transmissions between each pair of levels

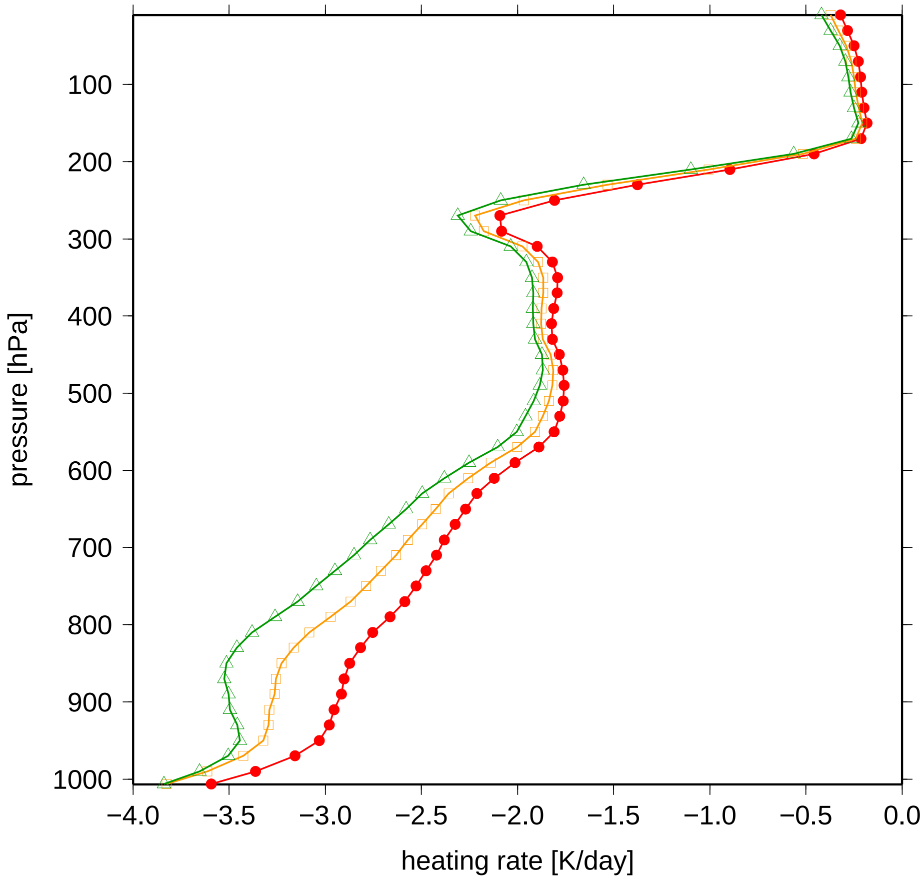
- fixed $CO_2$+ composition used in SPLIDACO inputs (corresponds to atmosphere of early 1990s):

  $CO_2$ . . . 353.200 ppmv
  $N_2O$ . . . 0.310 ppmv
  CO . . . 0.120 ppmv
  $CH_4$ . . . 1.725 ppmv
  $O_2$ . . . 209480.600 ppmv

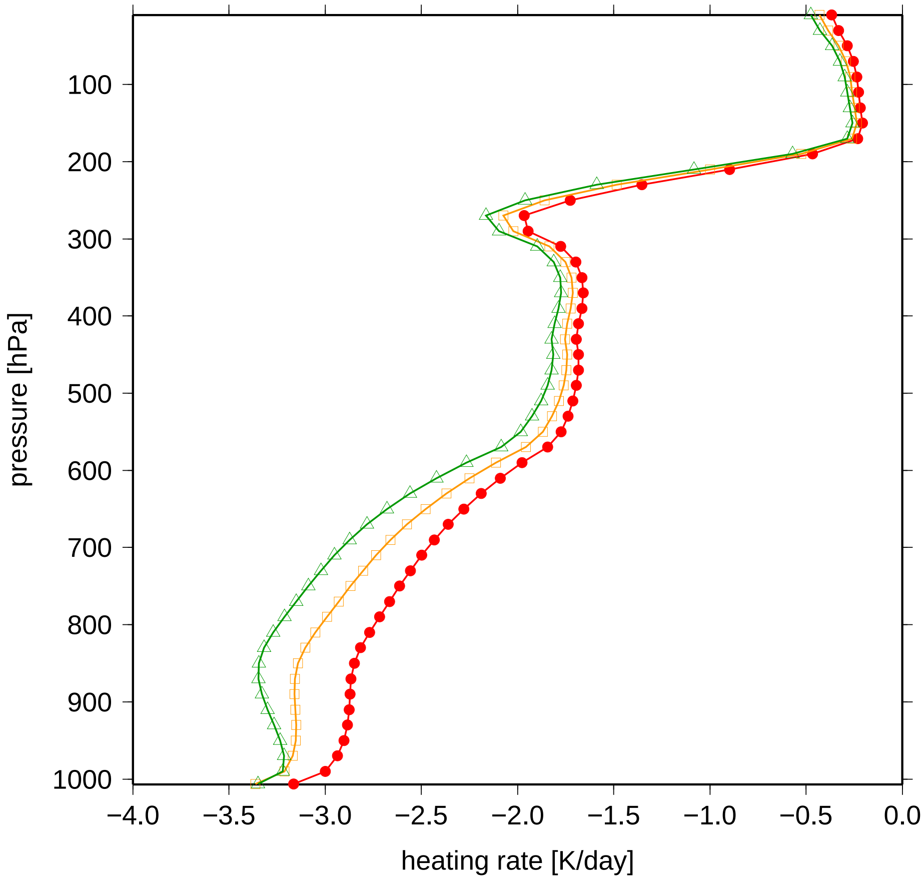
# Problem with fitting reference – thermal $H_2O$

mid-latitude summer case, $H_2O$ only (including e-type continuum)

SPLIDACO narrowband reference



GFDL line by line model

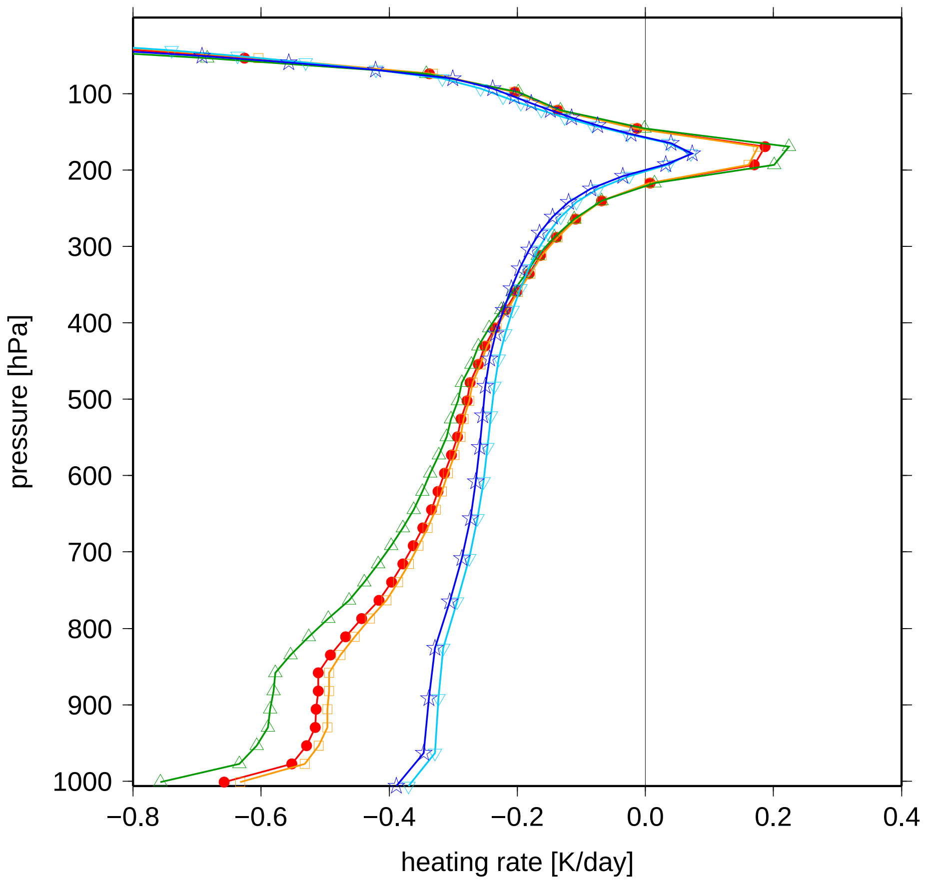


0.75 x $H_2O$ concentration
1.00 x $H_2O$ concentration
1.25 x $H_2O$ concentration

# Problem with fitting reference – thermal $CO_2$+

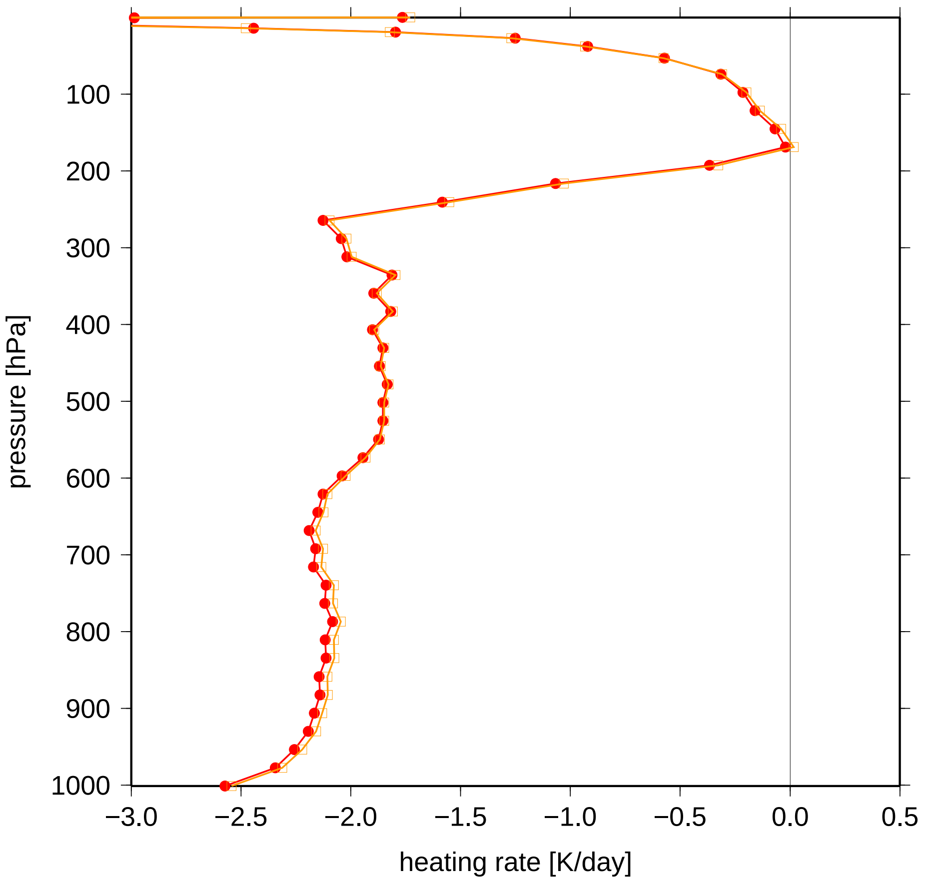
## mid-latitude summer case

impact of doubling $CO_2$, respectively $CO_2$+
SPLIDACO versus GFDL, $H_2O$ and $O_3$ absent



SPLIDACO, $CO_2$+ with 353.2 ppmv $CO_2$
SPLIDACO, $CO_2$+ scaled to 300 ppmv $CO_2$
SPLIDACO, $CO_2$+ scaled to 600 ppmv $CO_2$
GFDL, 300 ppmv $CO_2$
GFDL, 600 ppmv $CO_2$

impact of adding $CH_4$ and $N_2O$
GLA, $H_2O$ and $O_3$ present



300 ppmv $CO_2$
300 ppmv $CO_2$, 1.75 ppmv $CH_4$, 0.28 ppmv $N_2O$

# Double temperature dependency of broadband thermal transmissions

- in thermal band, broadband transmission $\tau$ should be function of absorber amount $u$, pressure $p$ and **two** temperatures: temperature of transmitting medium $T$ and temperature of emitting body $T_e$ (entering via Planck weights)

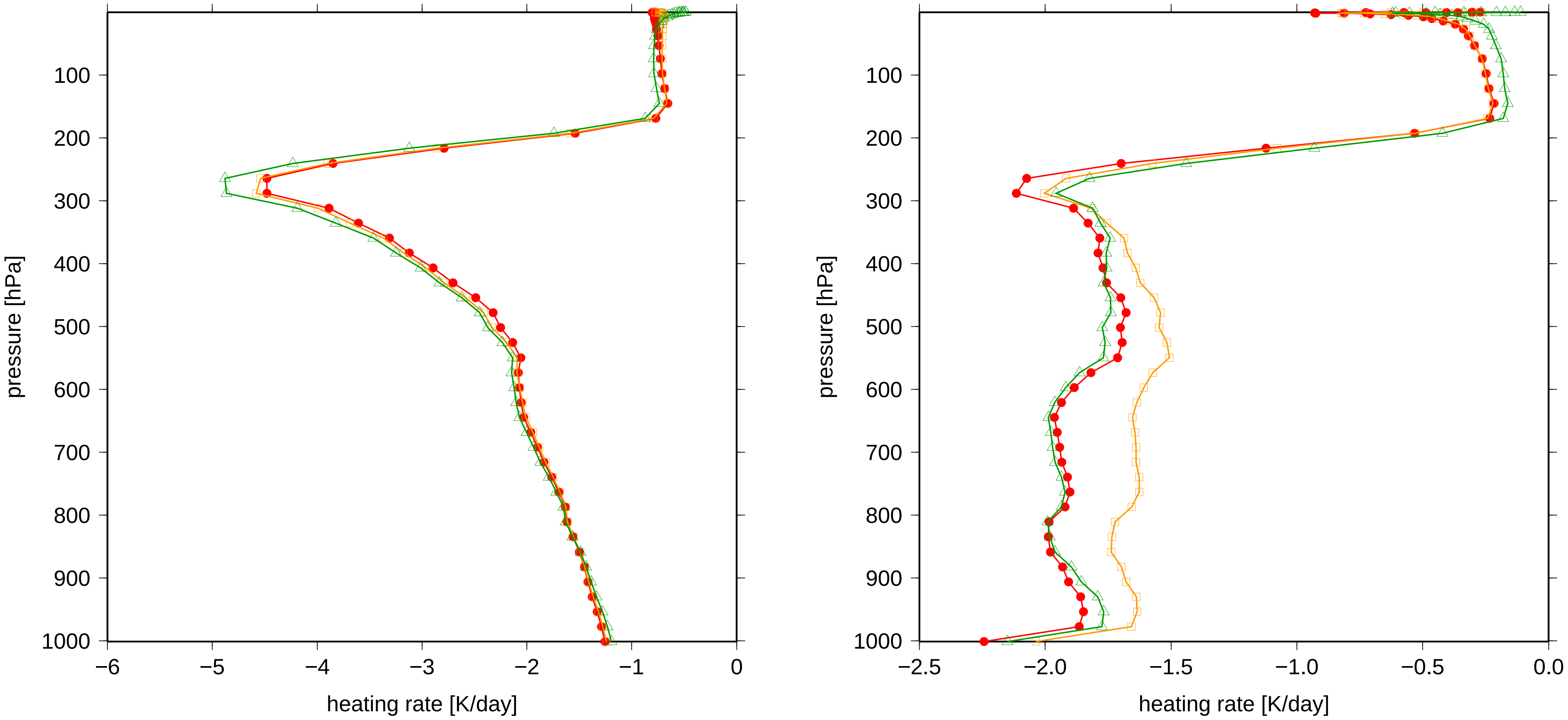
- both original SPLIDACO reference and ACRANEB scheme used assumption $T_e = T$, which is unphysical and causes significant error

- implementation of $T_e \neq T$ is straightforward in emissivity type computation, but much more tricky in NER scheme

- it can be made tractable by linearizing Planck **weights** with respect to temperature $T_e$ and using two sets of spectrally averaged quantities – one with weights proportional to $B_\nu(T_0)$, another to $\mathrm{d}B_\nu/\mathrm{d}T(T_0)$

# Error introduced assuming $T_e = T$

mid-latitude summer case, $H_2O$ only (excluding e-type continuum)


isothermal profile ($T = 281.7\,\text{K}$)

non-isothermal profile

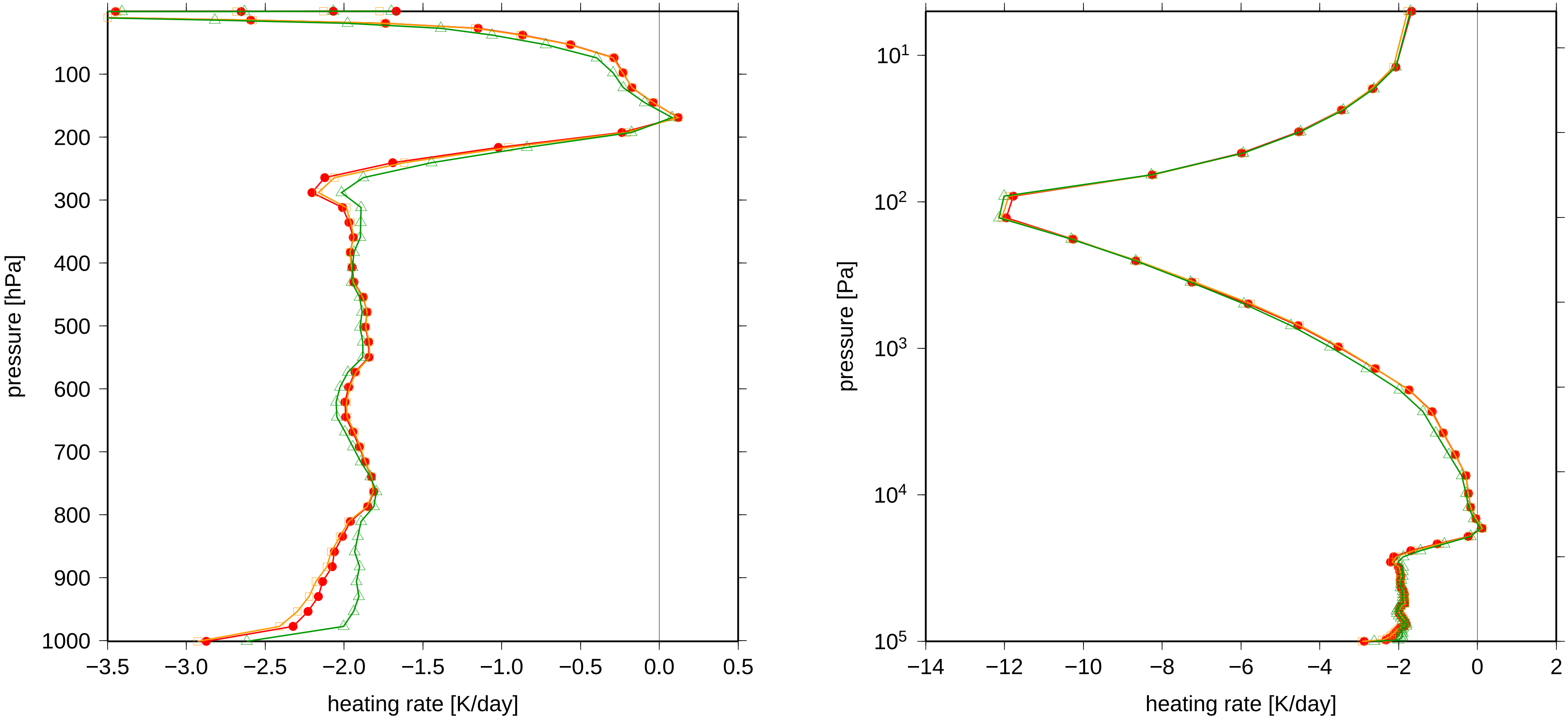
SPLIDACO with true $T_e$ (correct)

ACRANEB2 with $T_e = T$ (unphysical)

ACRANEB2 with $T_e = 255.8\,\text{K}$ (still unphysical)

# Impact of linearization of Planck weights with respect to temperature

mid-latitude summer case, all gases, SPLIDACO



vertical axis linear in pressure

vertical axis logarithmic in pressure

true Planck weights

Planck weights linearized in $T_e$

Planck weights with constant $T_e = 255.8\,\mathrm{K}$

# Accuracy of individual gaseous fits

- new broadband optical depths are based on Malkmus formula with additional 2-parametric rescaling taking into account secondary saturation (6 fitting parameters per gas and band)

- accuracy of such fits is not sufficient for individual gases, secondary corrective fits had to be introduced (27 additional fitting parameters per gas and band)

- since corrective fits are both pressure and temperature dependent, for nonhomogeneous optical paths they require ad hoc computation of $p_{\text{avg}}$ and $T_{\text{avg}}$

- such averaging is not fully consitent with Curtis-Godson approximation, but apparently it works with absorber amount weighted $p_{\text{avg}}$ and $T_{\text{avg}}$

# Parameterization of non-random gaseous overlaps

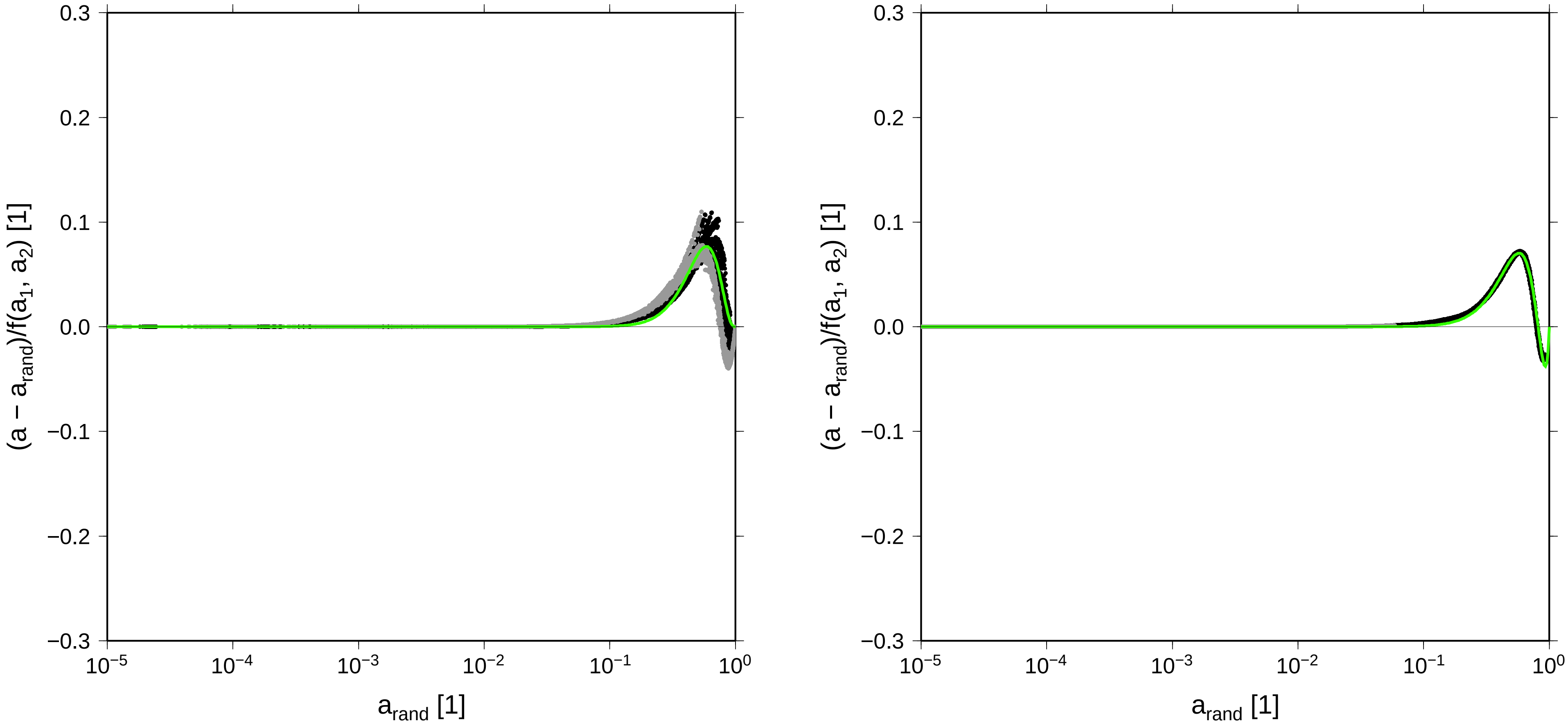
- in thermal band, gaseous overlaps cannot be ignored
- proposed parameterization relied on dominant role of pair overlaps
- however, this assumption turned to be false when $H_2O$ e-type continuum was treated as separate pseudo-gas
- inclusion of e-type continuum into $H_2O$ transmission (thus making it $q_\mathrm{v}$ dependent) solved the problem
- still, accuracy of parameterized pair overlaps was insufficient when fitted on sample of homogeneous optical paths (long homogeneous paths never occur in atmosphere)
- refitting on sample of nonhomogeneous optical paths extracted from 5 ICRCCM cases with revised fitting function helped

# Homogeneous versus nonhomogeneous overlap fit

## ($H_2O$, $CO_2$+) overlap in absorptivity space, thermal band

sample of homogeneous optical paths,
fitting parameters $A$, $B$, $C$ ($D = 0$)

sample of nonhomogeneous optical paths,
fitting parameters $A$, $B$, $C$, $D$ ($D > 1$)



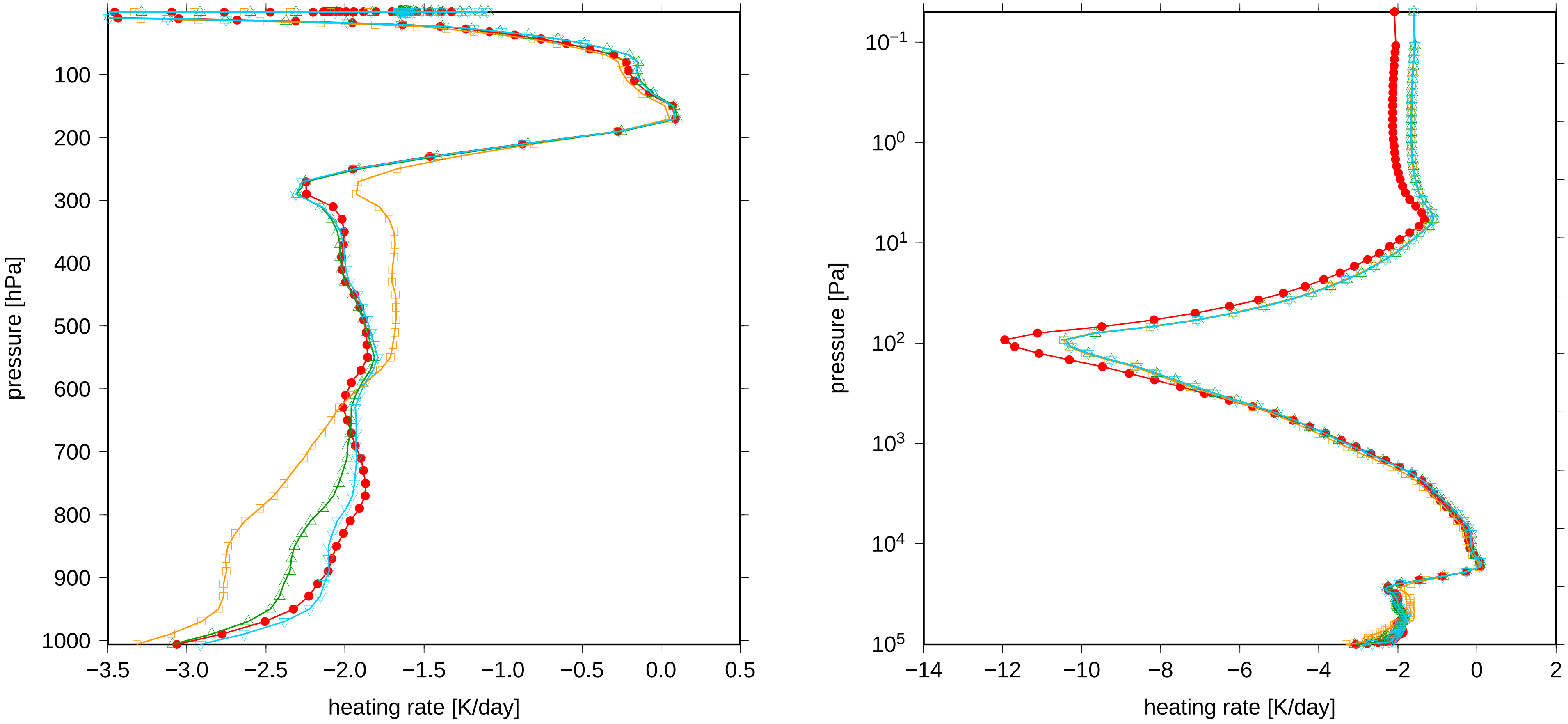
$a \equiv 1 - \tau$ – absorptivity of mixture $\qquad a_1, a_2$ – absorptivities of individual gases

$$a = a_{\rm rand} + f(a_1, a_2) A (1 - a_{\rm rand})^B a_{\rm rand}{}^C (1 - D a_{\rm rand})$$ – fitting formula

$$a_{\rm rand} = a_1 + a_2 - a_1 a_2 \qquad f(a_1, a_2) = \frac{2 a_1 a_2}{\varepsilon + a_1{}^2 + a_2{}^2} \qquad \varepsilon = 10^{-20}$$

# Impact of nonhomogeneous overlap fit

## mid-latitude summer case, all gases, thermal band



vertical axis linear in pressure

vertical axis logarithmic in pressure

ACRANEB2/SPLIDACO reference
ACRANEB2, no overlaps
ACRANEB2, homogeneous overlap fit
ACRANEB2, nonhomogeneous overlap fit

# Broadband Voigt treatment

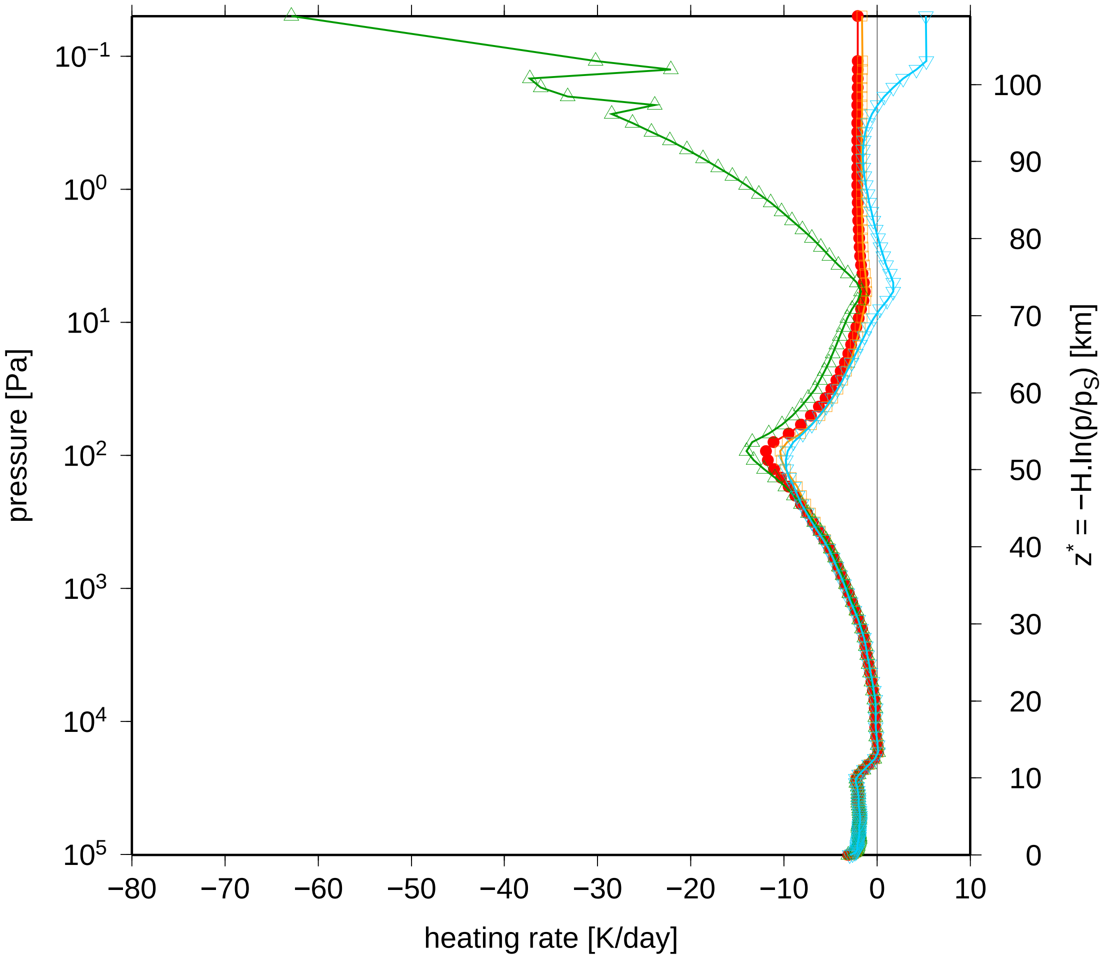
- effect of Voigt line shape is negligible in troposphere, but absolutely dominant above ∼70 km altitude (not yet interesting for LAM with 87 levels, but important for global models)

- treatment of Voigt line shape works well in narrowband case, but failed completely in broadband

- miraculous cure was refitting $CO_2$+ with restricted range of absorber amount (in thermal band $u_{\mathrm{max}} = 1000\,\mathrm{Pa}$ was used originally, while 100 Pa column is fully sufficient for Earth's atmosphere)

# Impact of Voigt line shape

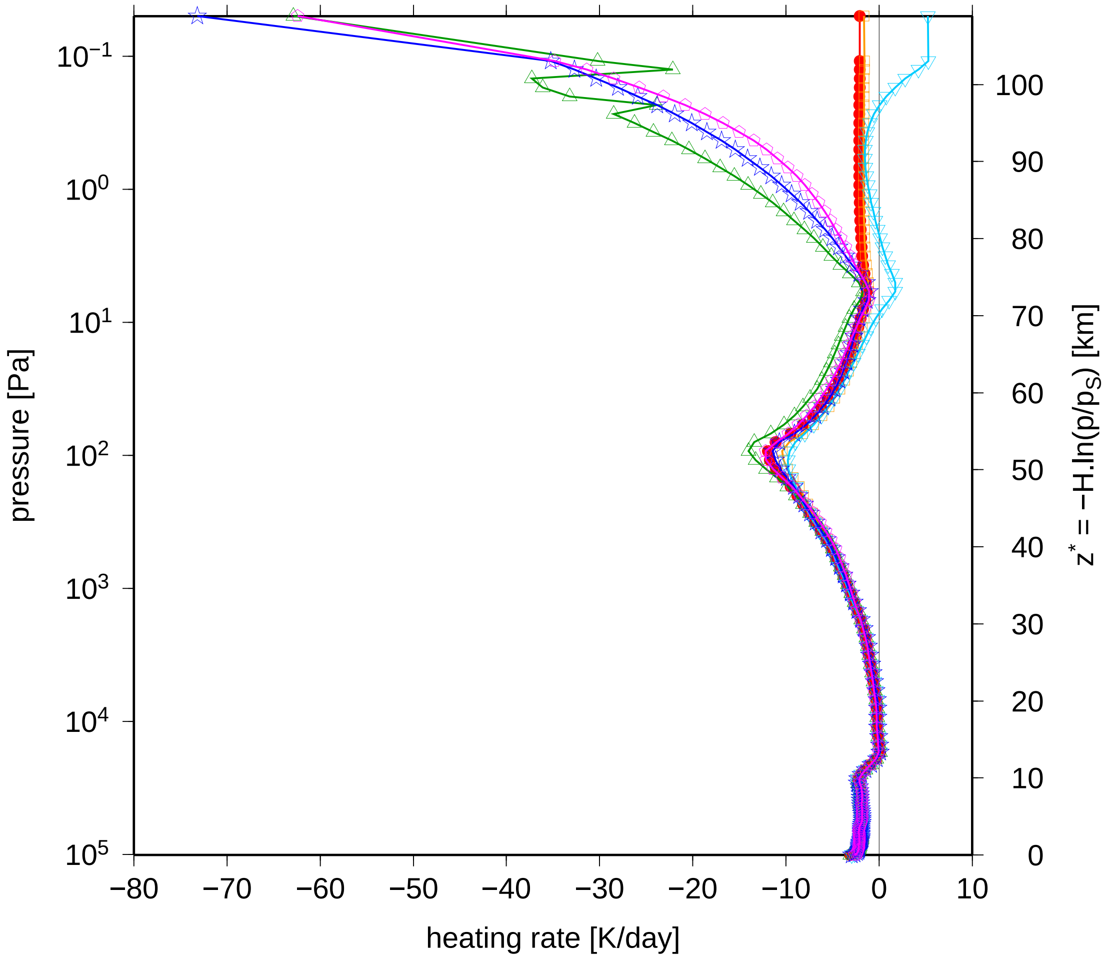
mid-latitude summer case, all gases, thermal band



ACRANEB2/SPLIDACO reference, Lorentz line shape
ACRANEB2, Lorentz line shape
ACRANEB2/SPLIDACO reference, Voigt line shape
ACRANEB2, Voigt line shape

# Impact of Voigt line shape

mid-latitude summer case, all gases, thermal band



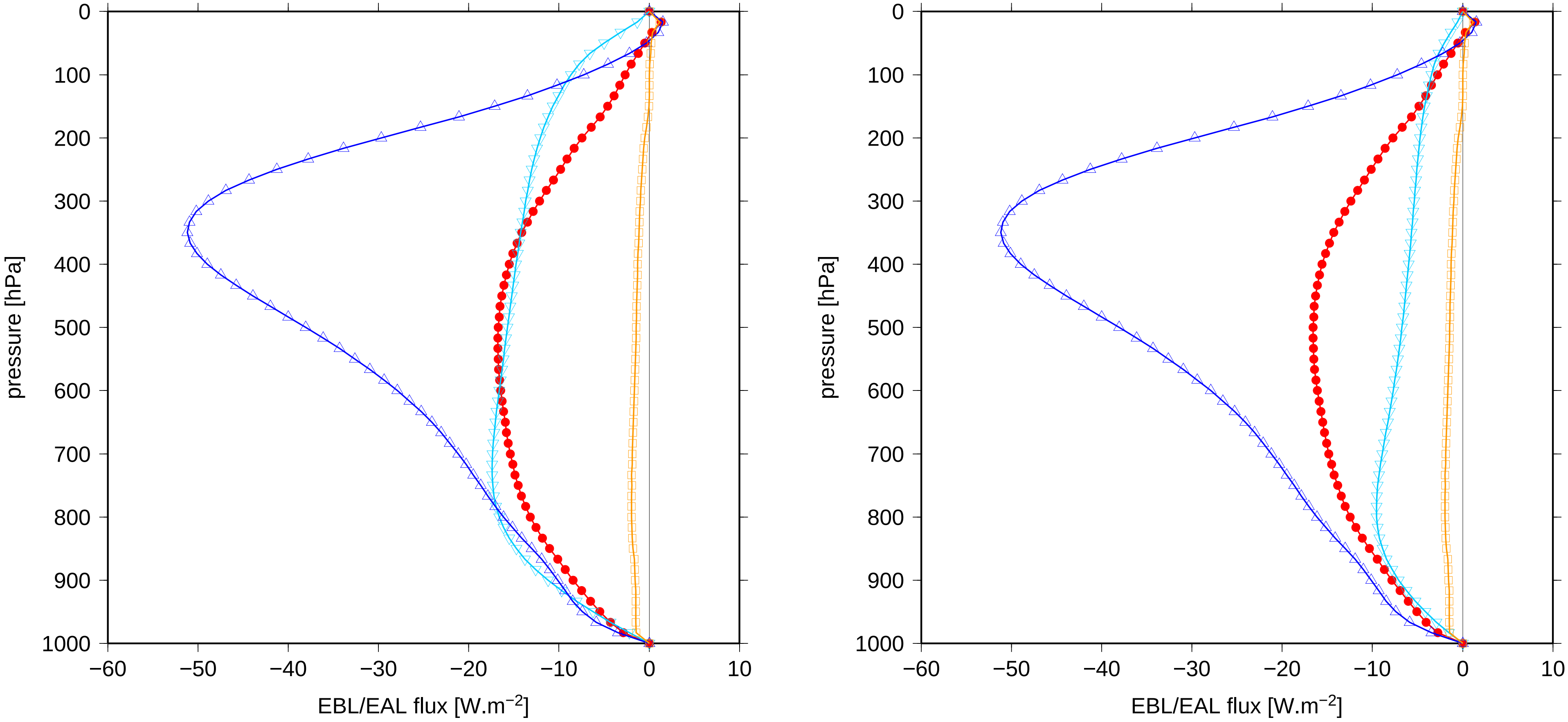
ACRANEB2/SPLIDACO reference, Lorentz line shape
ACRANEB2, Lorentz line shape
ACRANEB2/SPLIDACO reference, Voigt line shape
ACRANEB2, Voigt line shape
ACRANEB2, Voigt line shape, refitted $CO_2$+
GFDL, but with only 300 ppmv $CO_2$

# NER bracketing technique and statistical model

- when gaseous overlaps are present, they send true EBL flux out of bracket given by using distant and local optical depths $\delta$
- guilty overlap pair is ($H_2O$, $O_3$), having strong impact on min EBL flux but fortunately negligible impact on true EBL flux $\Rightarrow$ it can be switched off without much harm
- on the other hand, max EBL flux strongly depends on vertical resolution and statistical fit will have to take this into account

# True EBL flux out of bracket

mid-latitude summer case, all gases, ACRANEB2



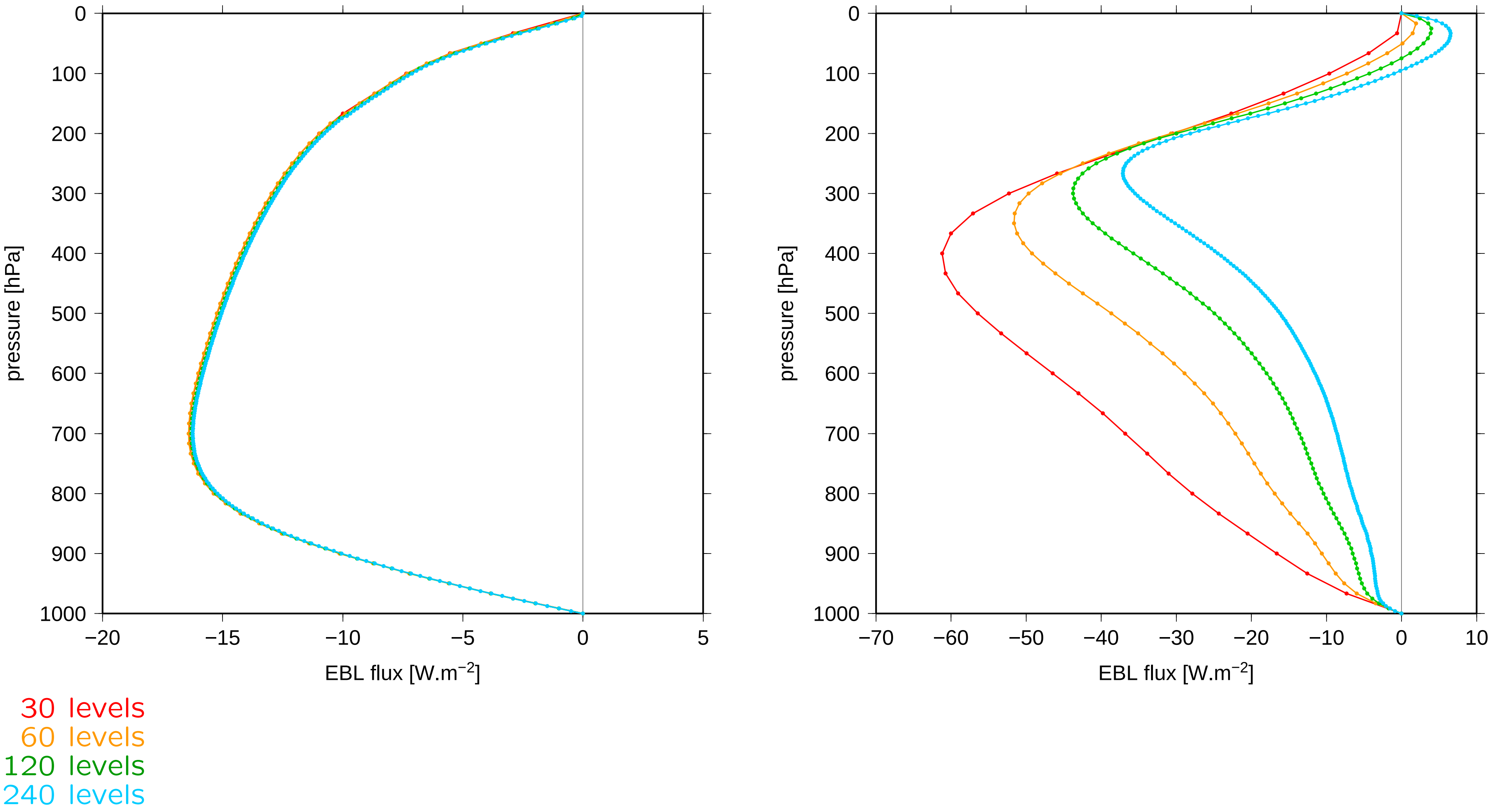
all overlaps on

($H_2O$, $O_3$) overlap off

min EBL flux (distant $\delta$)
max EBL flux (local $\delta$)
true EBL flux
EAL flux

# Dependency of min/max EBL fluxes on vertical resolution

mid-latitude summer case, all gases, ACRANEB2/SPLIDACO

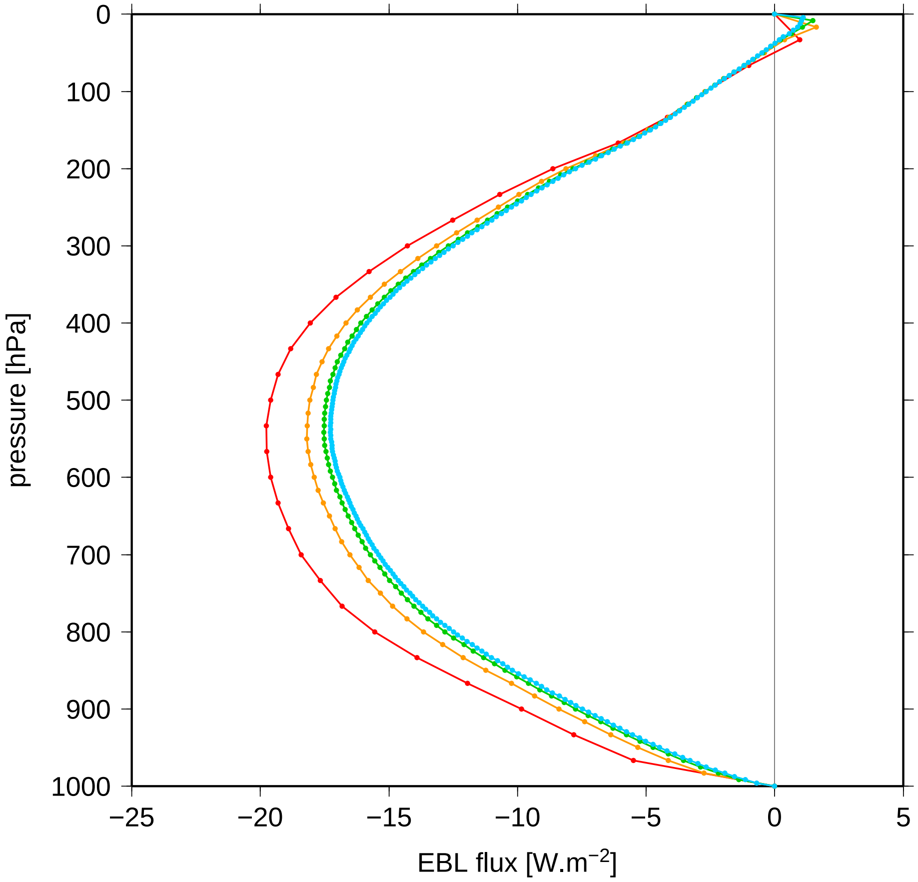


min EBL flux (distant $\delta$)

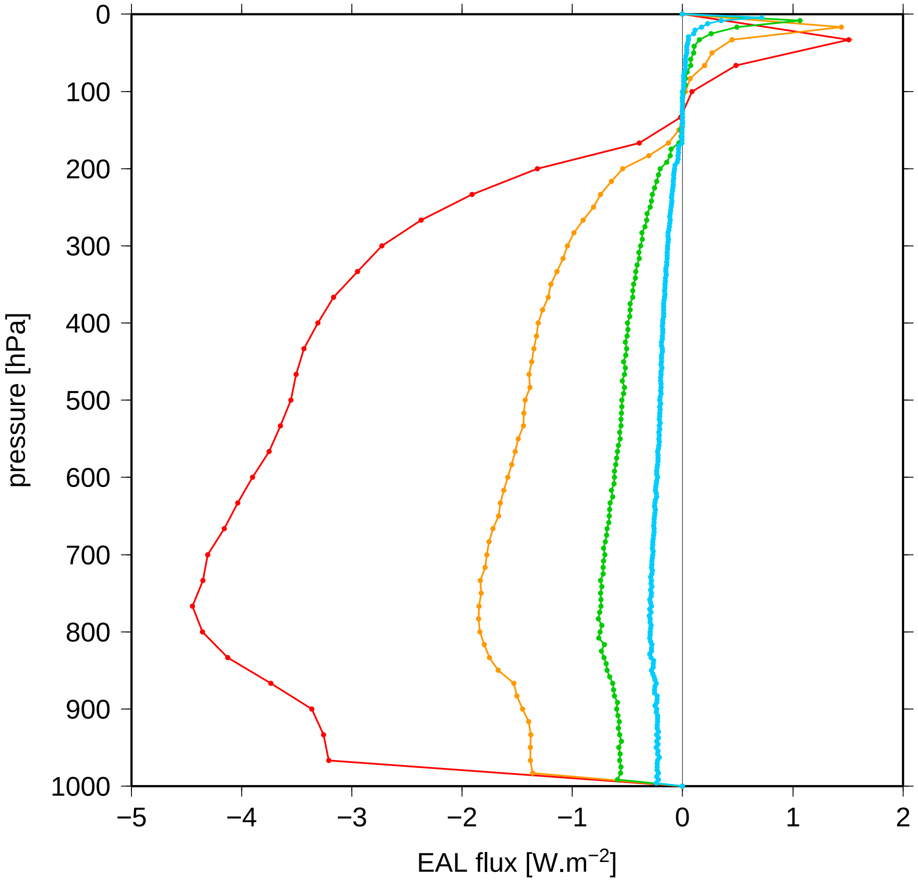
max EBL flux (local $\delta$)

# Dependency of true EBL/EAL fluxes on vertical resolution

mid-latitude summer case, all gases, ACRANEB2/SPLIDACO



true EBL flux



true EAL flux

30 levels
60 levels
120 levels
240 levels

# Current method

- gaseous overlaps fitted against SPLIDACO reference, using set of homogeneous optical paths (15 pressures, 5 temperatures, 33 absorber amounts)
- $H_2O$ e-type continuum imported from MT_CKD model developed by AER RT group
- gaseous overlaps fitted using nonhomogeneous optical paths extracted from 5 ICRCCM cases
- transmission part including LRAUTOEV branch completely rewritten
- NER part unchanged thanks to suitably redefined inputs $\Rightarrow$ we can fully benefit from existing implementation of LRPROX, LRTDL, LRSTAB and LRTPP options
- still there are expected small changes in statistical model

# Linearization of Planck weights with respect to temperature

$$\int_0^\infty \pi B_\nu(T)\,\mathrm{d}\nu = \sigma T^4 \quad \Rightarrow \quad \int_0^\infty \pi \frac{\mathrm{d}B_\nu}{\mathrm{d}T}(T)\,\mathrm{d}\nu = 4\sigma T^3$$

$$\tilde{w}_\nu \equiv \frac{1}{\sigma T_0^4} \cdot \pi B_\nu(T_0) \qquad \tilde{\tilde{w}}_\nu \equiv \frac{1}{4\sigma T_0^3} \cdot \pi \frac{\mathrm{d}B_\nu}{\mathrm{d}T}(T_0)$$

$$w_\nu(T) = \frac{\pi B_\nu(T)}{\sigma T^4} \approx w_\nu(T_0) + \frac{\mathrm{d}w_\nu}{\mathrm{d}T}(T_0) \cdot (T - T_0) =$$

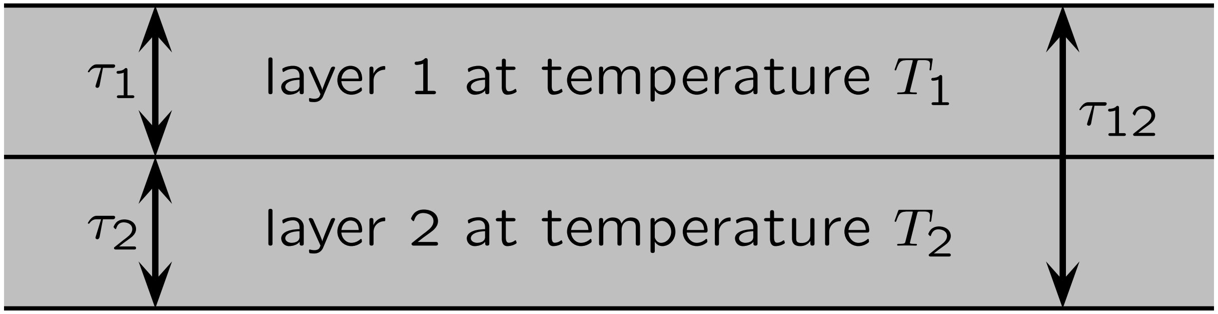
$$= \tilde{w}_\nu + 4\left(\frac{T}{T_0} - 1\right)(\tilde{\tilde{w}}_\nu - \tilde{w}_\nu)$$

$$\Downarrow$$

$$\overline{\tau}^T = \tilde{\tau} + 4\left(\frac{T}{T_0} - 1\right)(\tilde{\tilde{\tau}} - \tilde{\tau})$$

$\tilde{\tau}$, $\tilde{\tilde{\tau}}$ – broadband transmissions averaged with weights $\tilde{w}_\nu$, $\tilde{\tilde{w}}_\nu$

# Spectral averaging in NER exchanges (case of adjacent layers)



- original ACRANEB treatment (bar indicates spectral averaging using $T = T_e$ assumption combined with Curtis-Godson approximation):

$$E_{12} = (\sigma T_1^4 - \sigma T_2^4) \cdot \overline{1 - \tau_1 - \tau_2 + \tau_{12}} \equiv$$

$$\equiv (\sigma T_1^4 - \sigma T_2^4)\overline{\Delta\tau}$$

- physically correct treatment (bar indicates spectral averaging with given temperature $T_e$):

$$E_{12} = \sigma T_1^4 \cdot \overline{1 - \tau_1 - \tau_2 + \tau_{12}}^{T_1} - \sigma T_2^4 \cdot \overline{1 - \tau_1 - \tau_2 + \tau_{12}}^{T_2} \equiv$$

$$\equiv \sigma T_1^4 \overline{\Delta\tau}^{T_1} - \sigma T_2^4 \overline{\Delta\tau}^{T_2}$$

# Spectral averaging in NER exchanges (generally valid formula)

- original treatment can be made equivalent to the correct one by defining:

$$\overline{\Delta\tau}^{\text{true}} \equiv \frac{\sigma T_1^4 \overline{\Delta\tau}^{T_1} - \sigma T_2^4 \overline{\Delta\tau}^{T_2}}{\sigma T_1^4 - \sigma T_2^4}$$

- terms $\overline{\Delta\tau}^{T_1}$ and $\overline{\Delta\tau}^{T_2}$ can be expressed using $\tilde{w}_\nu$ and $\tilde{\tilde{w}}_\nu$ weighted quantities (linearization with respect to temperature)

- finally, exchange can be manipulated into form:

$$E_{12} = (\sigma T_1^4 - \sigma T_2^4)\overline{\Delta\tau}^{\text{true}}$$

$$\overline{\Delta\tau}^{\text{true}} = \Delta\tilde{\tau} + 4\left(\frac{T_1}{T_0} \cdot \frac{1 + x + x^2 + x^3 + x^4}{1 + x + x^2 + x^3} - 1\right)\left(\Delta\tilde{\tilde{\tau}} - \Delta\tilde{\tau}\right)$$

$$x \equiv \frac{T_2}{T_1} \qquad T_0 \text{ -- linearization temperature (255.8 K)}$$

# Using LRTDL option

- when LRPROX is used (adjacent exchanges computed exactly), option LRTDL relaxes simplifying assumption $\overline{\tau_{12}} = \overline{\tau_1} \cdot \overline{\tau_2}$

- in original ACRANEB code this was implemented using corrective ratio:

$$\text{PGRPROX} = \frac{\overline{\tau_{12}}}{\overline{\tau_1} \cdot \overline{\tau_2}}$$

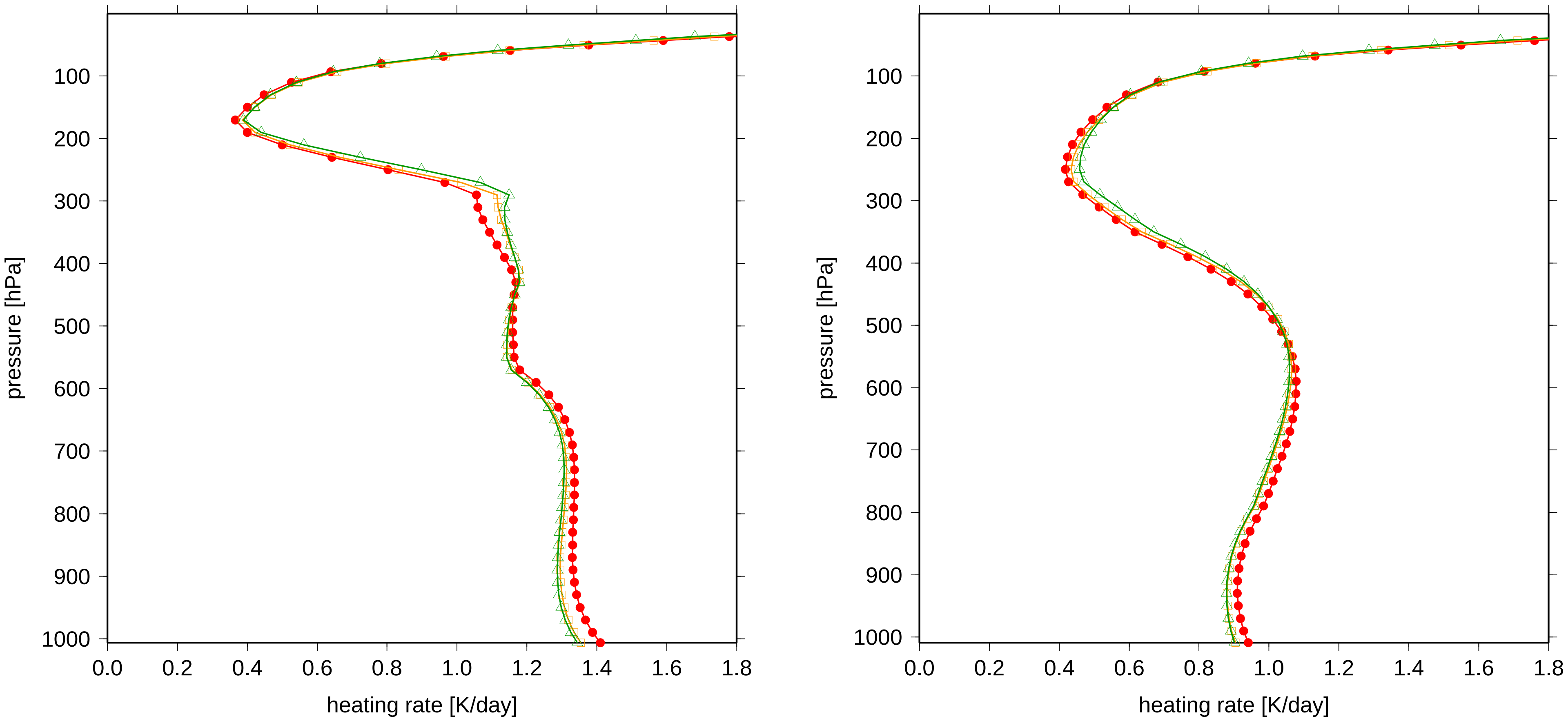
- in the new scheme, EAL term must accomodate $T_e \neq T$ assumption

- correct EAL flux is obtained with redefined PGRPROX:

$$\text{PGRPROX} = \frac{\overline{\tau_{12} - \tau_1 - \tau_2}^{\text{true}} + \overline{\tau_1}^{T_1} + \overline{\tau_2}^{T_2}}{\overline{\tau_1}^{T_1} \cdot \overline{\tau_2}^{T_2}}$$

# Results obtained with current method – solar band

## all gases present



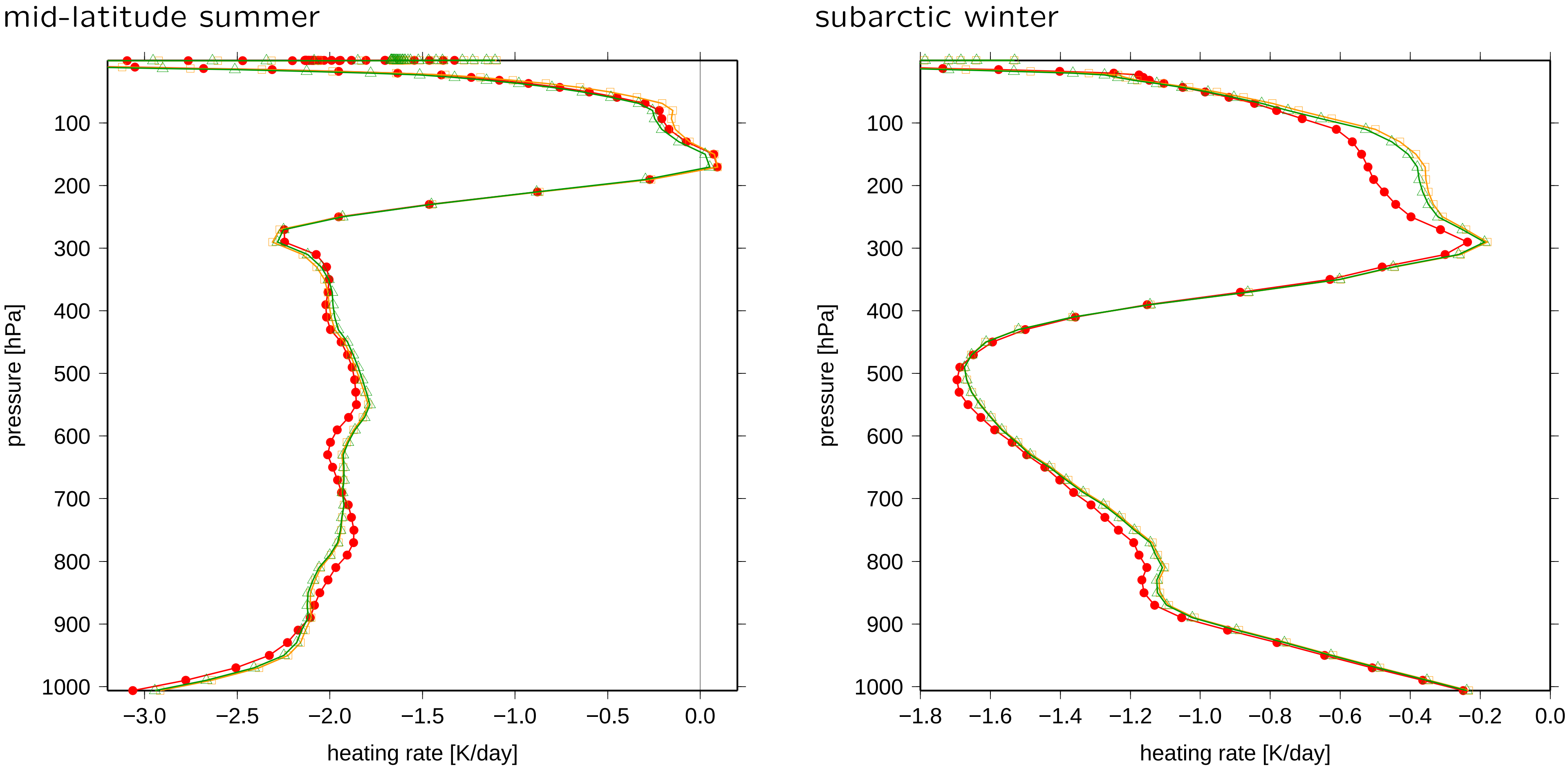
mid-latitude summer

mid-latitude winter

ACRANEB2/SPLIDACO reference
ACRANEB2 with all overlaps
ACRANEB2 without overlaps

# Results obtained with current method – thermal band

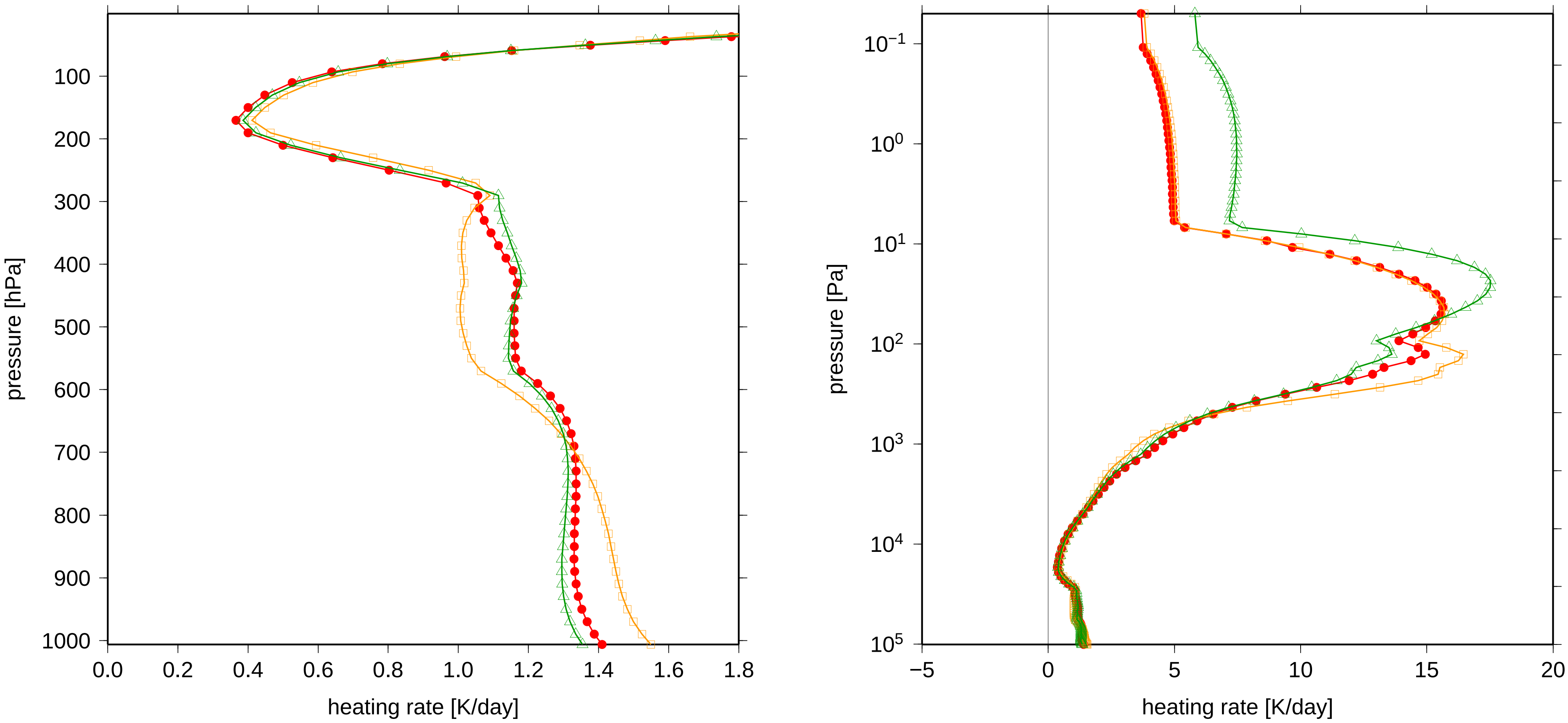
all gases present



ACRANEB2/SPLIDACO reference
ACRANEB2 with all overlaps
ACRANEB2 without ($H_2O$, $O_3$) overlap

# Comparison with old ACRANEB – solar band

## mid-latitude summer, all gases present

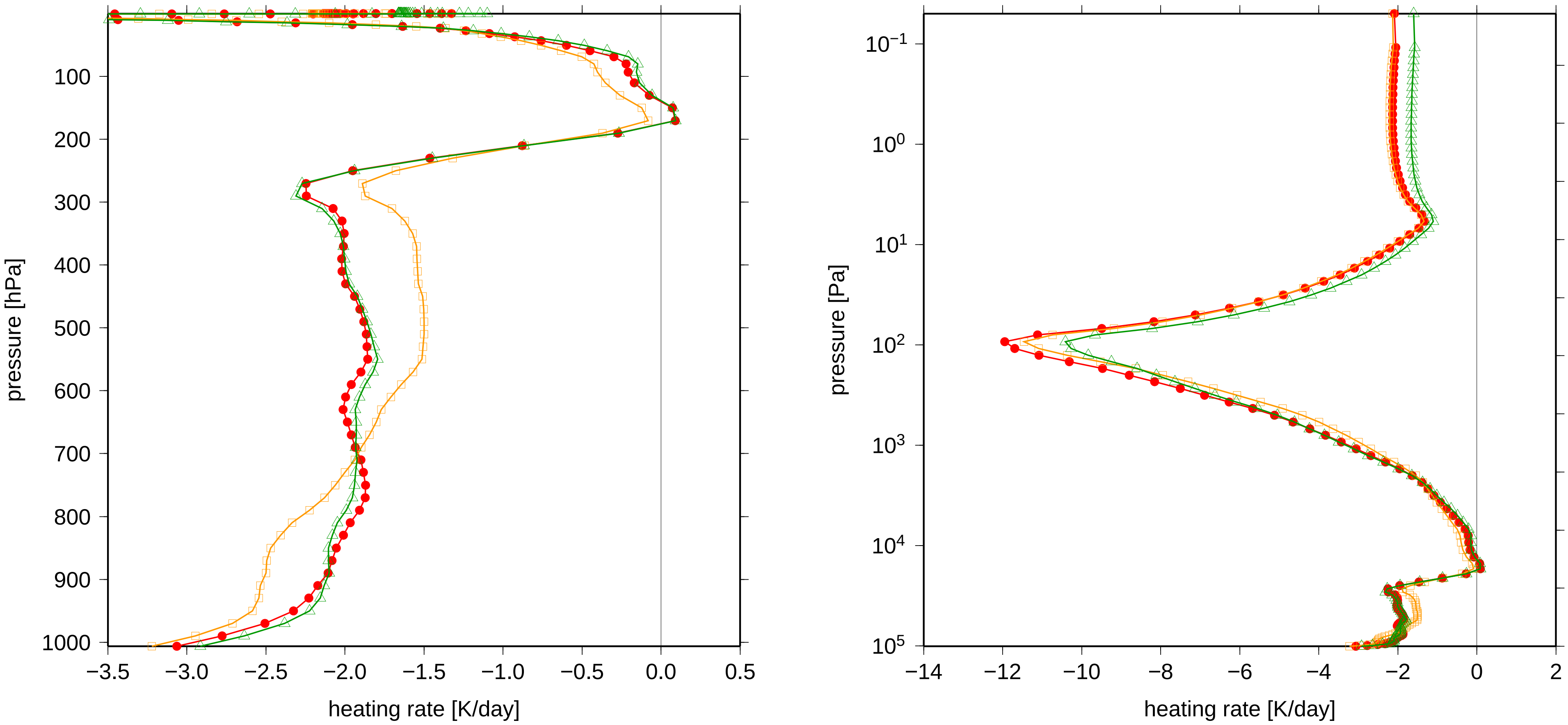

vertical axis linear in pressure

vertical axis logarithmic in pressure

ACRANEB2/SPLIDACO reference
ACRANEB
ACRANEB2

# Comparison with old ACRANEB – thermal band

## mid-latitude summer, all gases present



vertical axis linear in pressure

vertical axis logarithmic in pressure

ACRANEB2/SPLIDACO reference
ACRANEB
ACRANEB2

# Remaining issues
# (not necessarily in chronological order)

- improvement of thermal $O_3$ fit
- retuning of statistical model, incorporating dependency on vertical resolution
- validation in 3D model, comparison with RRTM
- going to more reliable fitting reference (LBLRTM?) – current fits reproduce SPLIDACO reference with error $\sim$0.1 K/day, but error of reference itself is several times higher
- addressing problem of spectral overlap between gases and clouds
- publication (probably in two steps, but what if we are not lucky with gas-cloud overlap?)

# Priorities (based on afternoon discussion 7.3.2013)

- improve thermal $O_3$ fit so that statistical model is not contaminated by error seen in subarctic winter case

- put ACRANEB2 code into 3D model, perform basic validation, evaluate and possibly optimize CPU cost

- perform clearsky comparisons against RRTM

- run stretched ARPEGE with ALARO physics and 87 levels to get EBL fluxes for retuning statistical model (short integration adapting to new vertical resolution followed by single timestep integration in clearsky mode; 4 cases covering all seasons)

- retune statistical model with 87 levels (reformulate it if needed)

- test performance of statistical model with various vertical resolutions, find some simple solution if dependency on vertical resolution turns to be significant

# Priorities (continued)

- baseline version of ACRANEB2 should be delivered in June 2013
- publication strategy should be agreed, there are still some problems to be addressed:
    - insufficient accuracy of SPLIDACO fitting reference
    - unknown importance of gas-cloud overlaps
    - need for reliable reference including clouds and aerosols

# Additional issues (possibly contributed by UGent students)

- solar intermittency
  - target is to parameterize dependency of solar transmissions on sun elevation
  - within intermittency time interval, solar transmissions would be computed accurately for lowest sun elevation and interpolated for higher elevations (shorter optical paths)
  - only minor CPU savings are expected
- recreating narrowband SPLIDACO inputs from more up to date spectroscopic dataset
  - target is to obtain more reliable fitting reference and allow for updates of $CO_2$+ composition
  - mastering of some publicly available line by line model will be necessary