Progress in radiation since the last ALARO-1 Working Days

J. Mašek
J.-F. Geleyn
R. Brožková
O. Giot
H. O. Achom
P. Kuma

Introduction

- on previous ALARO-1 Working Days (Ljubljana, June 2012) it seemed that the new gaseous transmissions are mostly done
- remaining challenges were unsatisfactory H_2O thermal transmissions plus some minor issues
- in the next months single column versions of ACRANEB and corresponding narrowband SPLIDACO reference were developed
- they revealed several fundamental problems, calling for revision of some basic assumptions
- solution of detected problems enabled creation of ACRANEB2 baseline version

Remaining work and problems (retro June 2012)

1) H_2O thermal transmissions do not work well in lower troposphere, giving too much cooling

   – it is not clear yet whether the problem is due to insufficient quality of the fits or some more fundamental reason (unreliable reference? reaching limits of broadband approach?)

   – empirical reduction of self continuum by factor 4 is not justified, but it gives hope to broadband approach

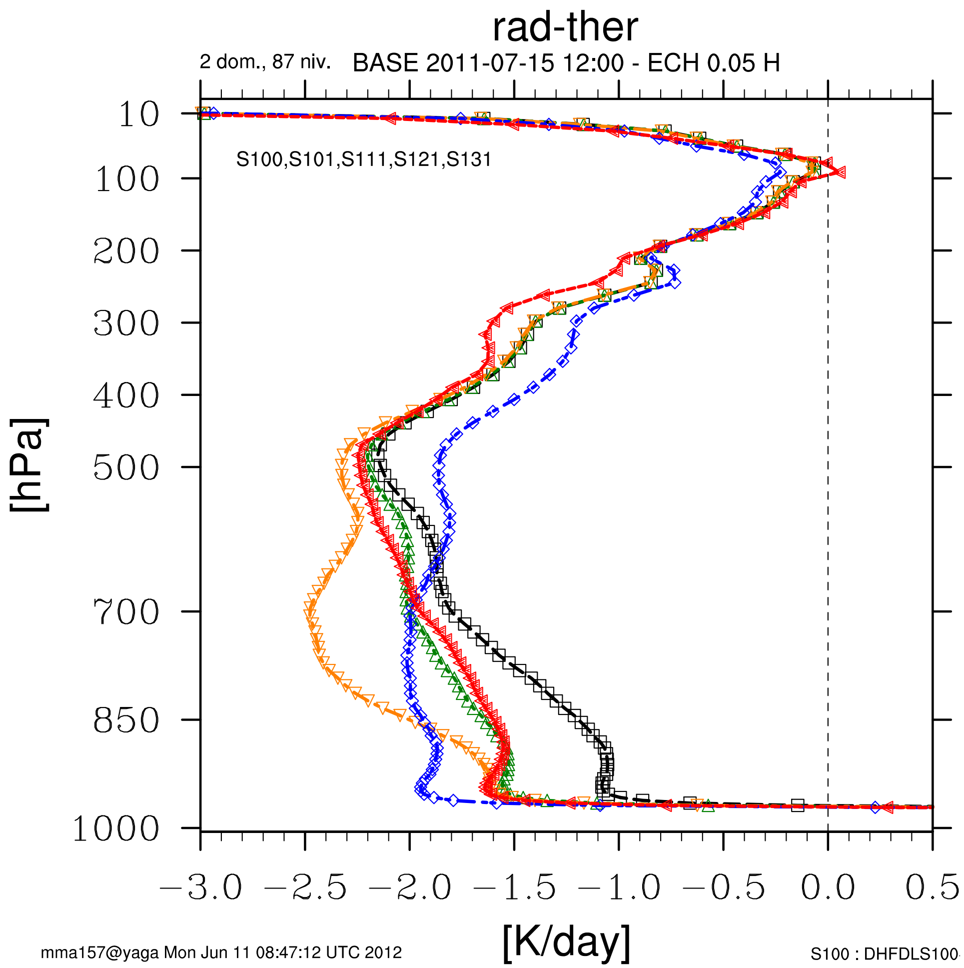
2) statistical model for NER method was not yet retuned for the new gaseous transmissions (no complications expected)

3) update of reference line by line computations is needed, probably using LBLRTM code (our CO_2+ composition is valid for 1992 but not 2012!)

So let's have a look how the above problems were solved one by one

Problem 1) – old illustrating result

DDH thermal heating rates, clearsky, exact exchanges, single timestep experiment



RRTM reference
old ACRANEB
new ACRANEB, e-type
new ACRANEB, e-type/4
new ACRANEB, e-type off

Problem 1) – three headed dragon

- this problem turned to be a difficult one, hiding three subproblems:

  1. broadband Malkmus fits with 2-parametric rescaling of optical depths are not accurate enough, even if $\log(\delta) - \log(u)$ plots gave feeling that they are

  2. Planck weights should depend on temperature of emitting body T_{e}, not on local temperature T

  3. when H_2O e-type continuum is treated as a separate H_4O_2 pseudo-gas, (H_2O, H_4O_2, CO_2+) triple overlap cannot be neglected

- success of e-type/4 "tuning" was just misleading coincidence (well, one is sometimes tempted to combine numerics with numerology)

- killing the dragon took six months and few times our fight seemed to be desperate

Problem 1.1) – need of secondary corrective fits

- original broadband gaseous optical depths were based on Malkmus formula with additional 2-parametric rescaling taking into account secondary saturation (8 fitting parameters per gas and band)

- accuracy of such fits was not sufficient for individual gases, secondary corrective fits had to be introduced (25 additional fitting parameters per gas and band)

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

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

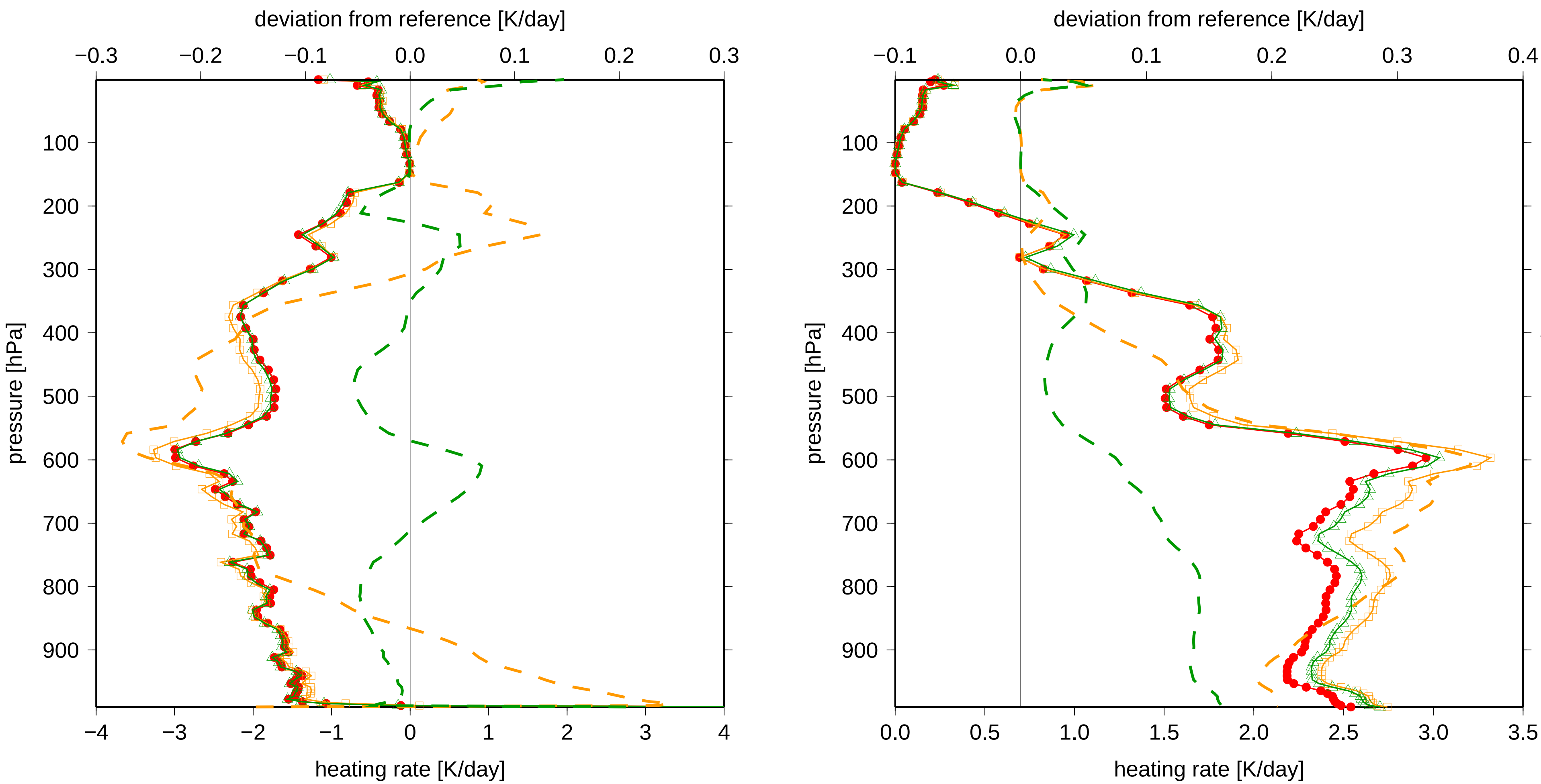
- biggest error reduction can be seen for solar O_3 and CO_2+ fits

Problem 1.1) – need of secondary corrective fits

SCM heating rates, summer noon, clearsky,
H_2O only (excluding e-type continuum)

thermal band

solar band



ACRANEB2/SPLIDACO reference
ACRANEB2 with primary fits
ACRANEB2 with secondary corrective fits

Problem 1.2) – relaxing $T_\mathrm{e} = T$ assumption

- in thermal band, broadband transmission τ 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)

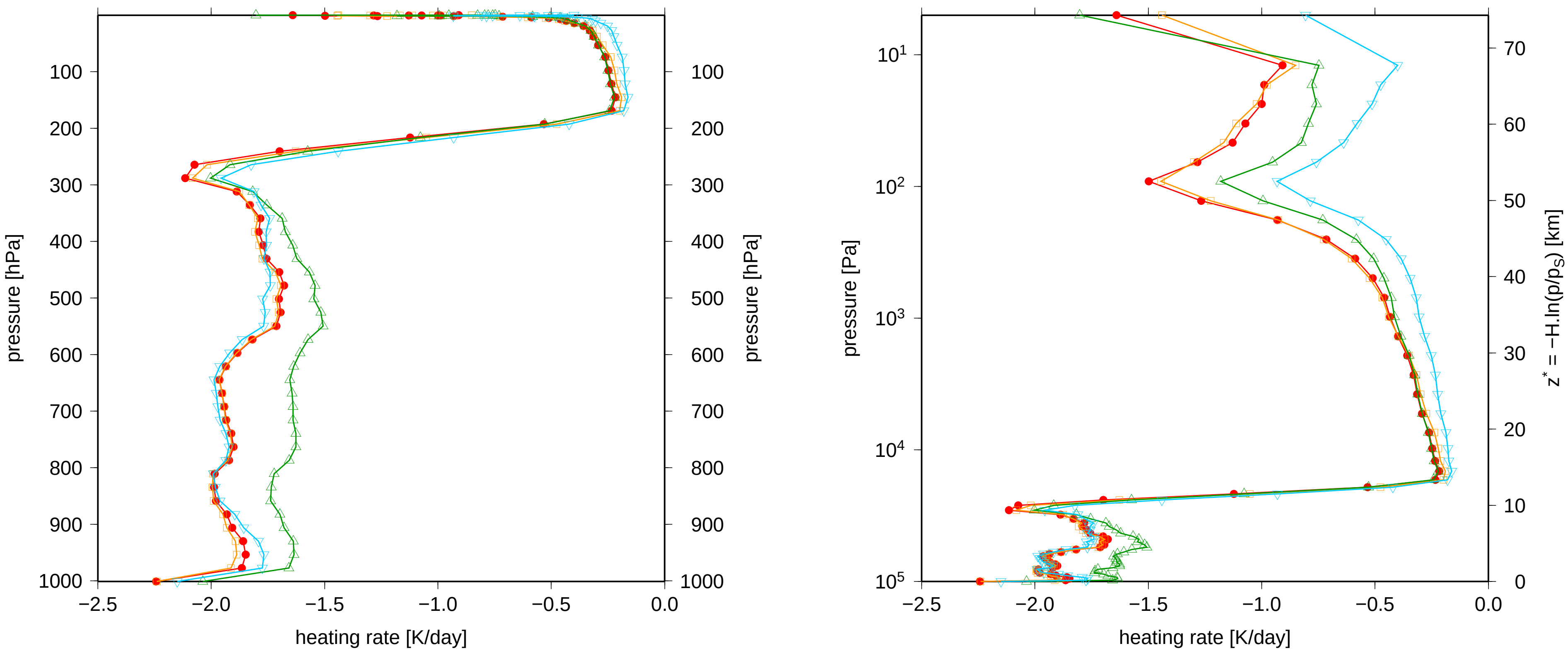
- both original SPLIDACO reference and ACRANEB scheme used assumption $T_\mathrm{e} = T$, which is unphysical and causes significant error unless the system is isothermal

Problem 1.2) – relaxing $T_\mathrm{e} = T$ assumption

SCM thermal heating rates, mid-latitude summer, clearsky,
H_2O only (excluding e-type continuum)

vertical axis linear in pressure

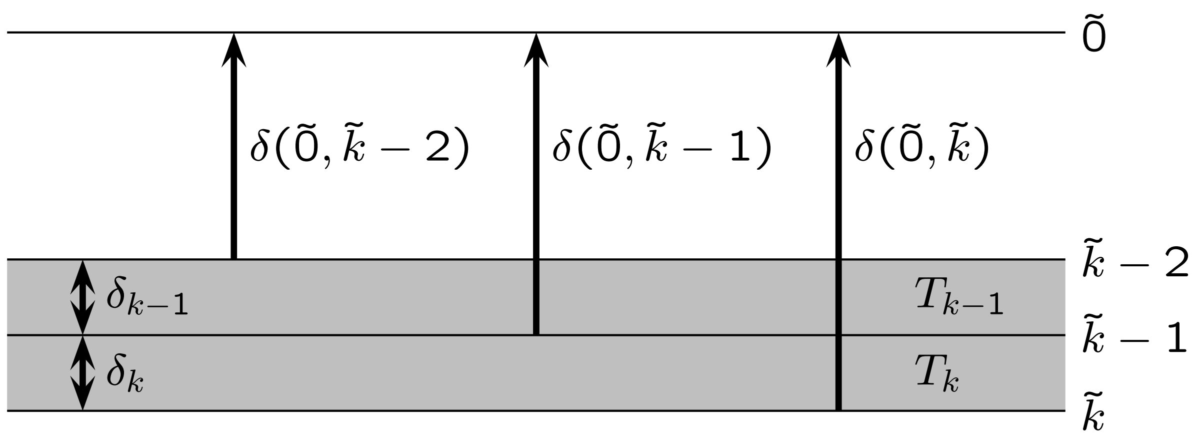
vertical axis logarithmic in pressure



SPLIDACO with true T_e
SPLIDACO with linear T_e correction
ACRANEB2 with $T_\mathrm{e} = T$ (unphysical)
ACRANEB2 with $T_\mathrm{e} = 255.8\,\mathrm{K}$ (still unphysical)

Problem 1.2) – relaxing $T_\mathrm{e} = T$ assumption

- implementation of $T_\mathrm{e} \neq T$ 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 T_e and using two sets of spectrally averaged quantities – one with weights proportional to $B_\nu(T_0)$, another to $\mathrm{d}B_\nu/\mathrm{d}T(T_0)$
- main trap long preventing successful implementation was non-additivity of T_e corrected incremental optical depths (illustration for cooling to space case):



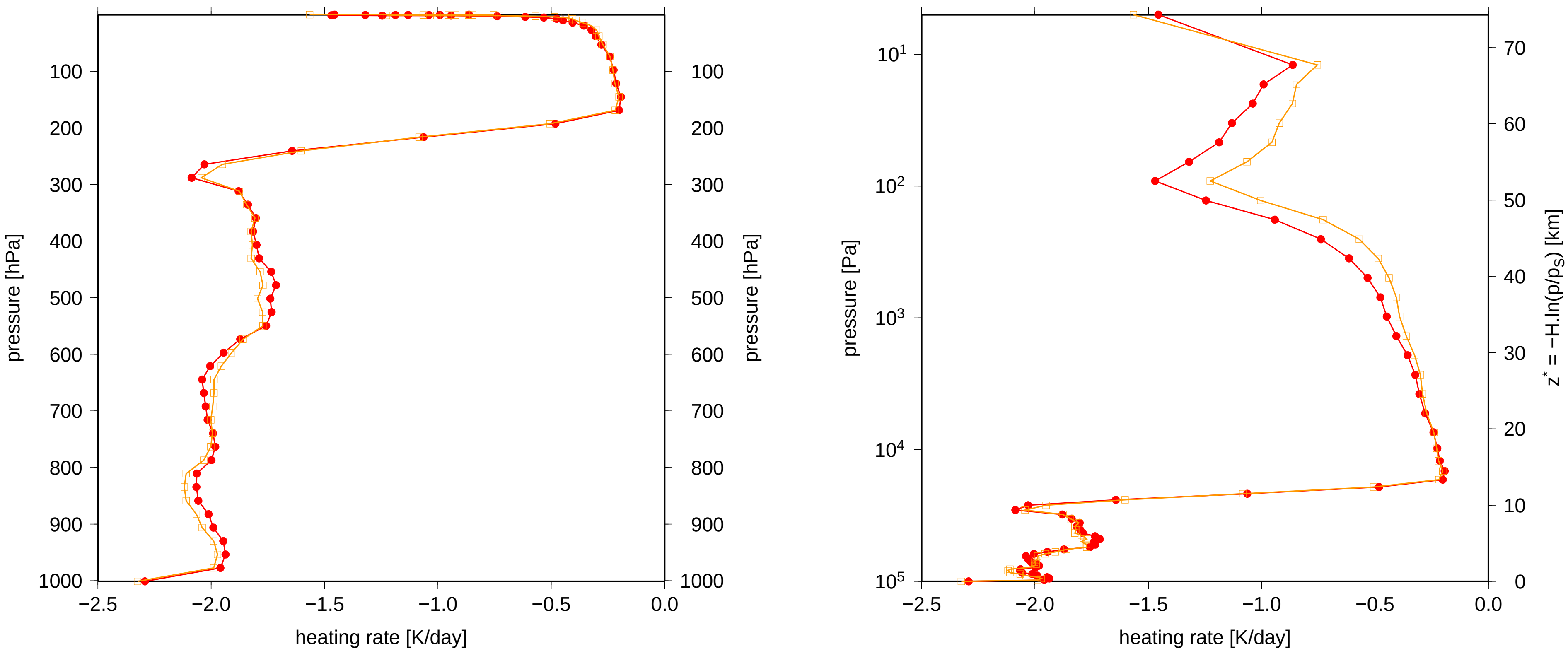
$$\delta_{k-1} = \delta(\tilde{0},\tilde{k}-1)|_{T_\mathrm{e}=T_{k-1}} - \delta(\tilde{0},\tilde{k}-2)|_{T_\mathrm{e}=T_{k-1}}$$
$$\delta_{k} = \delta(\tilde{0},\tilde{k})|_{T_\mathrm{e}=T_{k}} - \delta(\tilde{0},\tilde{k}-1)|_{T_\mathrm{e}=T_{k}}$$

Problem 1.2) – relaxing $T_\mathrm{e} = T$ assumption

SCM thermal heating rates, mid-latitude summer, clearsky, H_2O only (excluding e-type continuum)

vertical axis linear in pressure

vertical axis logarithmic in pressure



ACRANEB2/SPLIDACO with linear T_e correction
ACRANEB2 with linear T_e correction

Problem 1.3) – H_2O e-type continuum and overlaps

- H_2O e-type continuum was originally introduced as a separate pseudo-gas H_4O_2 with zero Malkmus core and non-zero continuum term (we believed it was necessary for correct treatment of non-homogeneous optical paths in Curtis-Godson spirit)

- continuum term was subject to saturation due to its broadband spectral variation

- pair overlaps of H_4O_2 with H_2O, CO_2+ and O_3 were parameterized, but it turned out that (H_2O, H_4O_2, CO_2+) triple overlap cannot be neglected

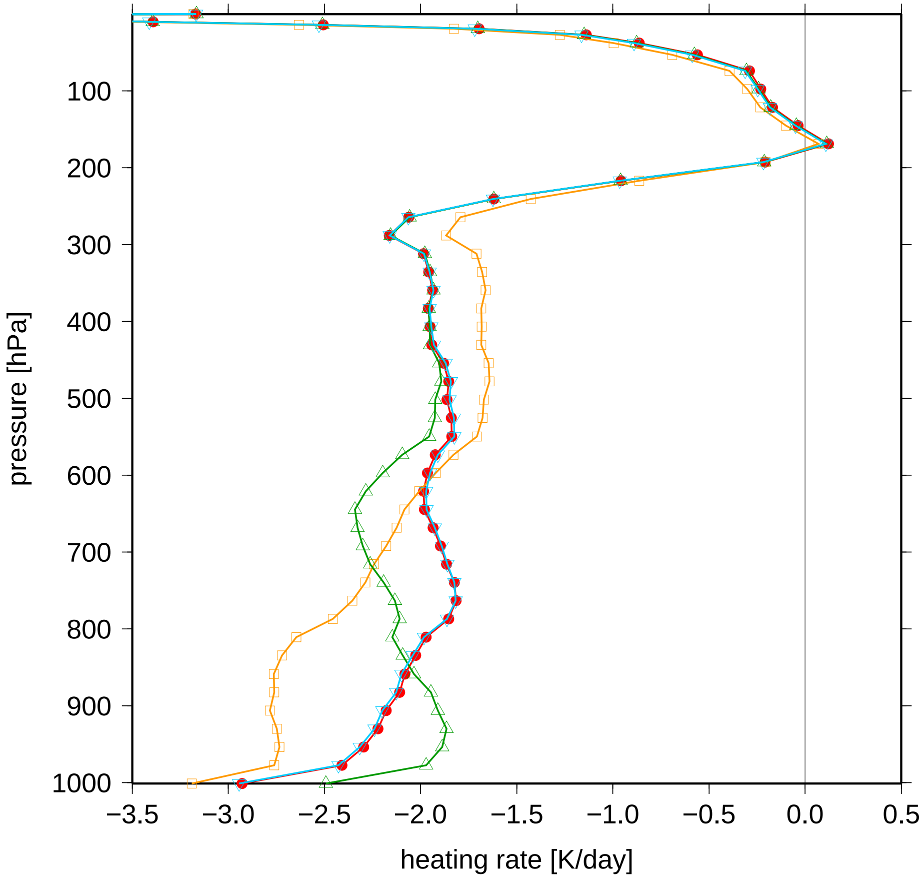
- it was then tried to include H_2O e-type continuum in broadband H_2Oe transmission, so that significant (H_2O, H_4O_2) pair overlap is treated implicitly

- idea worked, thanks to the fact that dependency on q_V did not cause much extra spread in H_2Oe pair overlaps and because (H_2Oe, CO_2+, O_3) triple overlap turned to be insignificant

Problem 1.3) – H_2O e-type continuum and overlaps

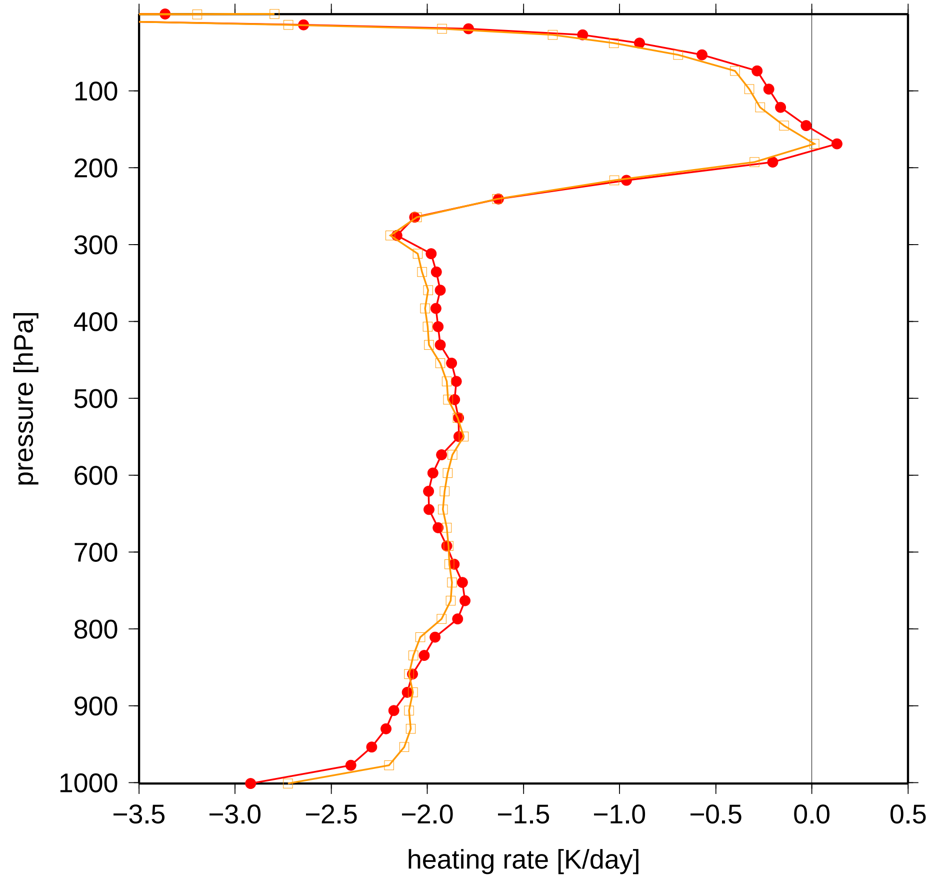
SCM thermal heating rates, mid-latitude summer, clearsky, all gases

ACRANEB2/SPLIDACO



exact overlaps
random overlaps
pair overlaps between H_2O, H_4O_2, CO_2+ and O_3
pair overlaps between H_2Oe, CO_2+ and O_3

ACRANEB2/SPLIDACO versus ACRANEB2



ACRANEB2/SPLIDACO
ACRANEB2

Problem 2) – reformulation of NER statistical model

- NER statistical model is used to estimate clearsky EBL flux (Exchange Between Layers), which is too costly for exact evaluation
- idea is to interpolate EBL flux between its min/max estimates:

$$F^{\text{EBL}} = (1-\alpha) \cdot F^{\text{EBL}}_{\text{min}} + \alpha \cdot F^{\text{EBL}}_{\text{max}}$$

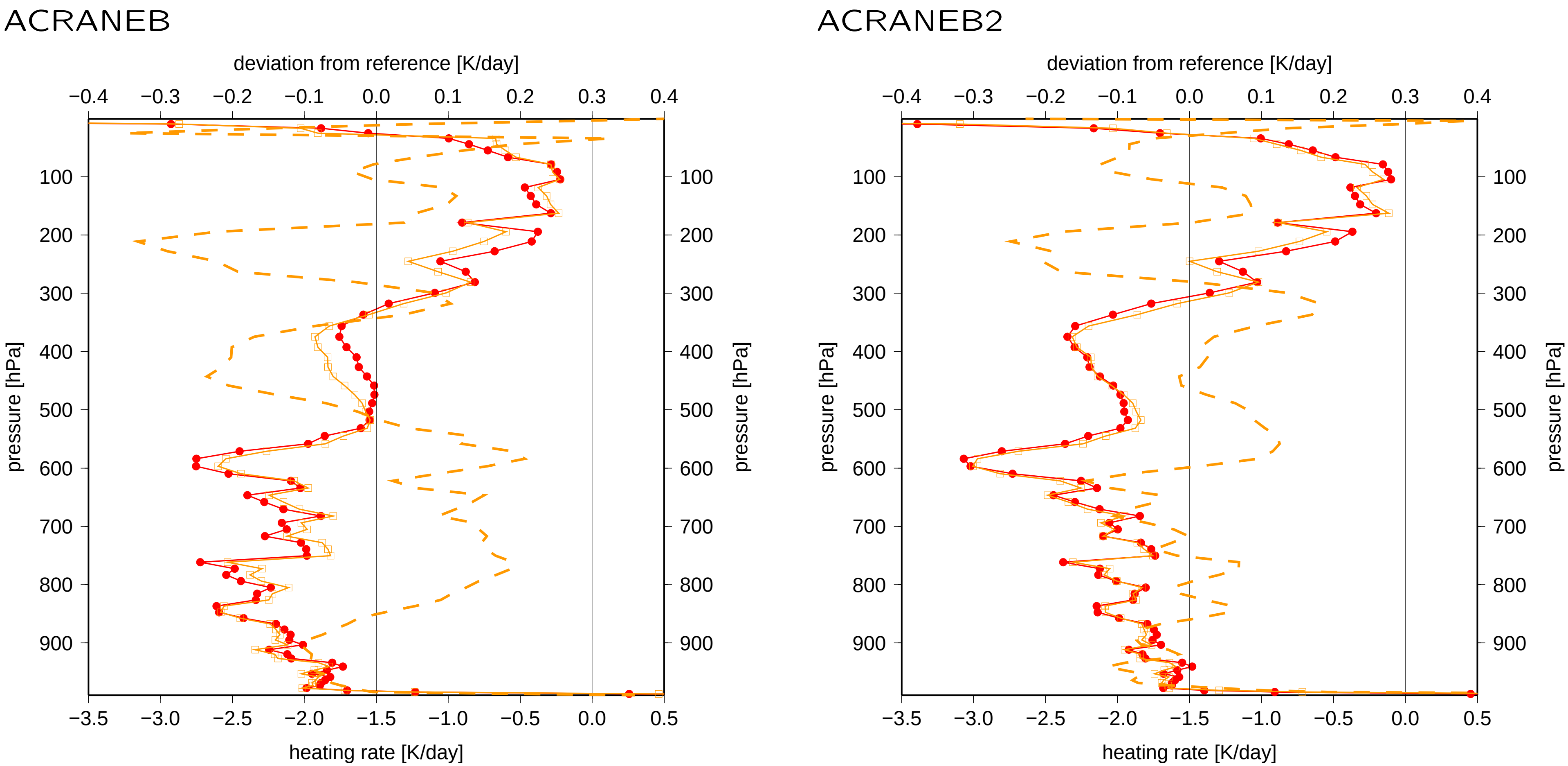
- α is so called bracketing weight, in old statistical model it was function of vertical coordinate σ and stability $c_p \, \mathrm{d}\theta / \mathrm{d}\phi$, having 7 fitting parameters
- accuracy of such fit proved to be insufficient and could not be improved much due to big spread of data points
- better alternative turned to be fitting directly EBL flux instead of α:

$$F^{\text{EBL}} = A(\sigma) \cdot F^{\text{EBL}}_{\text{min}} + B(\sigma) \cdot F^{\text{EBL}}_{\text{max}}$$

- having A and B second order polynomials in σ proved to be sufficient, with relaxed constraint $A + B = 1$ it means 6 fitting parameters

Problem 2) – reformulation of NER statistical model

SCM thermal heating rates, summer noon, clearsky, all gases present, exact computation of adjacent exchanges



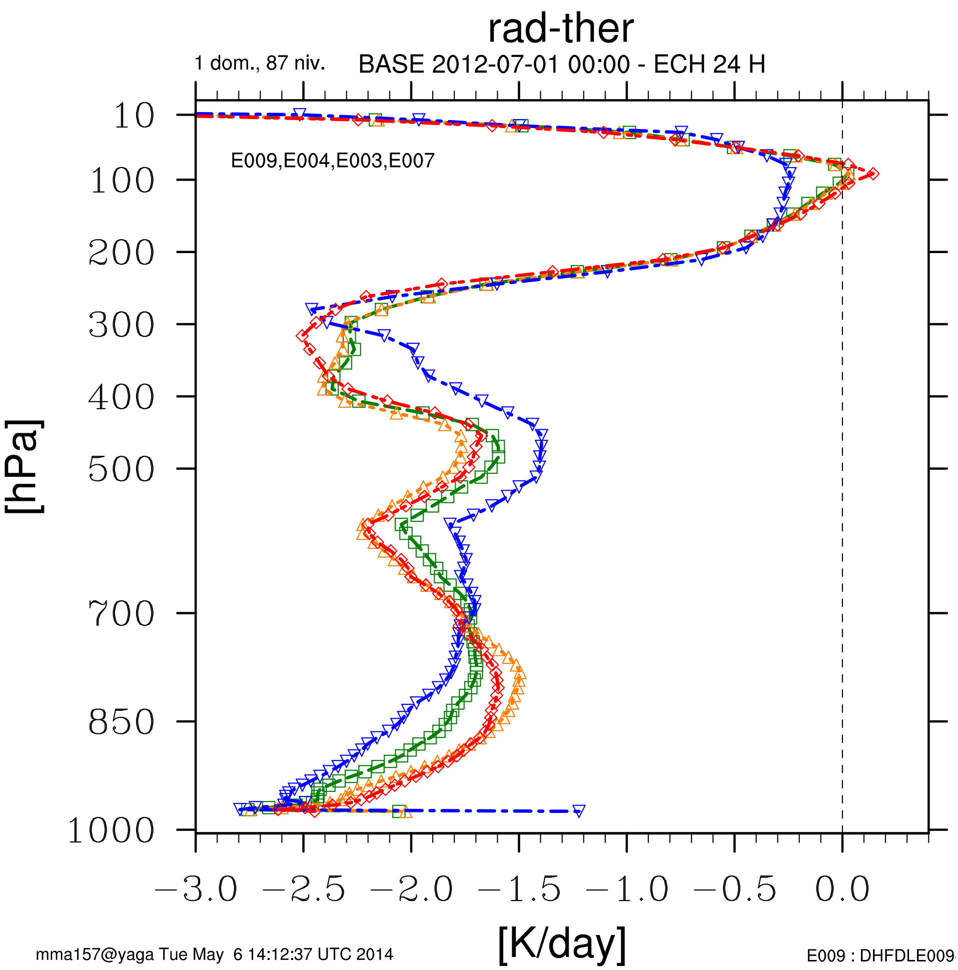
exact EBL
statistically fitted EBL

Problem 2) – bracketing hypothesis

- new statistical model works well for clearsky EBL flux with excluded adjacent exchanges, which are thus computed exactly
- fitted EBL flux is converted back to bracketing weight α, which is then used in final NER recombination including clouds
- such approach relies on assumption that true α is not sensitive to cloudiness
- this is roughly true when adjacent exchanges are **included** in EBL flux, but the new statistical model requires them **excluded**
- temporary (?) fix of the above contradiction was replacing statistical model with intermittent exact computation of clearsky EBL flux with adjacent exchanges included
- numerical experiments showed that 1 h update of gaseous transmissions together with 3 h update of bracketing weights (i.e. two level intermittency) is sufficiently accurate yet affordable

Problem 2) – bracketing hypothesis

DDH thermal heating rates, cloudy, 24 hour integration



RRTM reference, 1 h intermittency
ACRANEB, statistical model
ACRANEB2, 1 h/3 h intermittency, adjacent exchanges part of EBL flux
ACRANEB2, 1 h/3 h intermittency, adjacent exchanges not in EBL flux

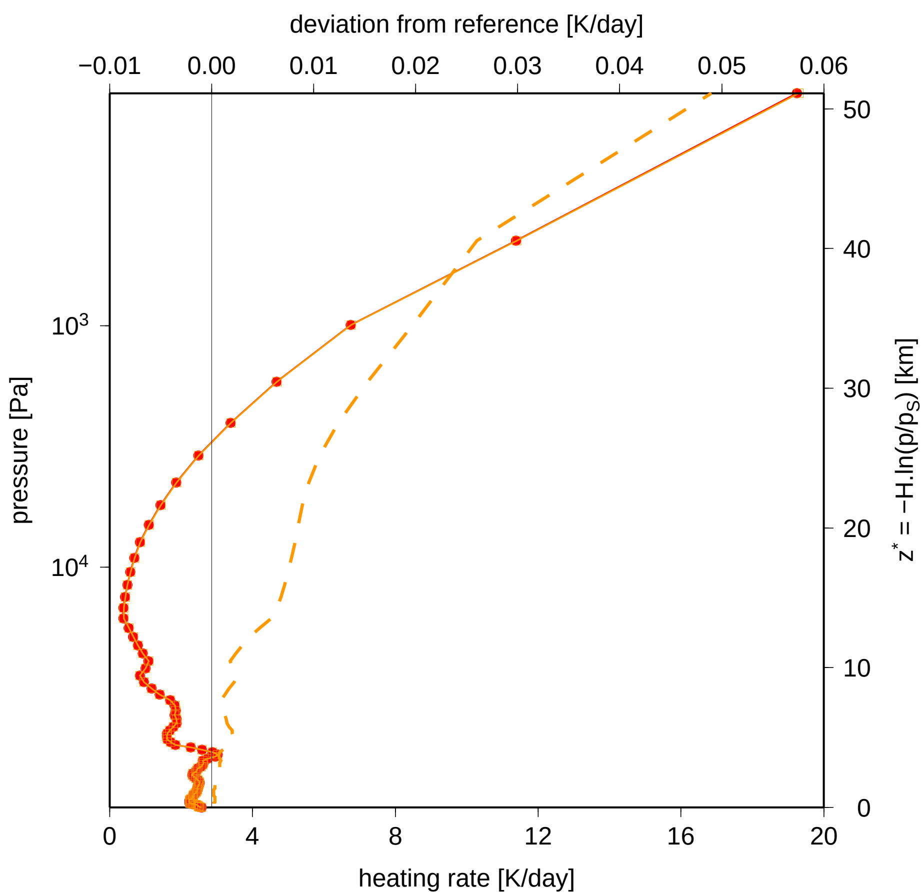
Problem 3) - new fitting reference

- original ACRANEB gaseous transmissions were based on AFGL data tape, with CO_2+ composite (mixture of CO_2, N_2O, CO, CH_4 and O_2) corresponding to 1990 concentrations
- in summer 2013, UGent students O. Giot and H. O. Achom recreated old line by line model of Ritter and Geleyn from the scratch and interfaced it with up to date spectroscopic data (HITRAN 2008 line parameters complemented by Serdyuchenko et al. 2013 dataset for shortwave ozone continuum absorption)
- they delivered narrowband Malkmus coefficients separately for H_2O, O_3, CO_2, N_2O, CO, CH_4 and O_2
- this enabled update of CO_2+ composite to 2010 concentrations and refitting of ACRANEB2 broadband gaseous transmissions against recent reference
- radiative impact of individual gases in CO_2+ composite could also be evaluated $\Rightarrow$ CO discarded, O_2 kept

Problem 3) - new fitting reference

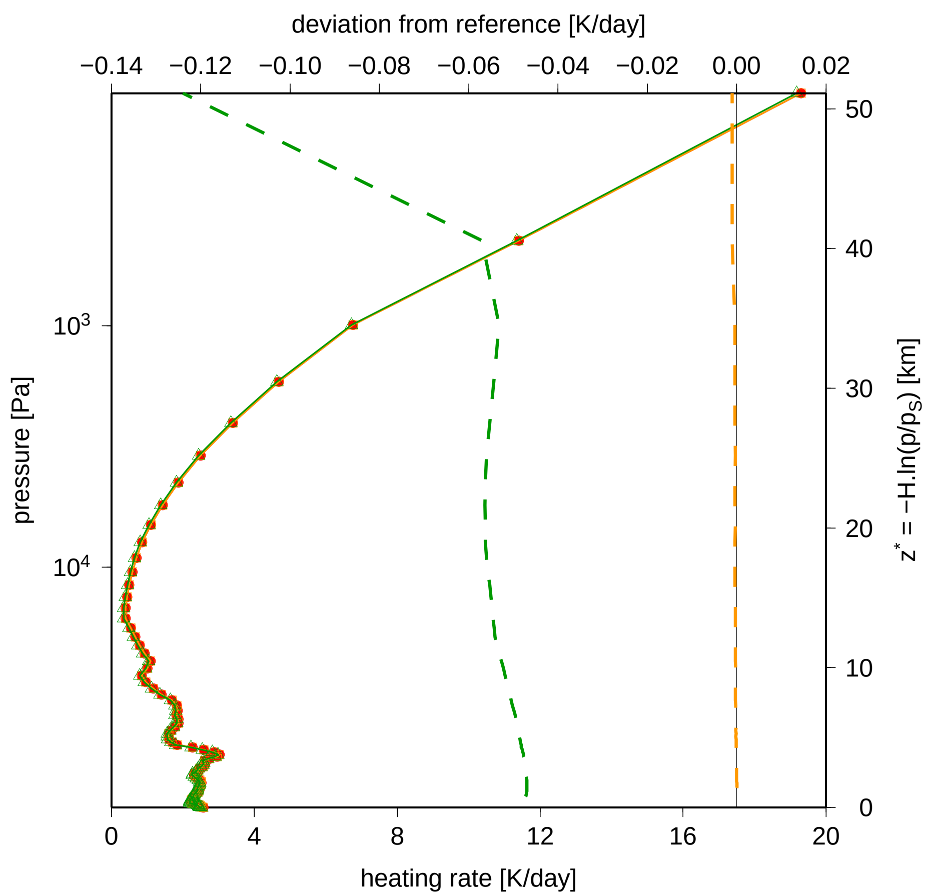
SCM solar heating rates, summer noon, clearsky, all gases present (ACRANEB2/SPLIDACO narrowband reference)

1990 versus 2010 CO_2+ composition



1990 CO_2+ composition
2010 CO_2+ composition

impact of CO and O_2



2010 CO_2+ composition
2010 CO_2+ composition without CO
2010 CO_2+ composition without O_2

Extra problems which had to be cured on the way

problem	cure
insufficient accuracy of fitted pair gaseous overlaps	enable change of overlap sign, refit on sample of non-homogeneous optical paths
$\mathrm{EBL_{min}}$ estimate often bigger than true EBL	exclude thermal (H_2O, O_3) pair overlap, having strong impact on $\mathrm{EBL_{min}}$ but only weak impact on true EBL
oscillations due to clearsky EBL flux out of bracket	apply suitable filter on bracketing weights, store clearsky EBL excess and add it to final cloudy EBL estimate
too big departure of solar heating rates from FMR cloudy results	revise geometry factors defining effective cloud optical depth
high clouds optically too thick	refit ice clouds against more recent reference (Edwards et al. 2007 instead of Rockel et al. 1991)
drifted net thermal surface flux	remove T_e related conceptual error in computation of surface CTS contribution
exaggerated dependency of direct surface albedo on sun elevation	add proportion of Lambertian reflection for solid surfaces, tune it against published references (Yang et al. 2008 for land, Gardner and Sharp 2010 for snow)

One good surprise - broadband Voigt treatment

- Voigt line shape combines effect of collisional broadening (Lorentzian profile) with Doppler broadening (Gaussian profile)

- impact of Voigt line shape is negligible in troposphere, but dominates above ~70 km altitude (not yet interesting for LAM with model top around 50 km, but important for global models)

- ACRANEB2 gaseous transmissions were fitted against SPLIDACO narrowband reference based on Malkmus band model and Lorentz line shape (with simple sub-Lorentzian treatment of line wings)

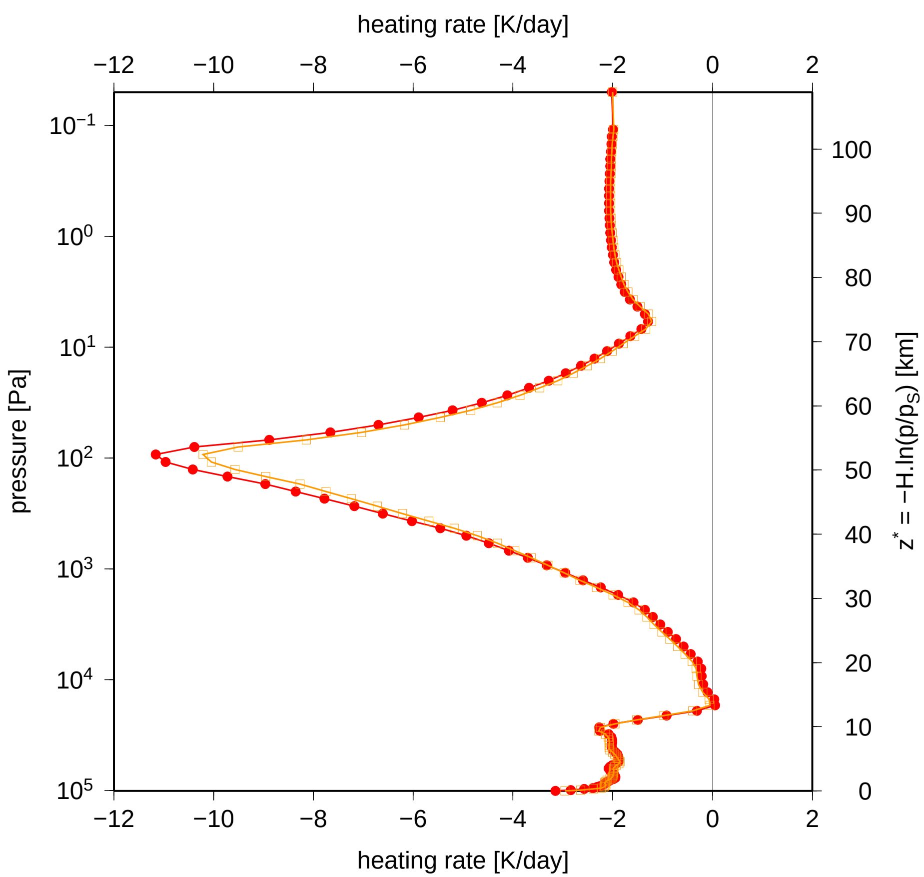
- effect of Voigt line shape was introduced via parameterization proposed by Geleyn et al. 2005, but it was not clear a priori how good will it work in broadband case

- tests showed that it performs well with broadband corrected Malkmus formula and can be used up to mesosphere (but radiative transfer in high atmosphere must account for breaking of local thermodynamic equilibrium)

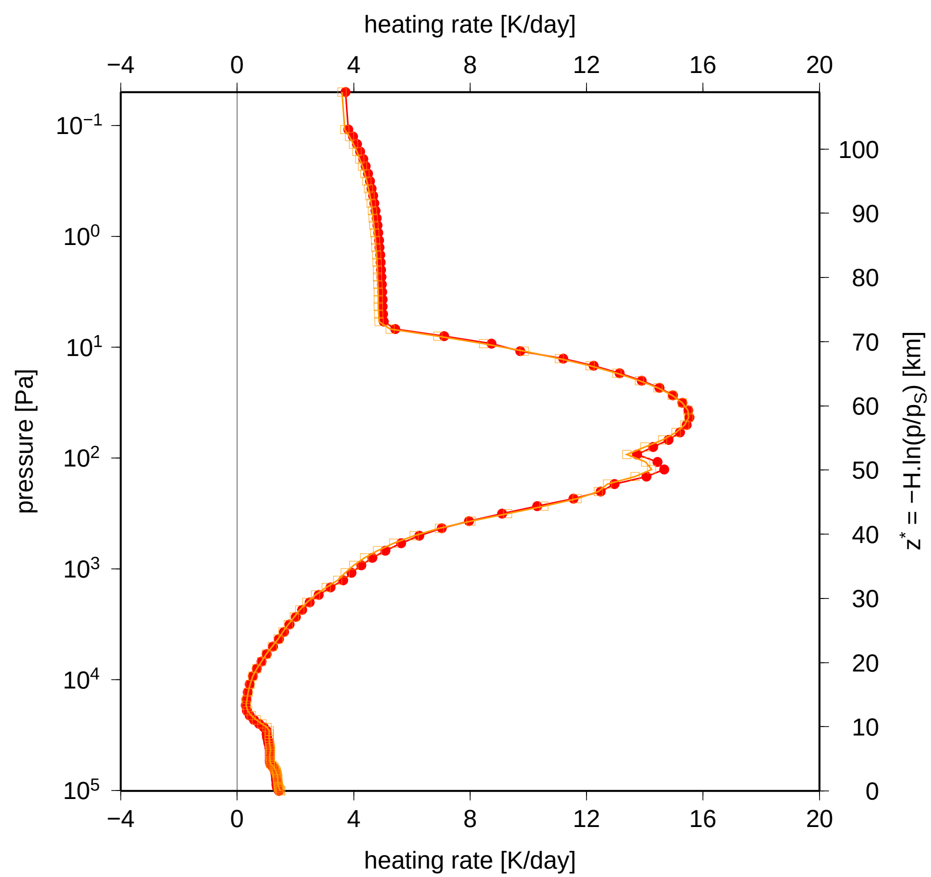
One good surprise - broadband Voigt treatment

SCM thermal heating rates, mid-latitude summer, clearsky,
H_2O, O_3 and 300 ppmv CO_2

thermal band



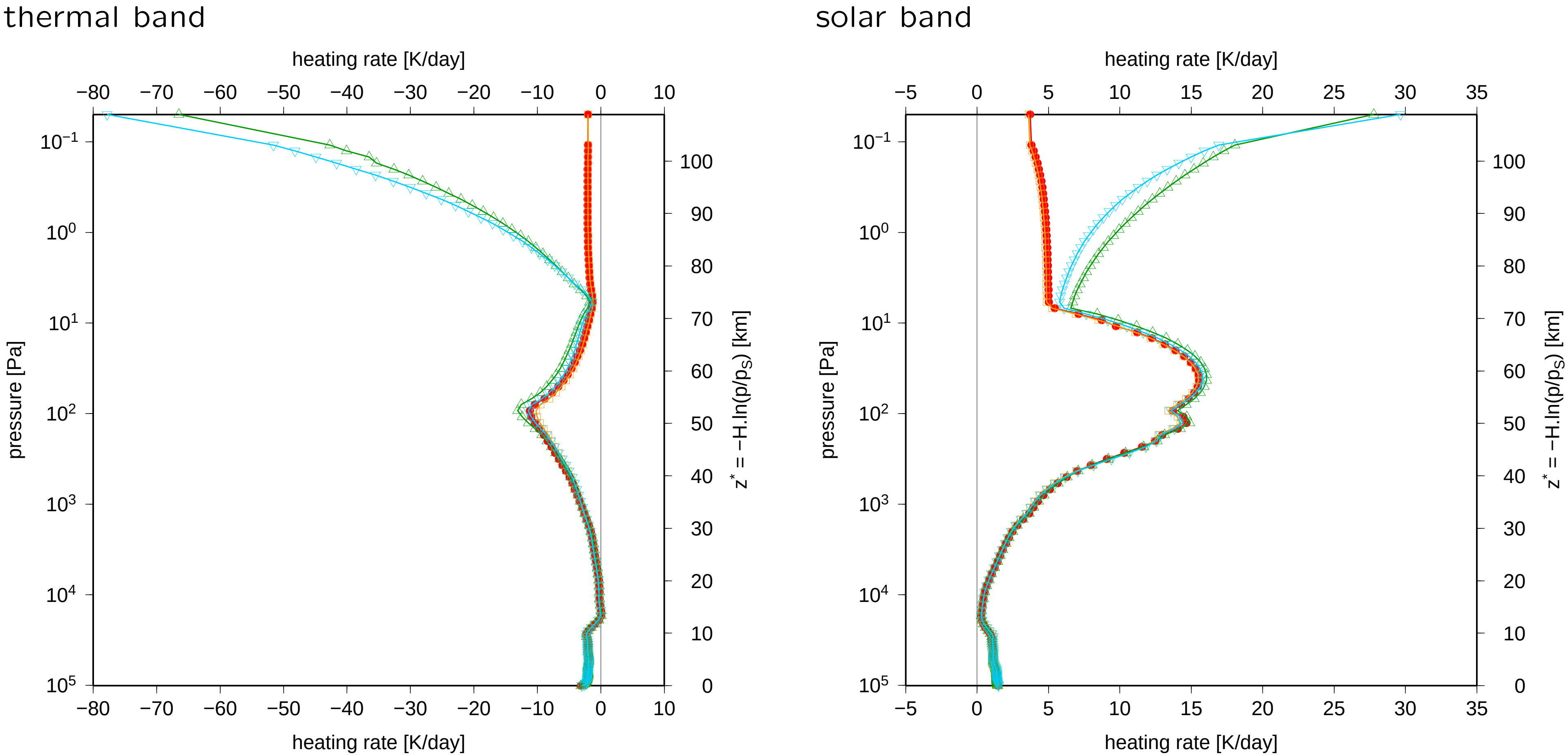
solar band



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

One good surprise - broadband Voigt treatment

SCM thermal heating rates, mid-latitude summer, clearsky, H_2O, O_3 and 300 ppmv CO_2



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

One good surprise - broadband Voigt treatment

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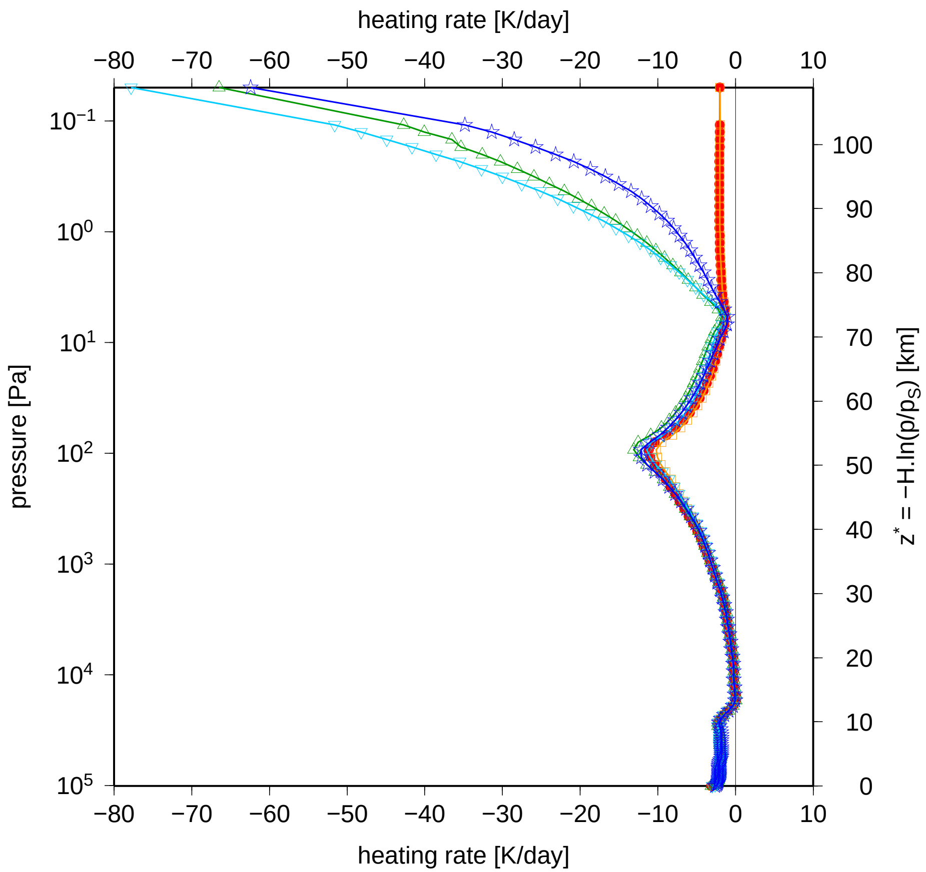
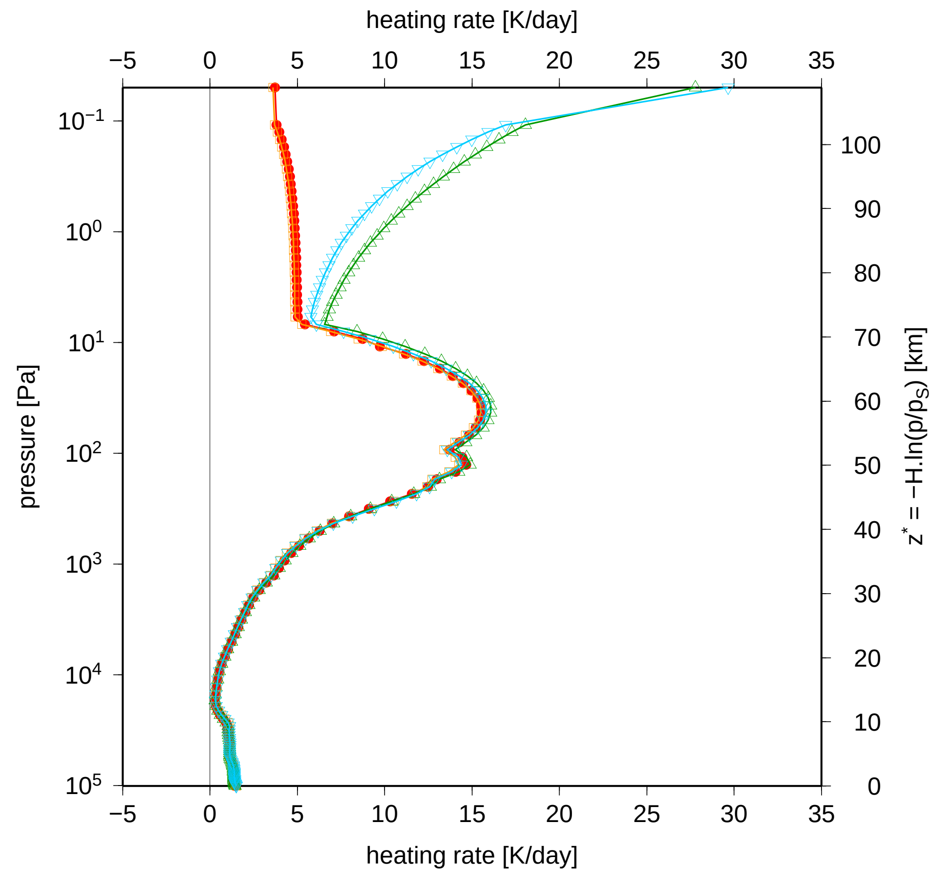
H_2O, O_3 and 300 ppmv CO_2

thermal band



solar band



ACRANEB2/SPLIDACO reference, Lorentz line shape
ACRANEB2, Lorentz line shape
ACRANEB2/SPLIDACO reference, Voigt line shape
ACRANEB2, Voigt line shape
GFDL line by line model, Voigt line shape

Opened issues

- importance of positive correlation between water vapor and cloud near-infrared absorption should be evaluated – if significant, some simple parameterization of gas-cloud solar overlap should be found
- in order to reduce CPU cost, it would be desirable to make statistical model working with clouds – most probably via empirical correction of clearsky bracketing weights in the presence of clouds
- another CPU saving could be achieved by introducing intermittent computation of solar gaseous transmissions – it has to address update of stored gaseous optical depths to actual sun elevation

Conclusions

- quite a lot of new developments were done during the last two years
- several fundamental problems were identified and solved, plus there were many tiny cleanings and improvements
- above developments resulted in creation of ACRANEB2 radiation transfer scheme, which now reached mature stage for operational usage
- ACRANEB2 baseline version was delivered and phased into official ARPEGE/ALADIN cycle 40t1, where it is available via new flexible phys-dyn interface
- still there are issues to be improved, but first of all ALARO tuning compatible with the new radiation and turbulence has to be found
- publication of the results is now **priority number one**

Thanks to all who contributed,
it was pleasing intellectual adventure!