Novelties in radiation

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Radiation status on previous ALARO-1 WD (May 2014)

- ACRANEB2 radiation in a mature stage, ready for operational usage

  [further developments followed, ALARO-1 was never tuned with ACRANEB2 baseline version]

- ACRANEB2 baseline version available in official ARPEGE/ALADIN cy40t1

  [new developments were phased into official cy43t1, majority of them were backphased into cy40t1_bf5]

- ALARO-1 tuning with ACRANEB2 radiation and TOUCANS turbulence not yet available

  [ready in December 2014, ALARO-1 version A operational at CHMI since 22-Jan-2015]

- publication of ACRANEB2 developments being priority number one

  [SW part published, LW part in a review process]

Opened issues (May 2014)

- importance of positive correlation between water vapour and cloud near-infrared absorptions

  [parameterized]

- empirical correction of clearsky bracketing weights in the presence of clouds in order to enable use of statistical model

  [abandoned]

- intermittent update of SW gaseous transmissions

  [implemented]

Overview of novelties (since May 2014)

○ SW and LW narrowband references

○ intermittent update of SW gaseous transmissions (P. Kuma)

• new cloud optical properties, revised cloud optical saturation

○ parameterized gas-cloud spectral overlap

• exponential-random overlap between cloud layers

• revised bracketing

• sunshine duration, true direct solar flux

○ tuning of ALARO-1 version A with ACRANEB2 radiation, further ALARO-1 tuning with exponential-random cloud overlap (R. Brožková)

(○ – items not detailed in this presentation)

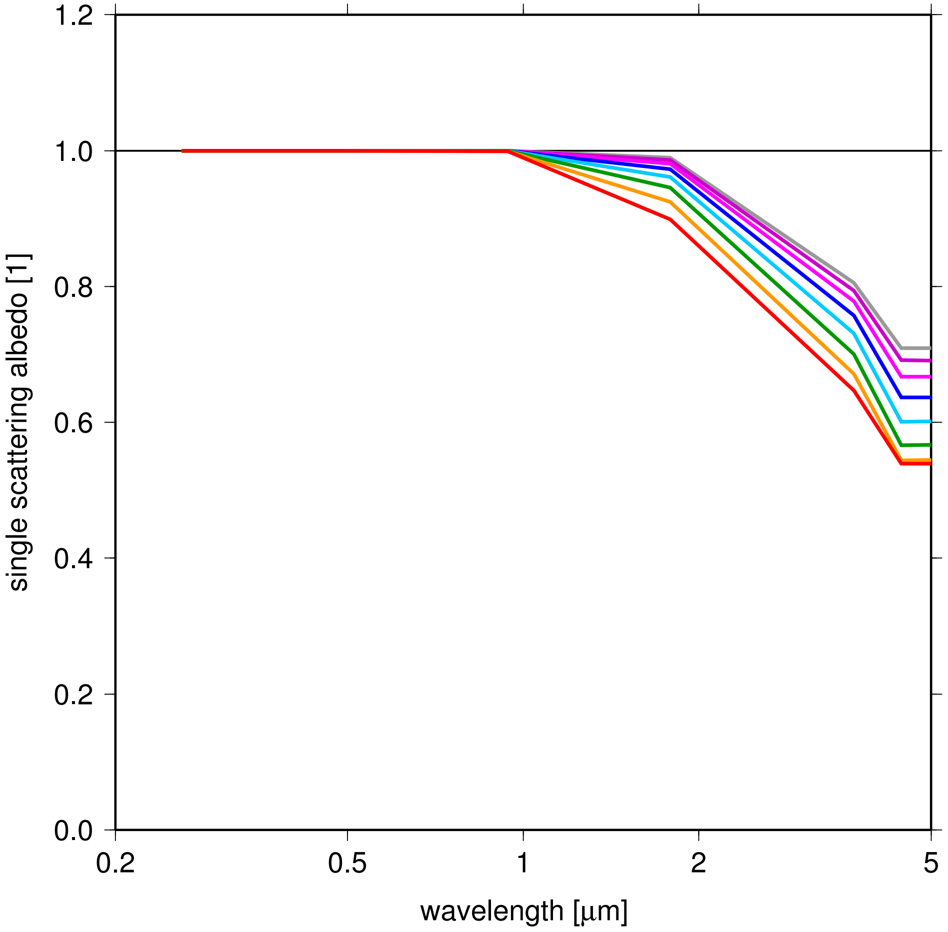
New cloud optical properties and revised cloud optical saturation

Motivation

- correct treatment of clouds is crucial for accurate radiative transfer
- in ACRANEB2 baseline version, optical properties of ice clouds were parameterized using modern Edwards et al. 2007 dataset
- its main weakness is the spectral resolution (5 SW bands, 10 LW bands), sufficient to get single scattering optical properties, but not optical saturation
- for this reason, optical saturation of ice clouds was still based on high resolution but older dataset of Rockel et al. 1991
- the latter dataset treats ice particles as spheres, obtaining their single scattering properties from Lorentz-Mie theory
- using this dataset led us to a false belief that cloud optical saturation is universal, i.e. independent of phase
- after revising ice clouds the liquid clouds followed, broadband single scattering properties are now fitted as functions of droplet effective radius R_{e} or ice particle effective dimension D_{e}

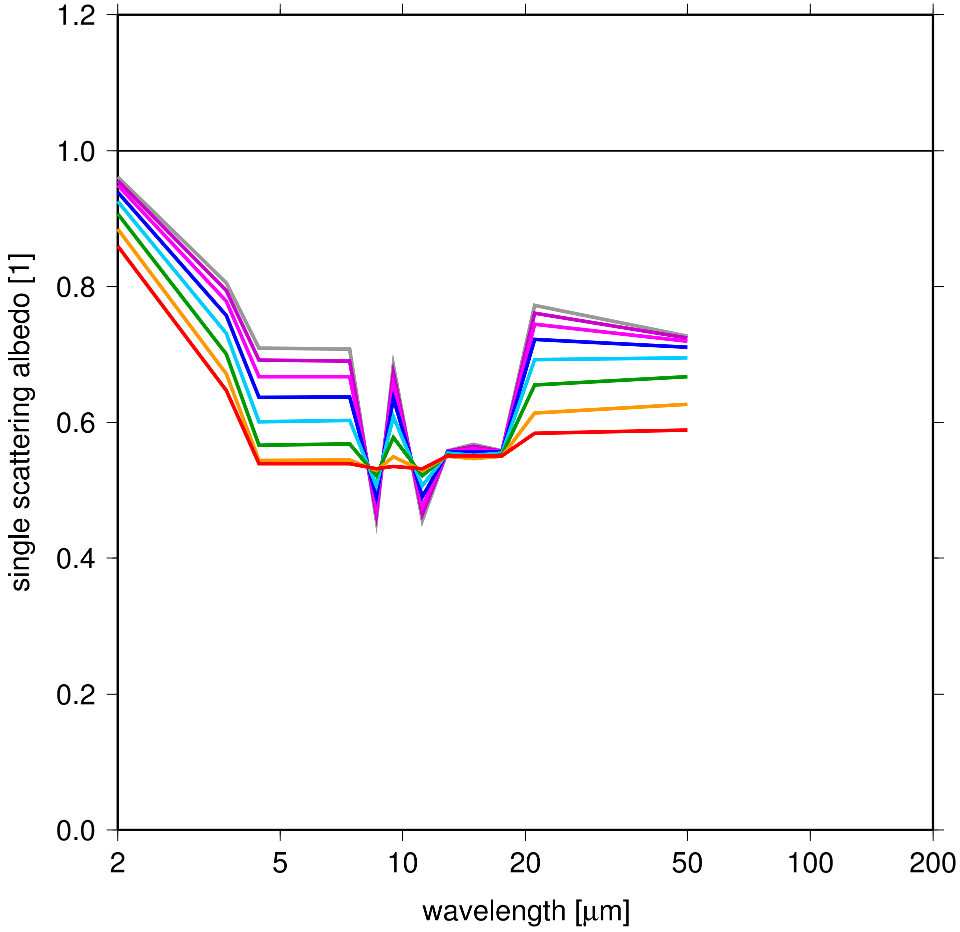
Old spectral profile of single scattering albedo (ice clouds)

SW – Edwards et al. 2007
(5 bands)



$R_e = \ \ 4\ \mu$m
$R_e = 60\ \mu$m

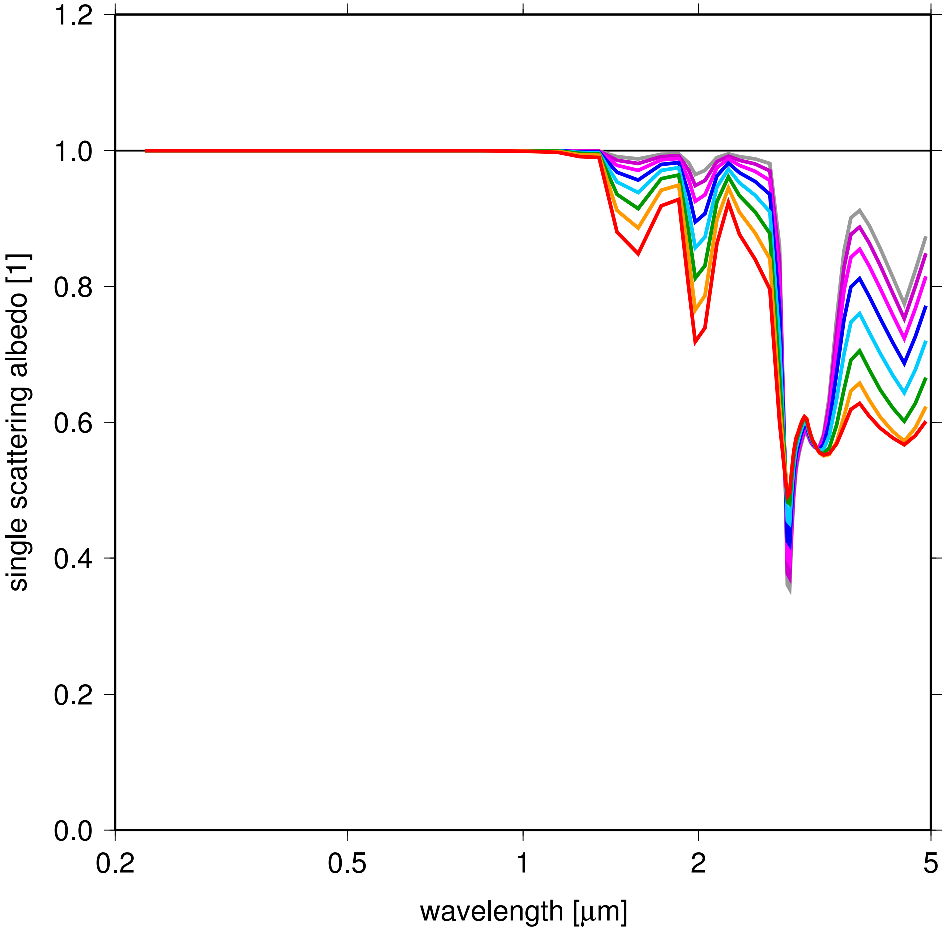
LW – Edwards et al. 2007
(10 bands)



$D_e = \ \ 10\ \mu$m
$D_e = 150\ \mu$m

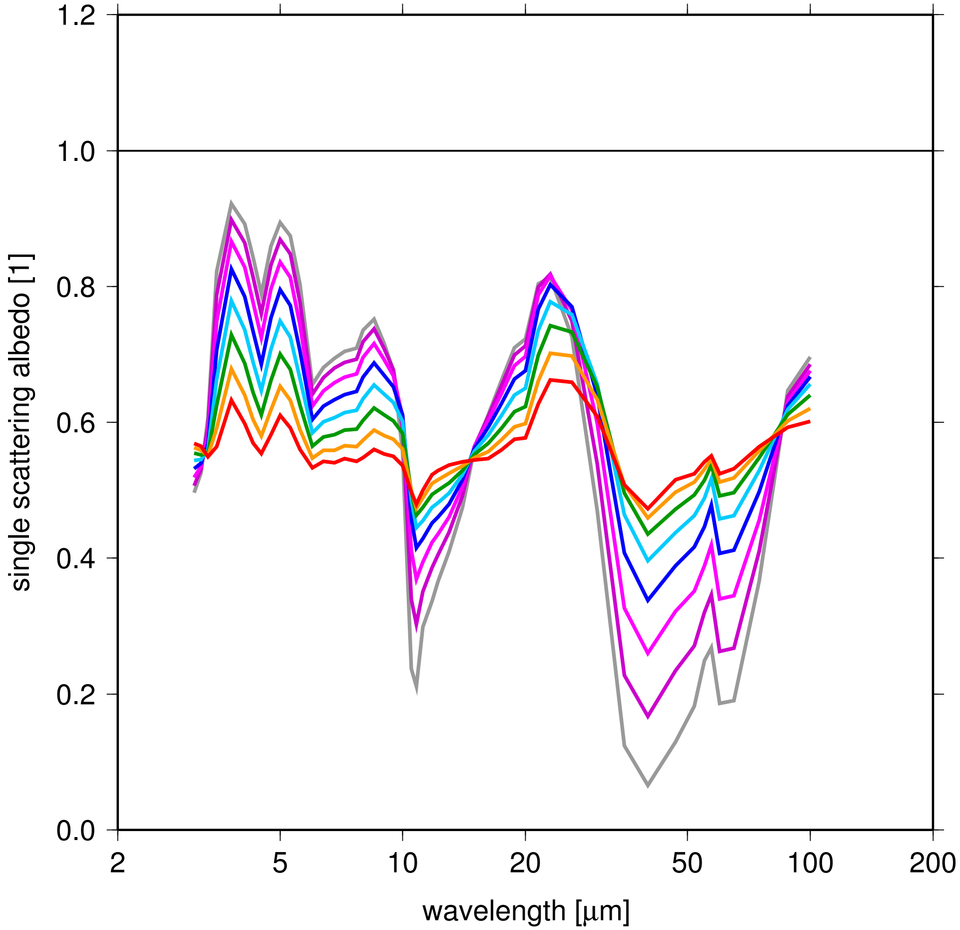
New spectral profile of single scattering albedo (ice clouds)

SW – rough aggregate of Key et al. 2002
(56 bands)



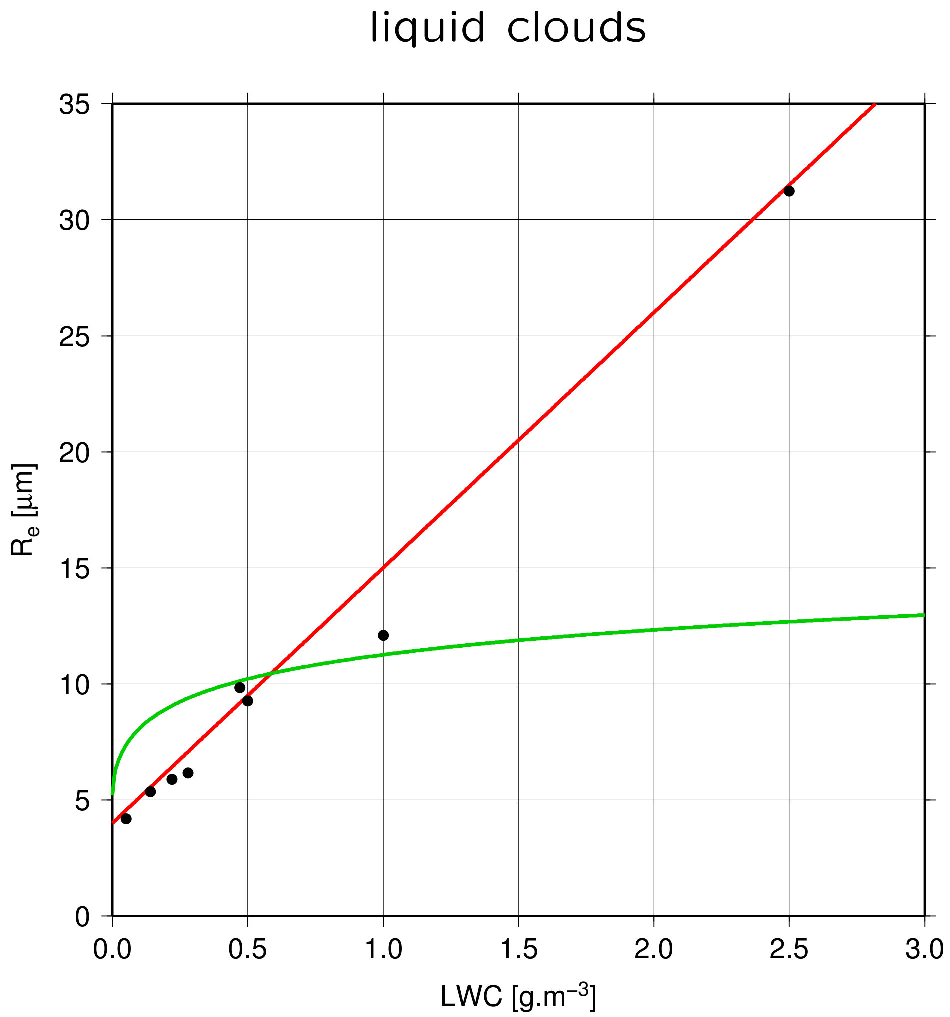
$R_\mathrm{e} = \ \ 4\,\mu\mathrm{m}$
$R_\mathrm{e} = 60\,\mu\mathrm{m}$

LW – Yang et al. 2005
(49 wavelengths)



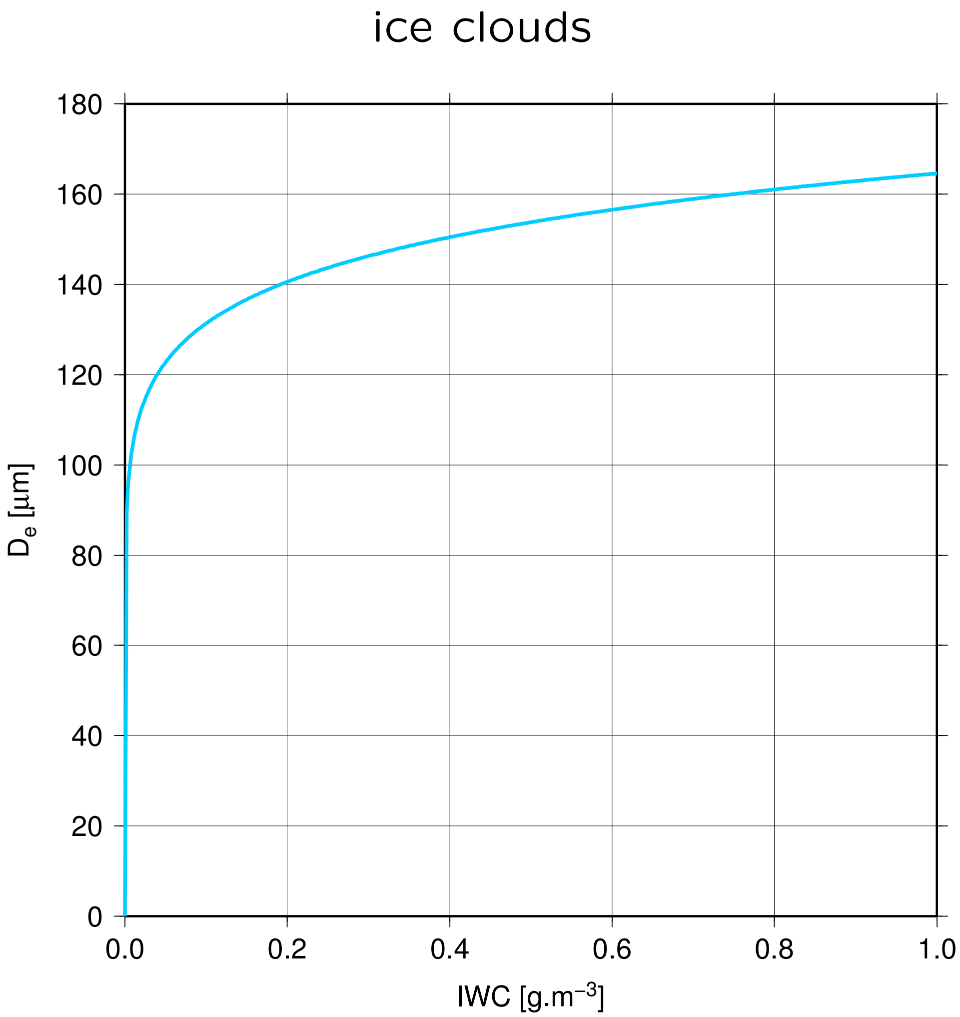
$D_\mathrm{e} = \ \ 10\,\mu\mathrm{m}$
$D_\mathrm{e} = 150\,\mu\mathrm{m}$

Relation between cloud water content and effective particle size



Fouquart et al. 1990

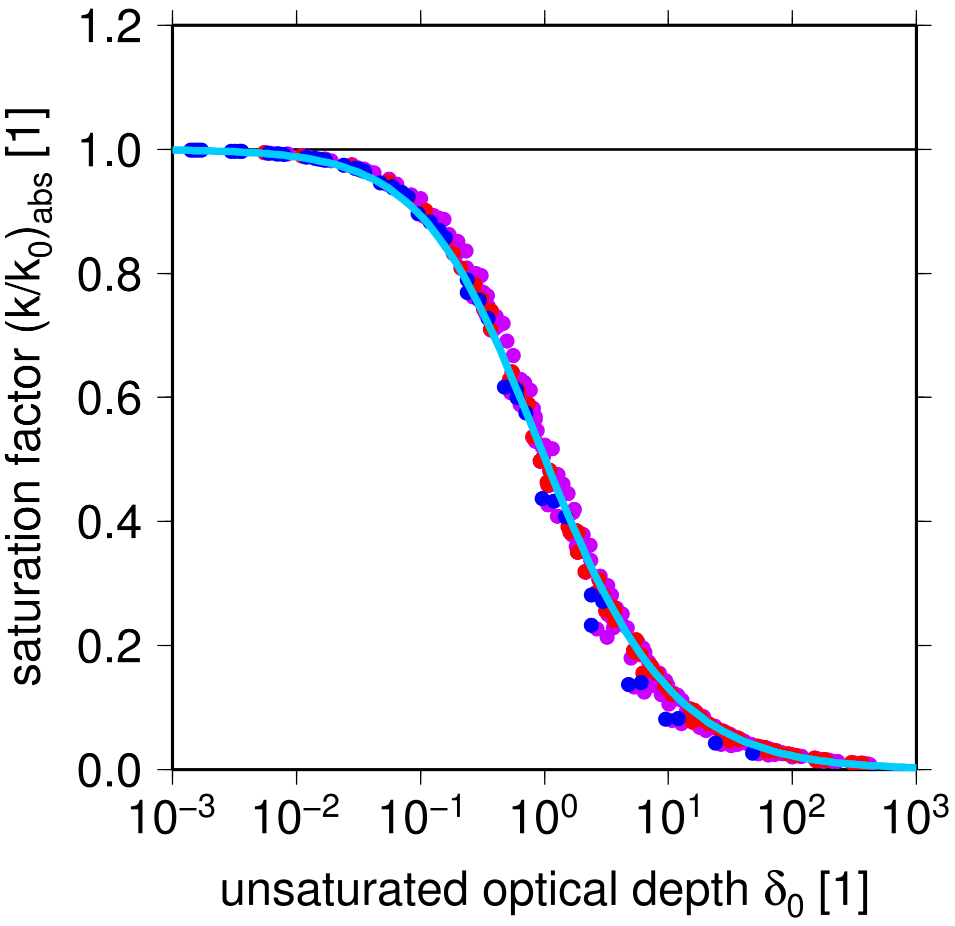
Reid et al. 1999 (ALARO-1 version A)

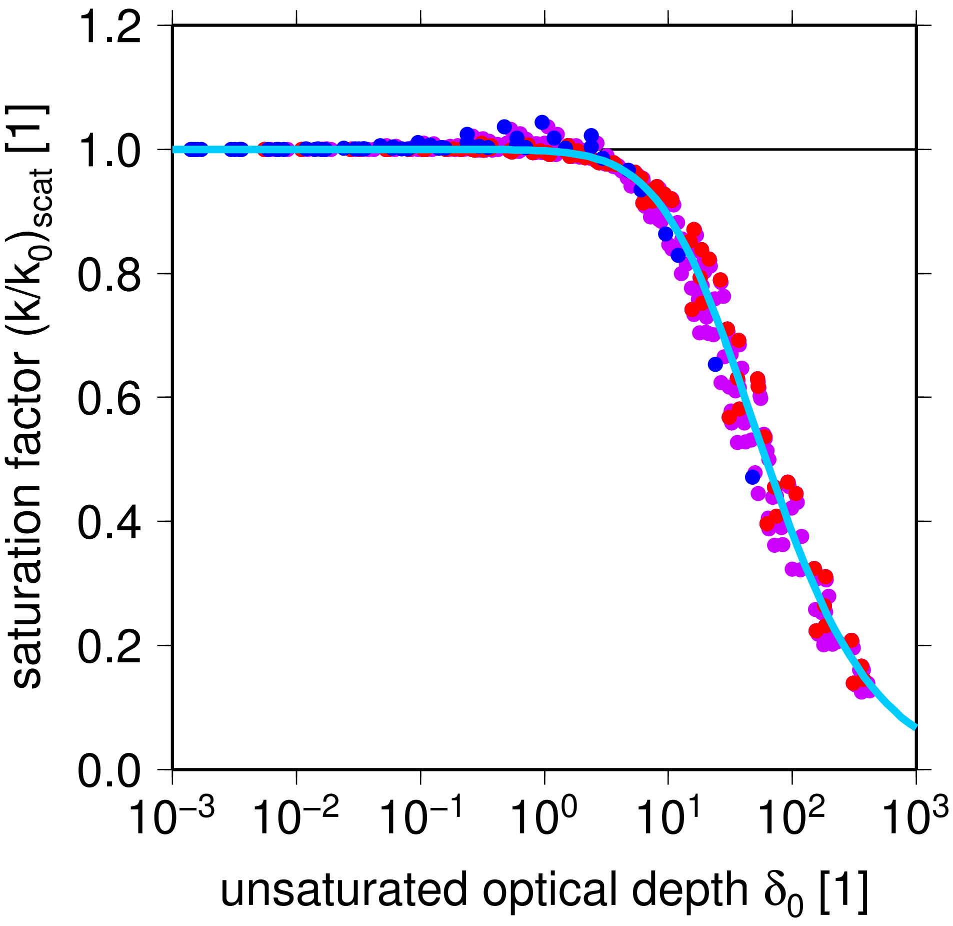


Heymsfield and McFarquhar 1996 (ALARO-1 version A)

(● – 8 standard liquid clouds of Stephens 1978 fitted by the red curve; the green curve is based on the fit of more realistic aircraft measurements)

Old SW saturation curves

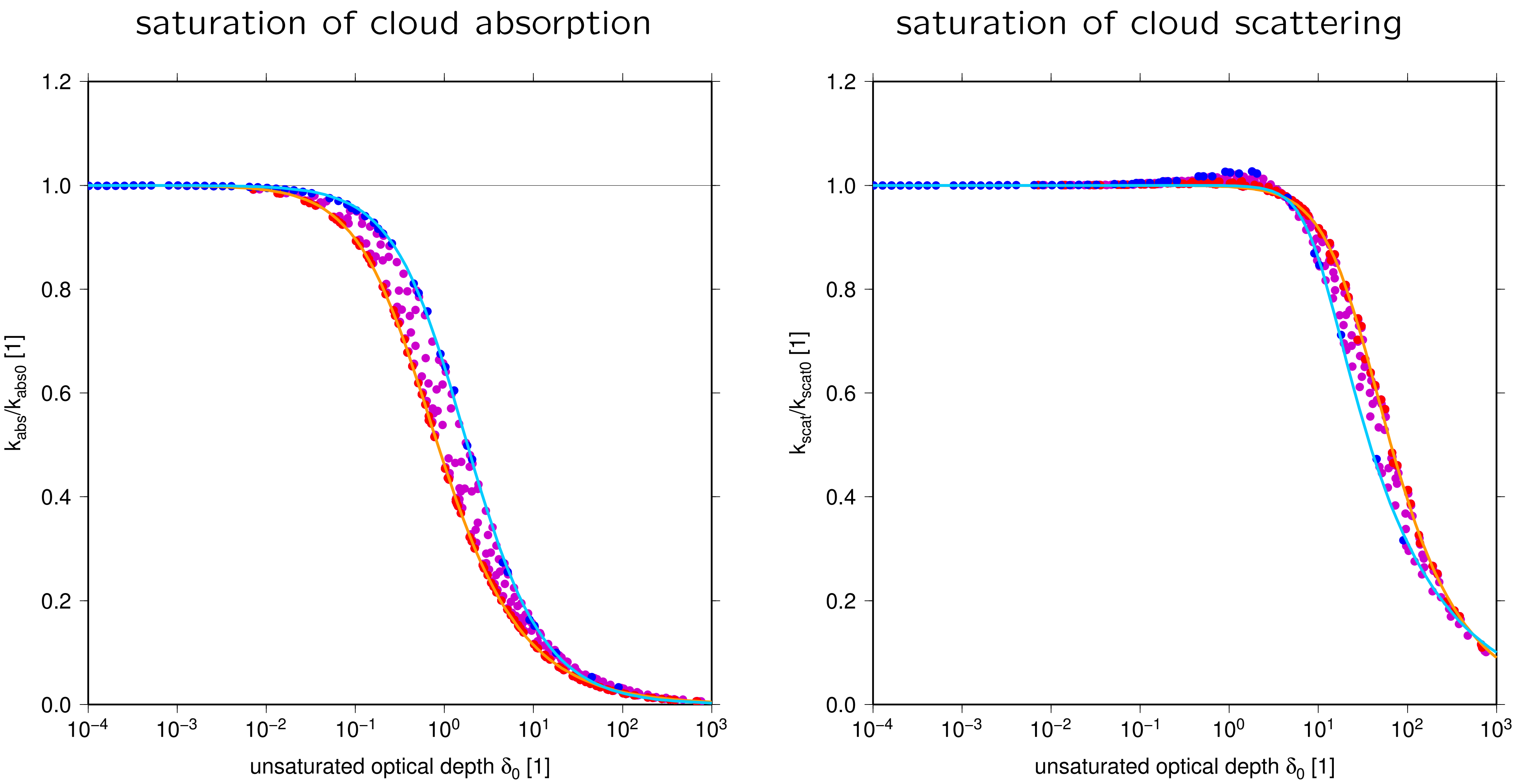

saturation of cloud absorption


saturation of cloud scattering

liquid clouds
ice clouds
composed clouds

common fit for liquid
and ice clouds

New SW saturation curves



saturation of cloud absorption

saturation of cloud scattering

liquid clouds
ice clouds
composed clouds

fit for liquid clouds
fit for ice clouds

Functional form of the new fits

- saturation factor $c^{\mathrm{abs}} \equiv k^{\mathrm{abs}}/k_0^{\mathrm{abs}}$ can be fitted with respect to unsaturated cloud optical depth δ_0 using simple 3-parametric formula:

$$c^{\mathrm{abs}}(\delta_0) = \frac{1}{\left[1 + \left(\frac{\delta_0}{\delta_{00}}\right)^m\right]^n} \qquad \delta_{00}, m, n > 0$$

- distinct fits for liquid and ice clouds are needed, there are thus 6 fitting parameters altogether

- saturation of SW cloud scattering can be neglected by setting $c^{\mathrm{scat}} = 1$

- in LW band, cloud optical saturation can be ignored completely

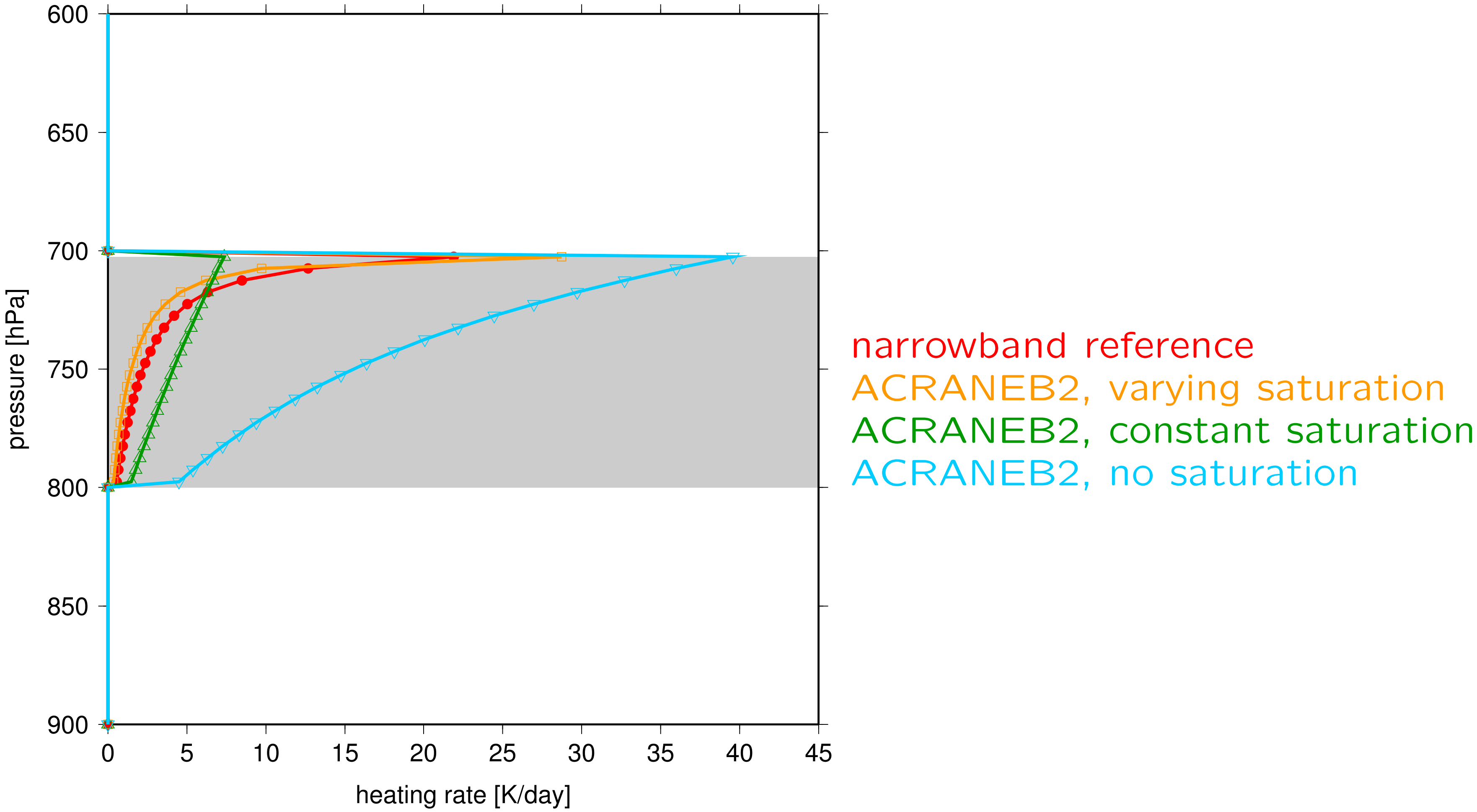
- generalization to multi-layer case builds on the concept of effective cloud optical depth, containing another 4 fitting parameters:

$$\delta_{0j}^{\mathrm{eff}} = \sum_{k=1}^{j-1} B_k^{\mathrm{above}} n_k \delta_{0k} + \delta_{0j} + \sum_{k=j+1}^{N} B_k^{\mathrm{below}} n_k \delta_{0k}$$

$$B_k^{\mathrm{above|below}} \equiv \frac{B_{\mathrm{l}}^{\mathrm{above|below}} \rho_{\mathrm{l}k} + B_{\mathrm{i}}^{\mathrm{above|below}} \rho_{\mathrm{i}k}}{\rho_{\mathrm{l}k} + \rho_{\mathrm{i}k}}$$

Vertical dependence of cloud optical saturation

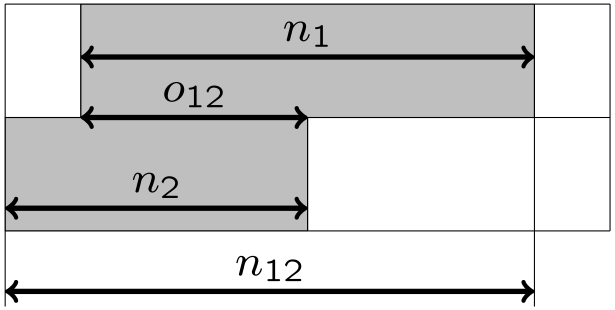
SW heating rates for liquid cloud with $q_\mathrm{l} = 0.1\,\mathrm{g} \cdot \mathrm{kg}^{-1}$
(no gaseous absorption and scattering, no aerosols)



Exponential-random overlap between cloud layers

Basic model cloud overlaps

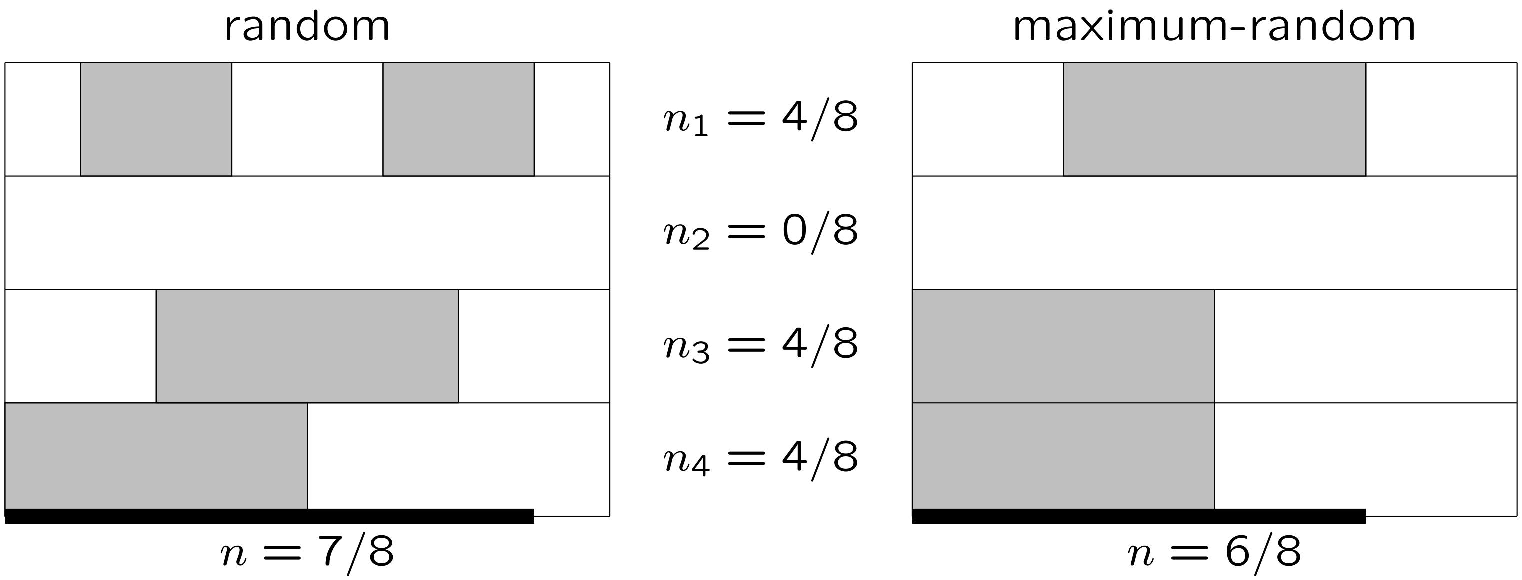
- adjacent cloud layers: random or maximum overlap



$$n_{12} = n_1 + n_2 - o_{12}$$

$$o_{12} = \begin{cases} n_1 n_2 & \text{– random} \\ \min(n_1, n_2) & \text{– maximum} \end{cases}$$

- more distant cloud layers: geometry not constrained by adjacent overlaps is random ⇒ **random** or **maximum-random** cloud overlap



Generalized cloud overlap

- random cloud overlap is unphysical for high vertical resolutions
- so far, ACRANEB2 used more realistic maximum-random cloud overlap
- still there is observational evidence that overlap of distant cloud layers is smaller than dictated by maximum-random overlap
- solution is to introduce generalized cloud overlap with weight $\alpha < 1$:

$$o_{12} = (1 - \alpha) n_1 n_2 + \alpha \min(n_1, n_2)$$

- when α is chosen to decay exponentially with layer separation Δp, **exponential-random** cloud overlap is obtained:

$$\alpha = \exp\left[-\Delta p / (\Delta p)_{\mathrm{decorr}}\right]$$

- decorrelation depth $(\Delta p)_{\mathrm{decorr}}$ is higher in situations with deep convection, it should be at least latitude and season dependent

Cloud overlaps in ALARO-1 version A

- for historical reasons, there are 3 independent cloud geometries in ALARO-1 – microphysical, radiative and diagnostic

- microphysics assumes **exponential-random** overlap between cloud layers when handling geometry of clouds and falling precipitation (subroutine APLMPHYS)

- radiation assumes random or **maximum-random** overlap between cloud layers (subroutine ACRANEB2)

- diagnostics computes high/medium/low and total cloud covers, assuming random, maximum-random or **nearly maximum-random** overlap between cloud layers (subroutine ACNPART)

- ALARO-1 version A combines 3 different cloud overlap hypotheses! (given in bold font)

Cloud overlap modes and related namelist variables

routine	cloud overlap mode	LRNUMX	LACPANMX
APLMPHYS	exponential-random	—	—
ACRANEB2	random	.F.	—
	maximum-random	.T.	—
ACNPART	random	.F.	—
	maximum-random	.T.	.F.
	nearly maximum-random	.T.	.T.

- cloud overlap in APLMPHYS is always exponential-random, with decorrelation depth RDECRD (default setting 20000. alias 200 hPa)
- nearly maximum-random overlap in ACNPART is controlled by weight WMXOV (ALARO-1 version A setting 0.8)
- WMXOV=0.0 reduces to random overlap and WMXOV=1.0 reduces to maximum-random overlap
- location:

&NAMPHY	LRNUMX, LACPANMX
&NAMPHY0	RDECRD, WMXOV

Step towards unified cloud geometry

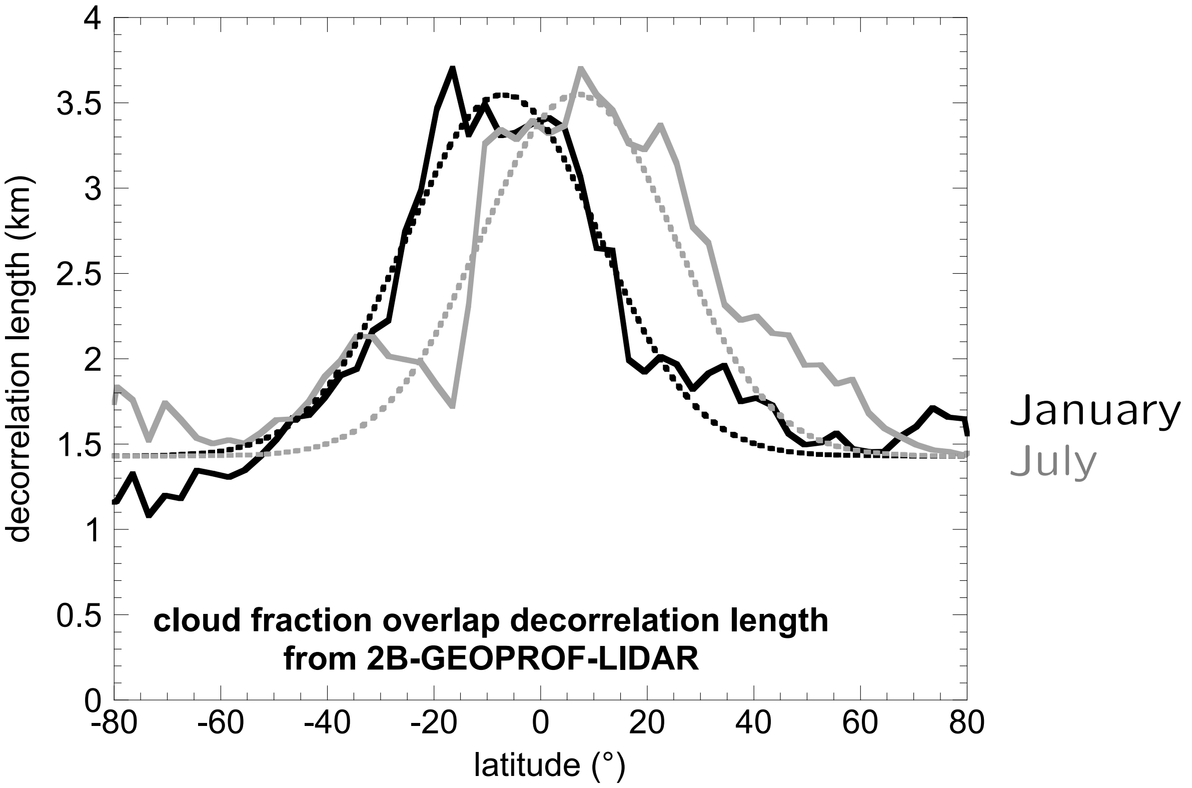
- in order to unify cloud geometry hypotheses in ALARO-1, exponential-random overlap was implemented in radiation and diagnostics
- for backward compatibility, decorrelation depth in microphysics can be held constant by setting RDECRD>0, otherwise it is shared with radiation and diagnostics (i.e. latitude and season dependent)
- **activation:**

&NAMPHY	LRNUEXP=LRNUMX=.T. LACPANMX=.F.
&NAMPHY0	RDECRD=0.

- **problem:** tuning of decorrelation depth suitable for radiation still gives insufficient cloud cover compared to SYNOP observations
- **solution:** scale decorrelation depth in diagnostic cloud cover by factor RDECRDRED=0.4 (namelist &NAMPHY0)
- we hope for full unification of cloudiness in future (including cloud condensates and layer cloud fractions)
- even with RDECRDRED=0.4, radiative and diagnostic cloud covers are closer than for old LACPANMX treatment with WMXOV=0.8

Decorrelation depth in ALARO-1

- decorrelation depth is inspired by results of Oreopoulos et al. 2012:

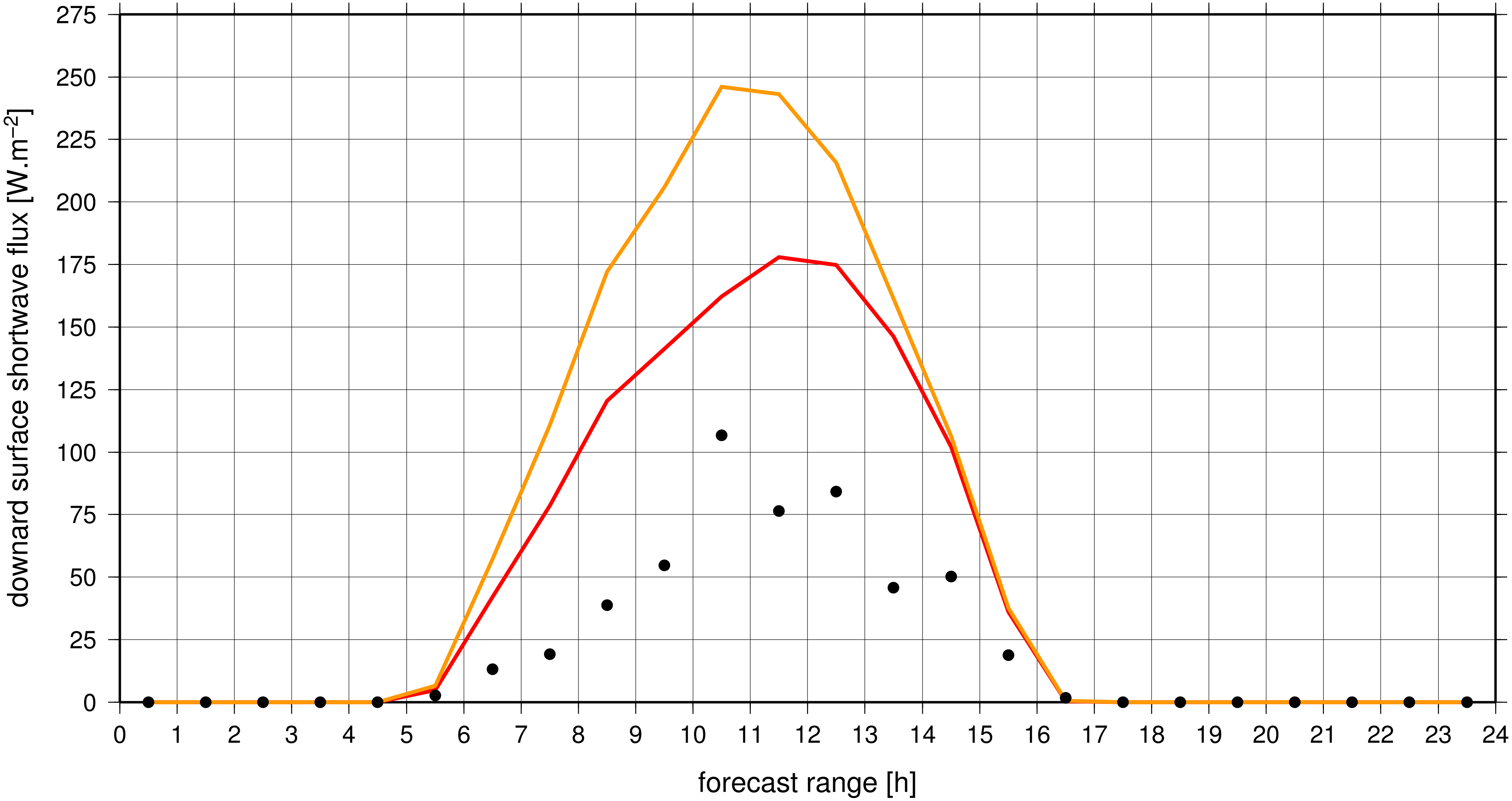


- in ALARO-1, decorrelation depth is modified into the shape:

$$(\Delta p)_{\mathrm{decorr}} = r_1 + r_2 \exp\left[-\left(\frac{\varphi - r_3\delta}{r_4}\right)^2\right] \qquad \begin{array}{ll} r_1 = 100\,\mathrm{hPa} & r_3 = 0.30 \\ r_2 = 200\,\mathrm{hPa} & r_4 = 0.45 \end{array}$$

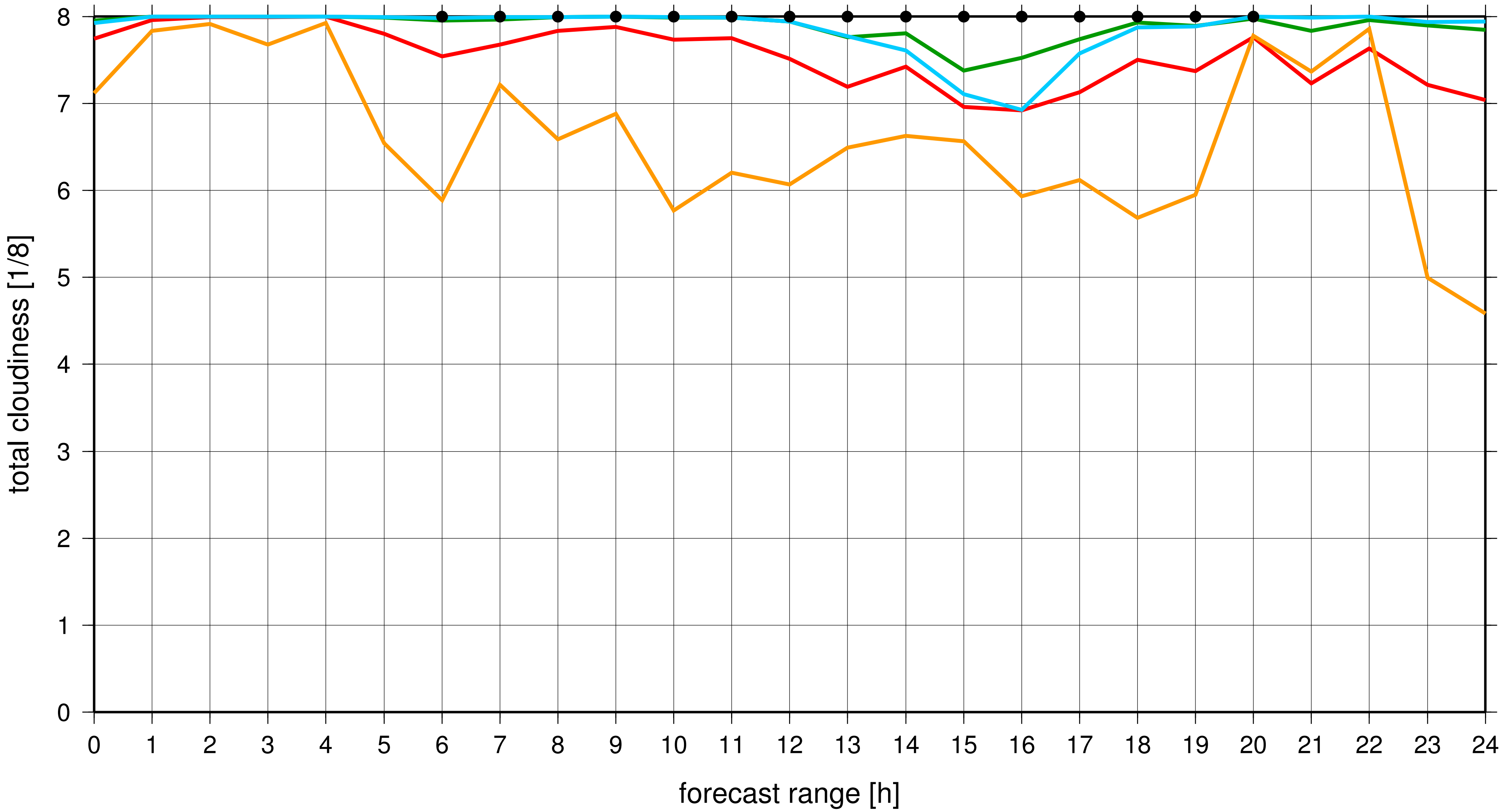
φ – latitude [rad], δ – solar declination [rad], $r_{[\mathrm{x}]}$ – RDECRD[x]

Case of Christoph Wittmann – global radiation (14-Oct-2015, Prague)



exponential-random overlap
maximum-random overlap

Case of Christoph Wittmann – cloud cover
(14-Oct-2015, Prague)



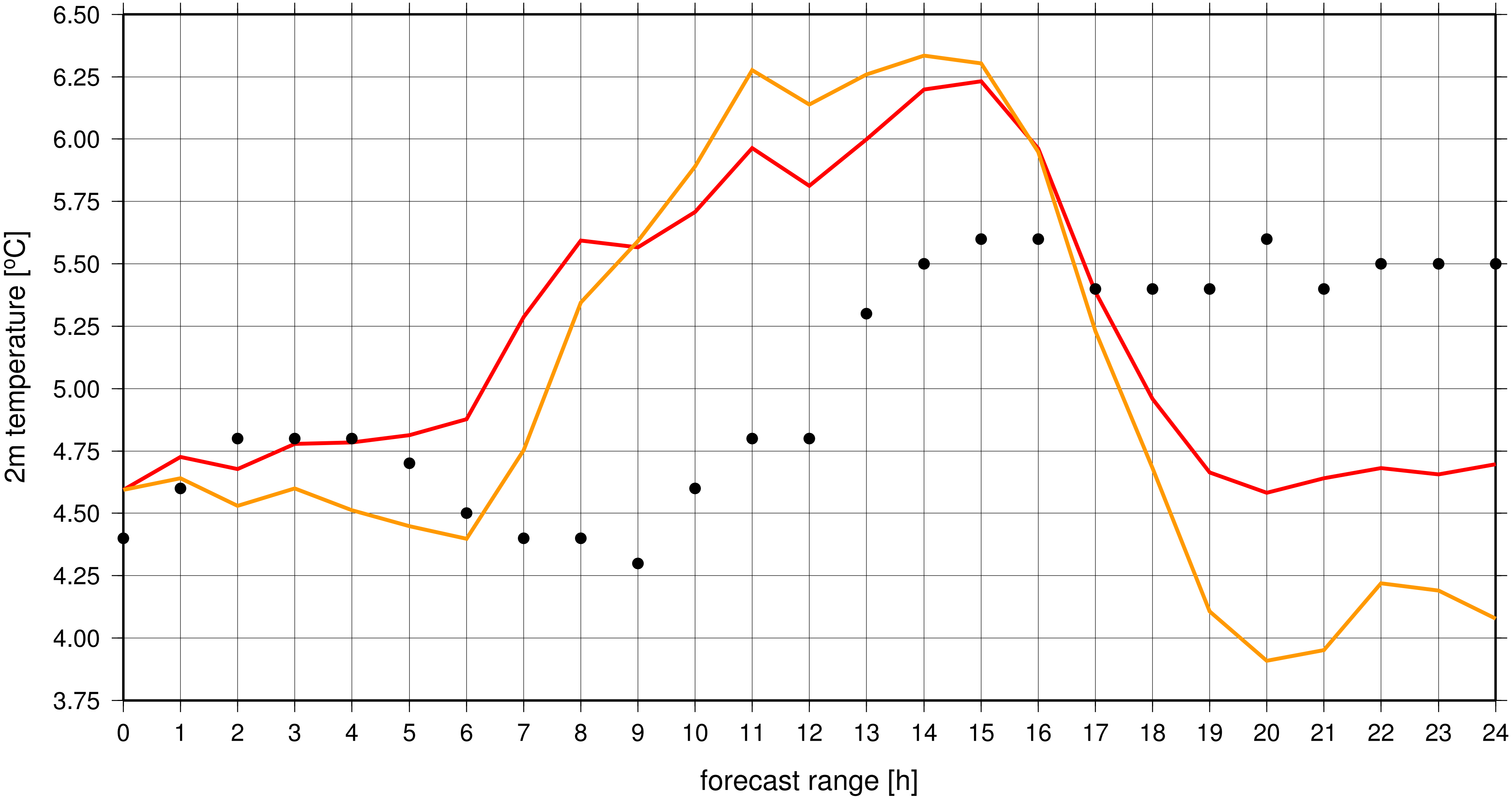
exponential-random overlap

maximum-random overlap

exponential-random overlap, RDECRDRED=0.4

nearly maximum-random overlap, WMXOV=0.8

Case of Christoph Wittmann – 2m temperature (14-Oct-2015, Prague)

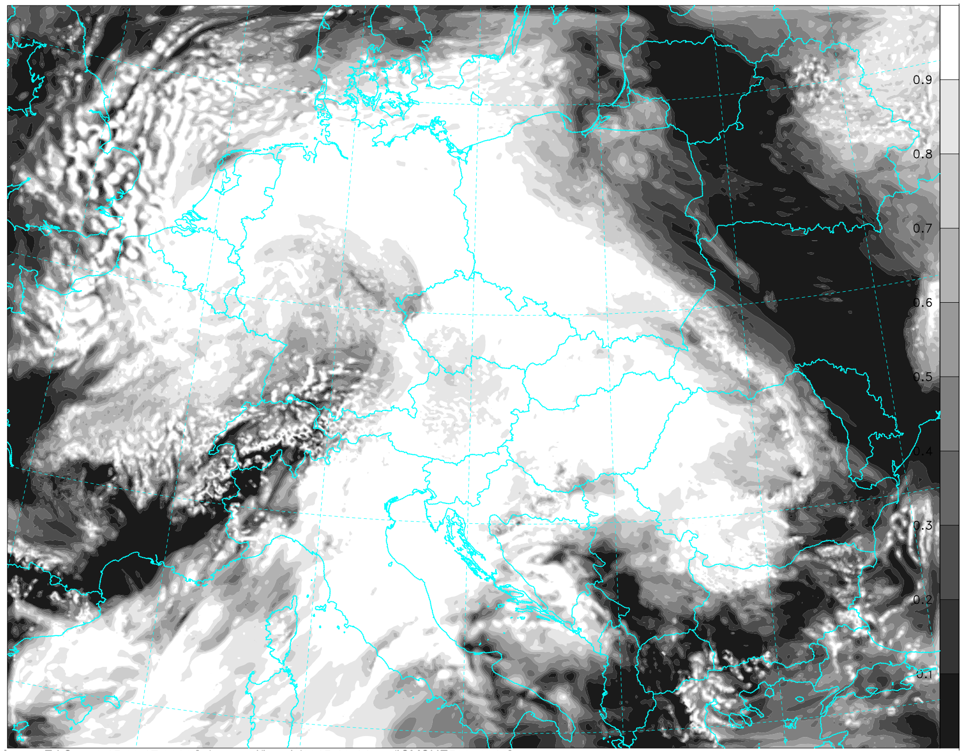


exponential-random overlap

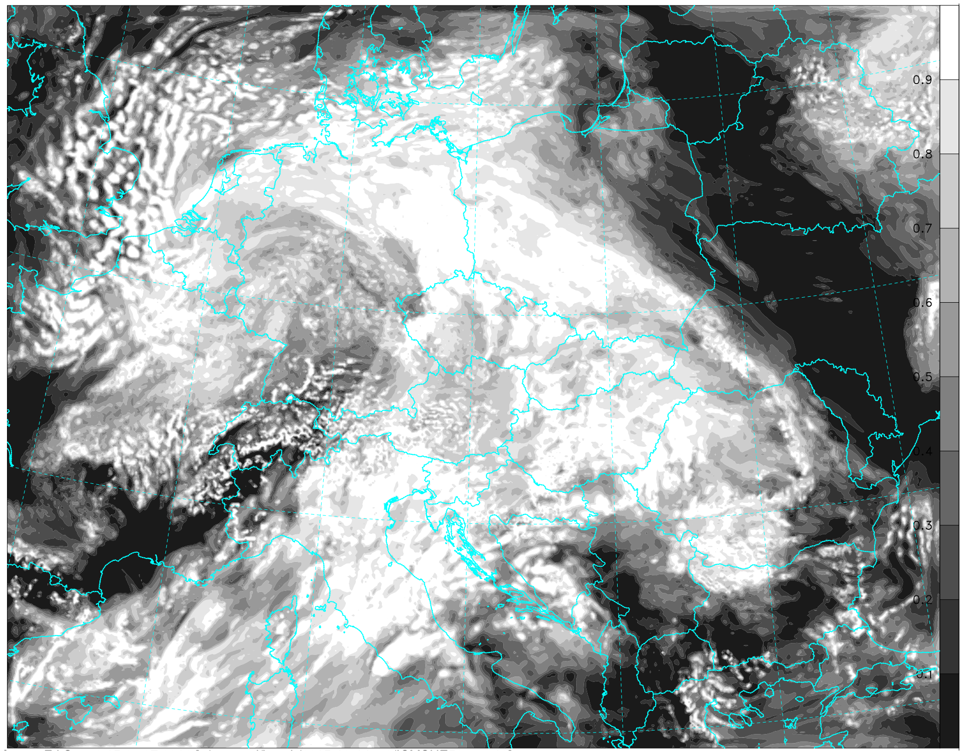
maximum-random overlap

Case of Christoph Wittmann – radiative cloud cover (14-Oct-2015, 12 UTC)

exponential-random overlap
(LRNUEXP)

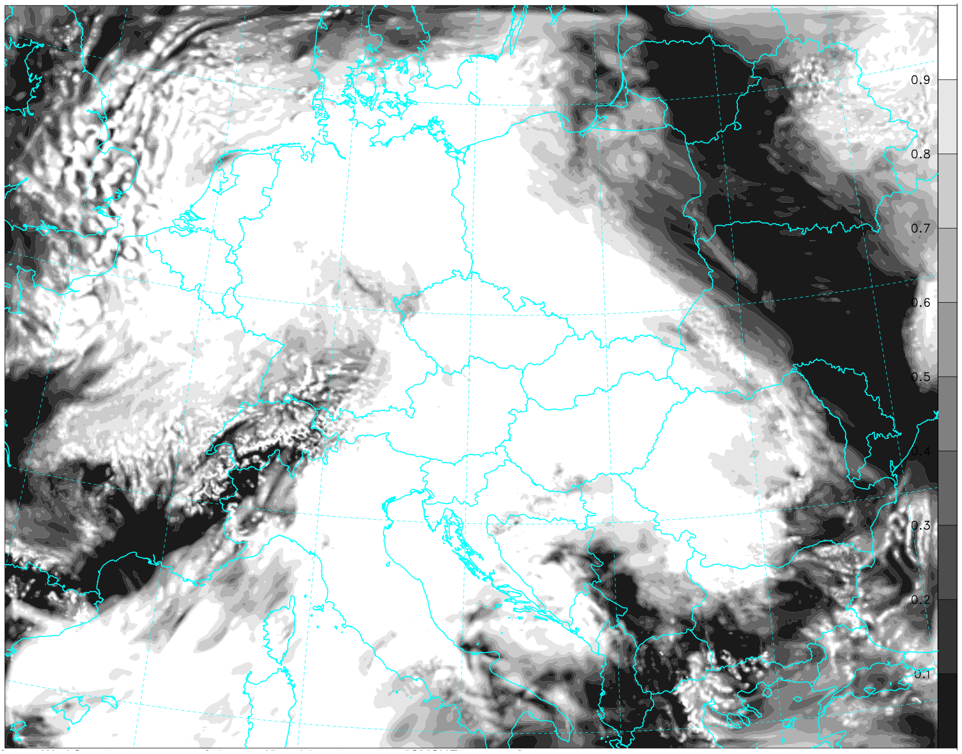


maximum-random overlap
(LRNUMX)

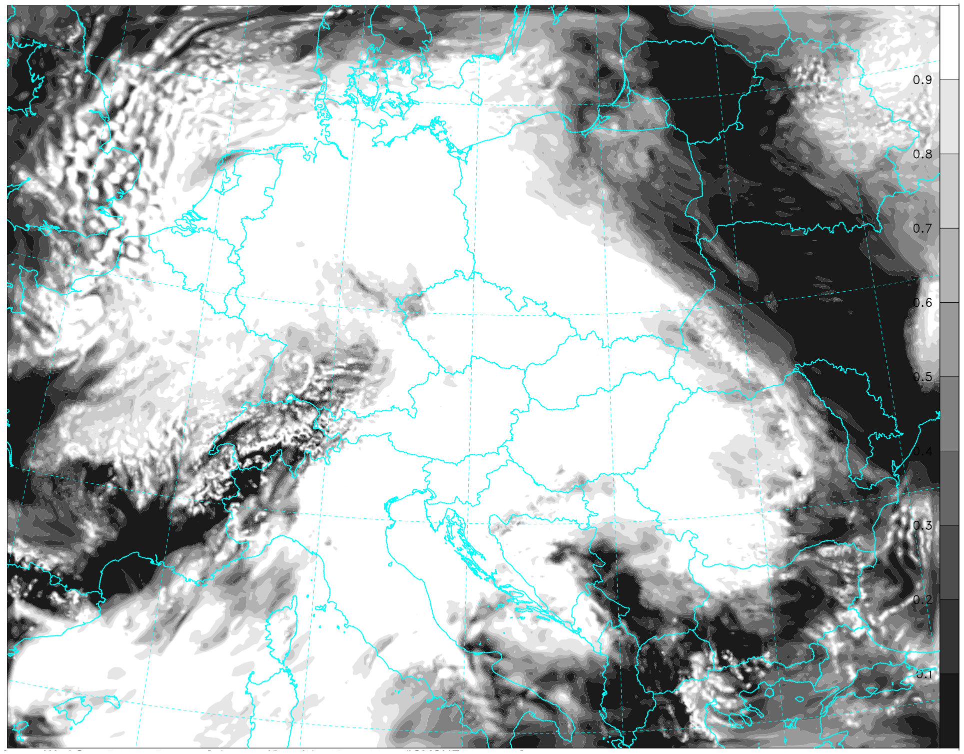


Case of Christoph Wittmann – diagnostic cloud cover (14-Oct-2015, 12 UTC)

exponential-random overlap
(LRNUEXP, RDECRDRED=0.4)



nearly maximum-random overlap
(LACPANMX, WMXOV=0.8)

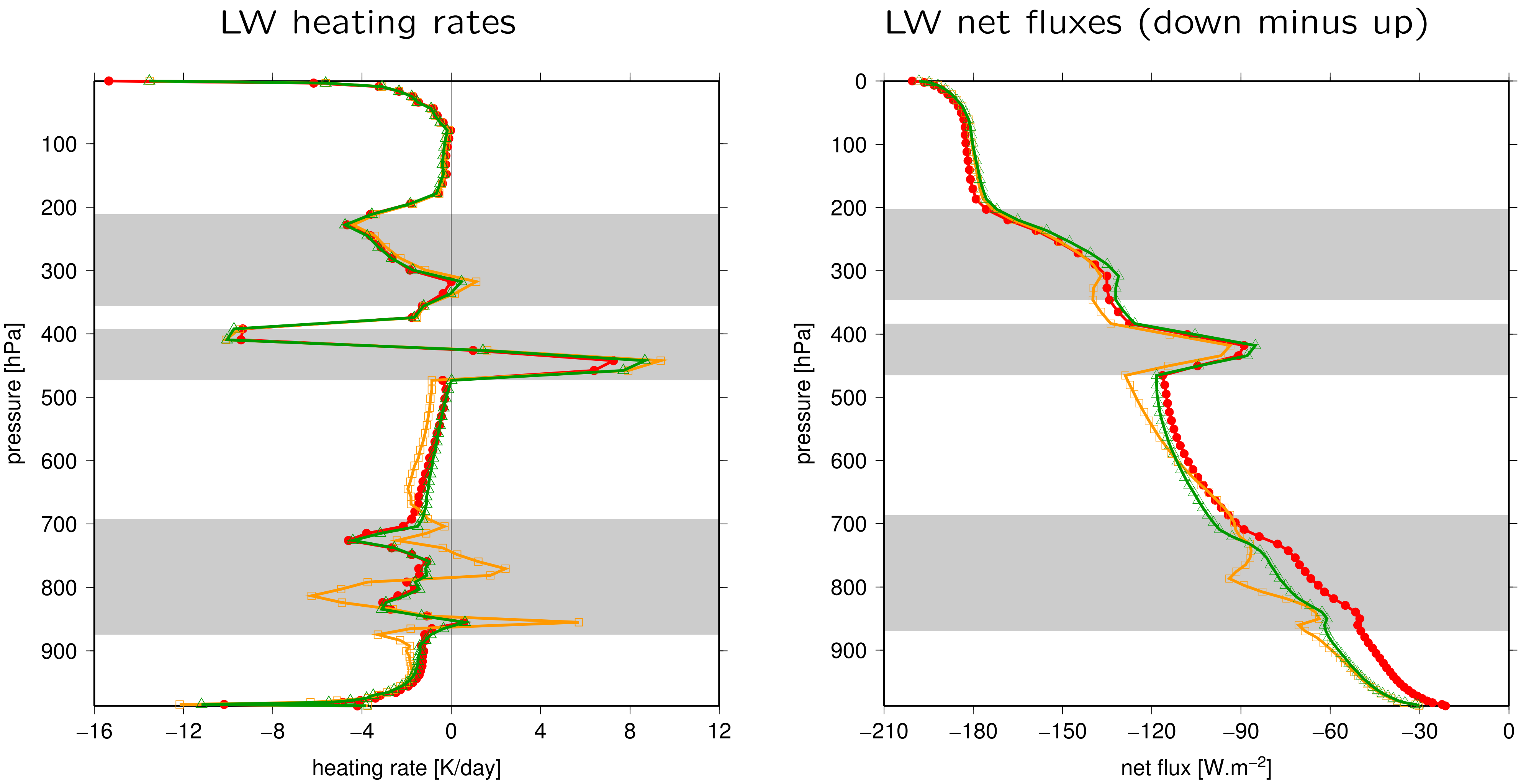


Revised bracketing

NER decomposition with bracketing

- in a band approach, computational cost of LW exchanges is **quadratic** in the number of levels L
- the above computational barrier can be broken by the net exchanged rate (NER) decompostition with bracketing, where the costly exchange between layers (EBL) is interpolated between its minimum and maximum estimates with the cost **linear** in L
- interpolation weights are obtained in a gaseous case, then applied in a full case including aerosols, clouds and LW scattering
- weights are uncertain in the vicinity of critical levels, where the gaseous min/max EBL estimates intersect $\Rightarrow$ numerical filter needed
- current empirical tuning of the filter turned to be weak, sometimes creating overshoots near the critical levels
- new tuning obtained on real case profiles removes overshoots and gives more accurate LW fluxes
- unfortunately, in 3D runs it increases warm bias around 700 hPa level, so it had to be deactivated in CHMI double suite (further ALARO-1 retuning needed before reactivation)

Overshoots due to old tuning of bracketing



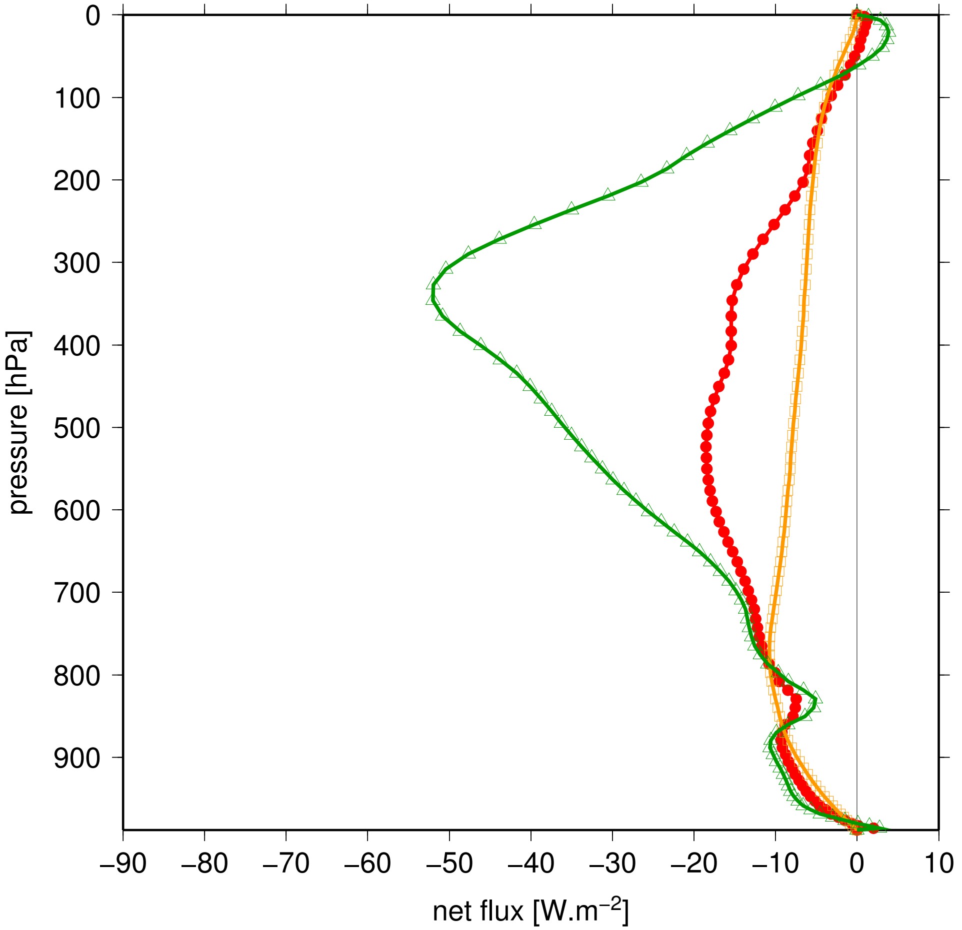
narrowband reference

ACRANEB2, old tuning of bracketing

ACRANEB2, new tuning of bracketing

Origin of overshoots

clearsky EBL fluxes

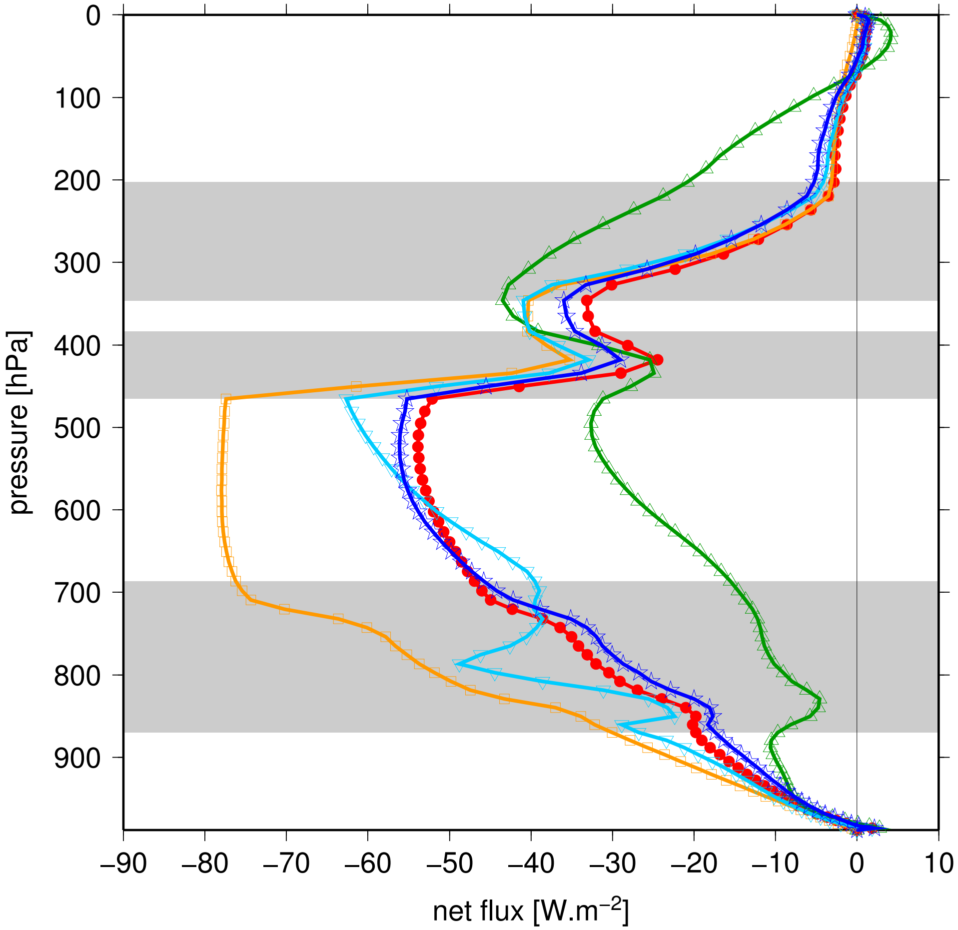


true EBL flux (cost quadratic in L)

minimum EBL estimate

maximum EBL estimate

cloudy EBL fluxes



bracketed EBL flux, new tuning

minimum EBL estimate

maximum EBL estimate

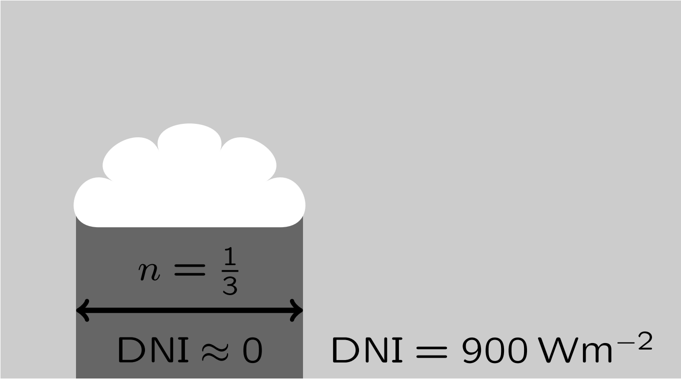
bracketed EBL flux, old tuning

true EBL flux, narrowband reference

Sunshine duration, true direct solar flux

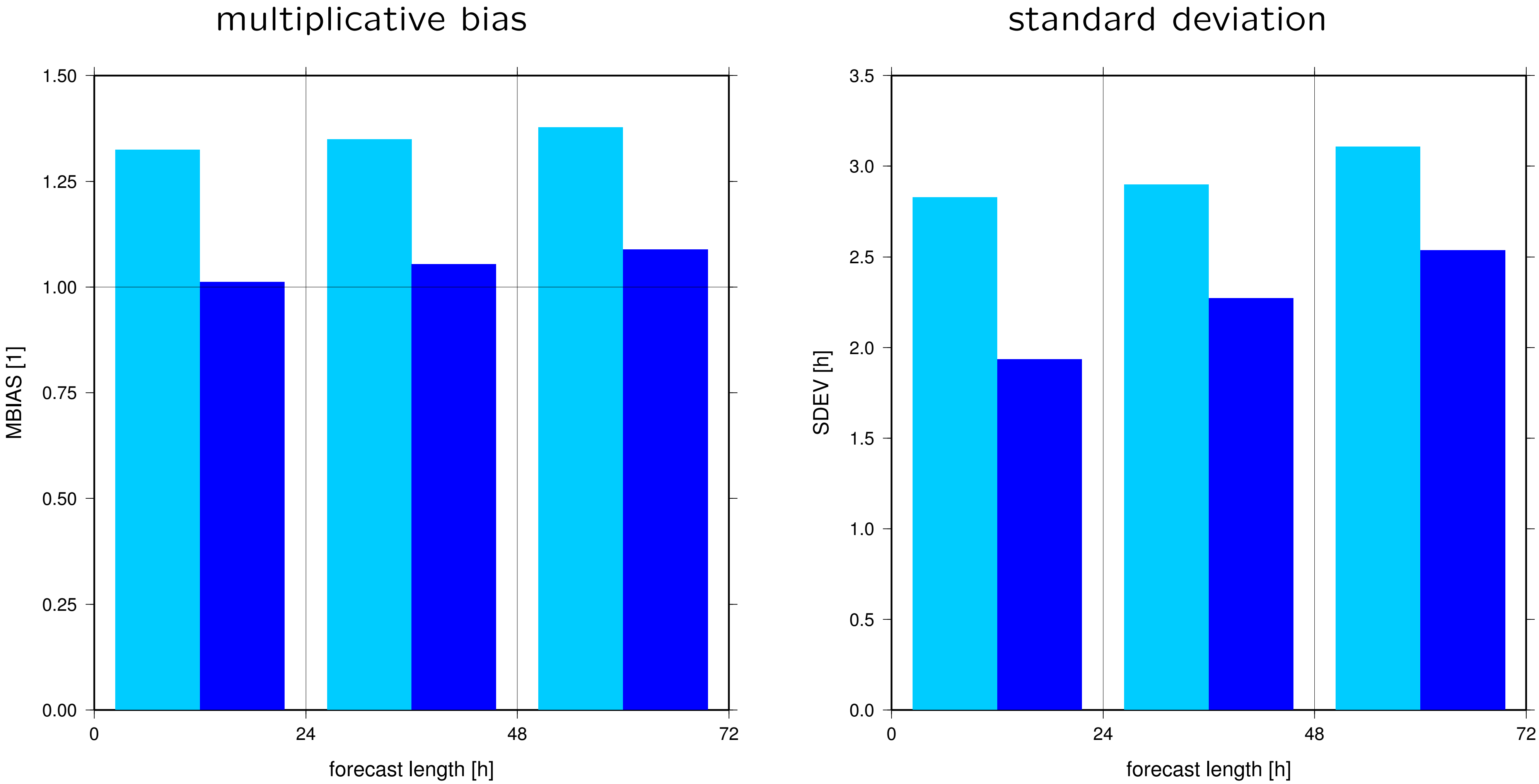
Tricky diagnostics of sunshine duration

- sunshine condition is defined as direct normal irradiance (DNI) at the surface exceeding 120 $\mathrm{W m^{-2}}$
- determining sunshine duration from gridbox averaged DNI leads to severe overestimation in cases with partial cloud cover



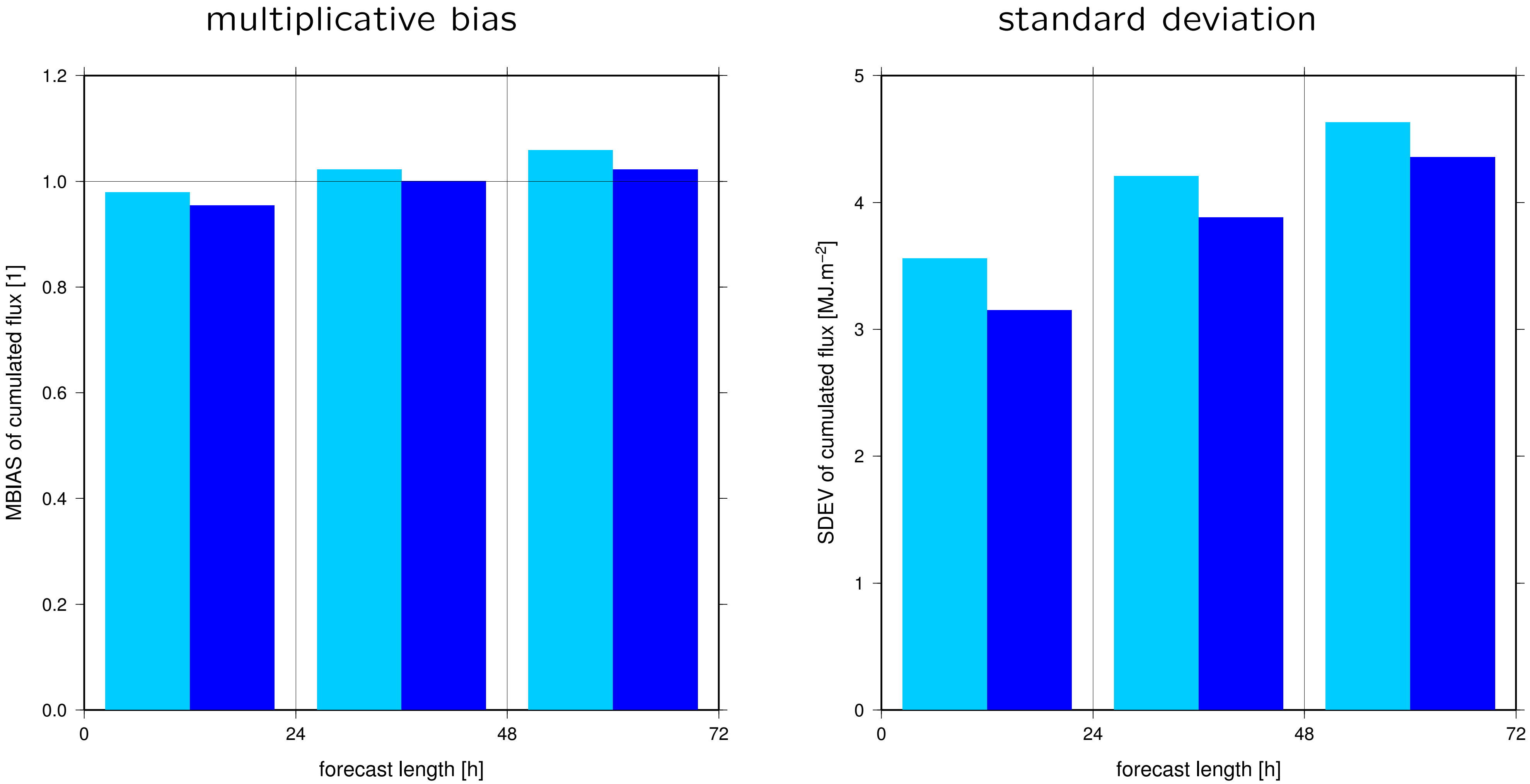
- gridbox averaged DNI $\approx 600\,\mathrm{W m^{-2}} \Rightarrow$ sunshine during whole timestep, while in reality it would be only during $\frac{2}{3}$ of timestep!
- **solution:** evaluate sunshine condition separately below clouds and in the clearsky part of gridbox, then weight the result by cloud cover

Scores of daily sunshine duration (30-Jun-2016 to 07-Sep-2016, 19 CZ stations)



CHMI oper suite
CHMI double suite

Scores of daily direct solar flux (30-Jun-2016 to 07-Sep-2016, 6 CZ stations)

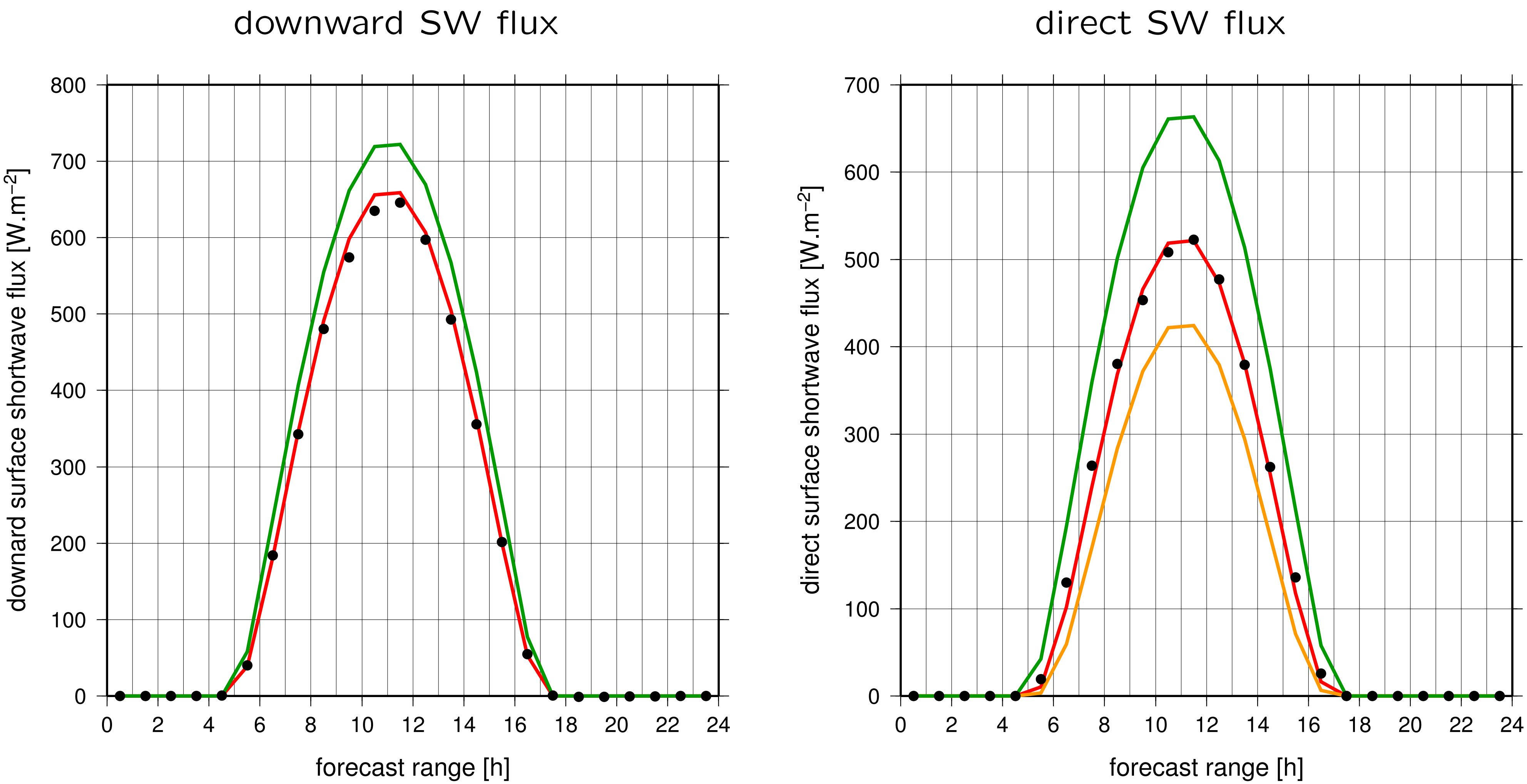


CHMI oper suite
CHMI double suite

Dilemma with direct solar flux

- delta-two stream formulation assumes direct (unscattered) solar radiation as perfectly collimated
- measuring instruments usually collect direct solar radiation from 5° wide circumsolar region, including also photons single scattered at small angles
- atmospheric aerosols produce bright aureole around the sun, that can significantly increase measured clearsky direct solar flux
- in model, similar effect can be achieved by delta-scaling, assuming direct solar radiation scattered via forward Dirac peak of approximated phase function as unscattered
- below thicker clouds, delta-scaling of direct solar flux causes its severe overestimation (multiple scattering at small angles can easily deflect photons by more than 2.5°, while multiple scattering via forward Dirac peak cannot)
- **solution:** diagnose surface direct solar flux separately below clouds and in the clearsky part of gridbox, apply delta-scaling only on clearsky part of direct flux ⇒ better correspondence with measurements

Impact of delta-scaling on clearsky direct solar flux (19-Mar-2015, Kuchařovice)



downward SW flux, no aerosols
downward SW flux

direct SW flux, no aerosols
direct SW flux, delta-scaled
direct SW flux, unscaled

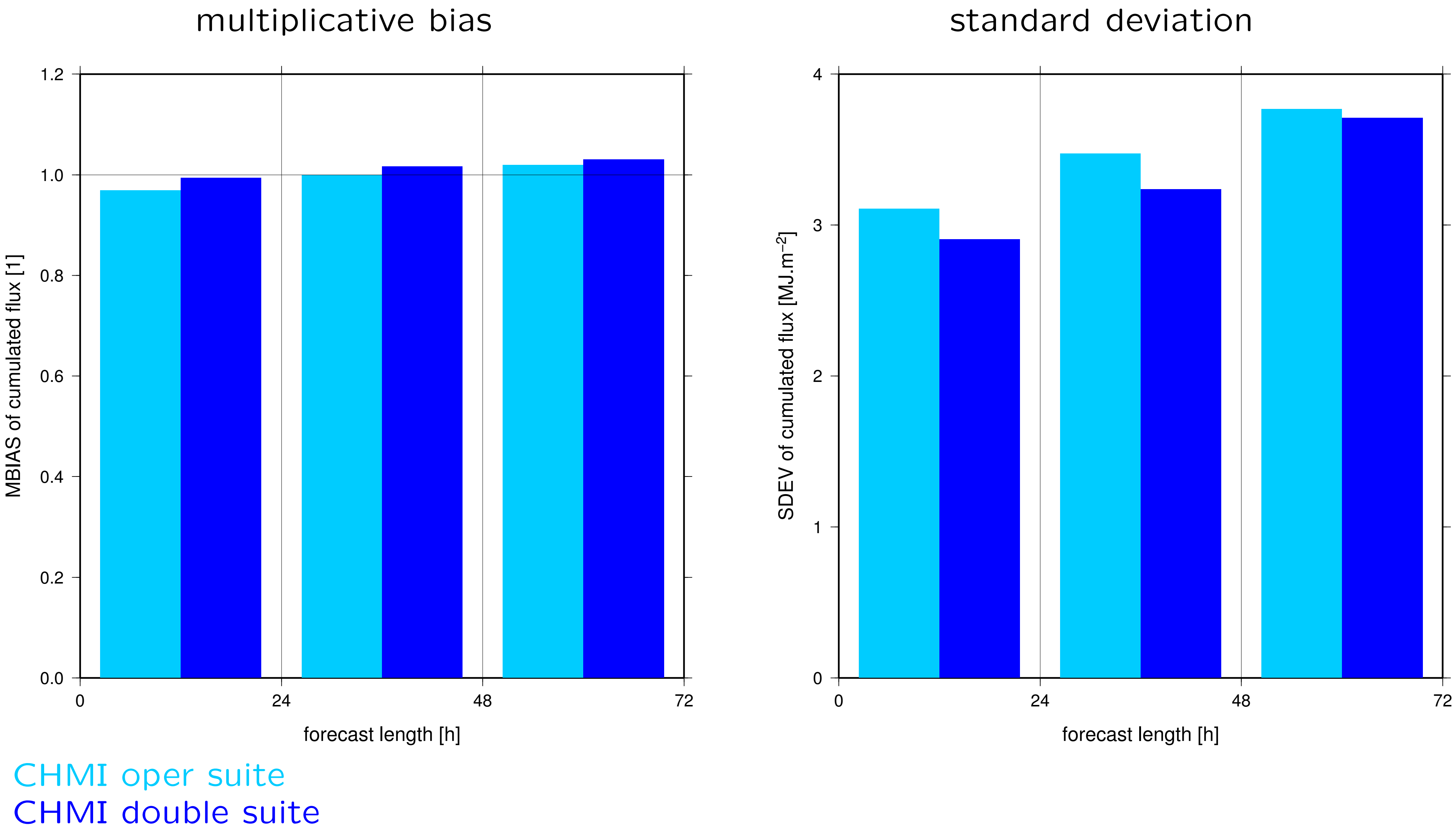
Few more verification results

Content of current oper and double suites at CHMI

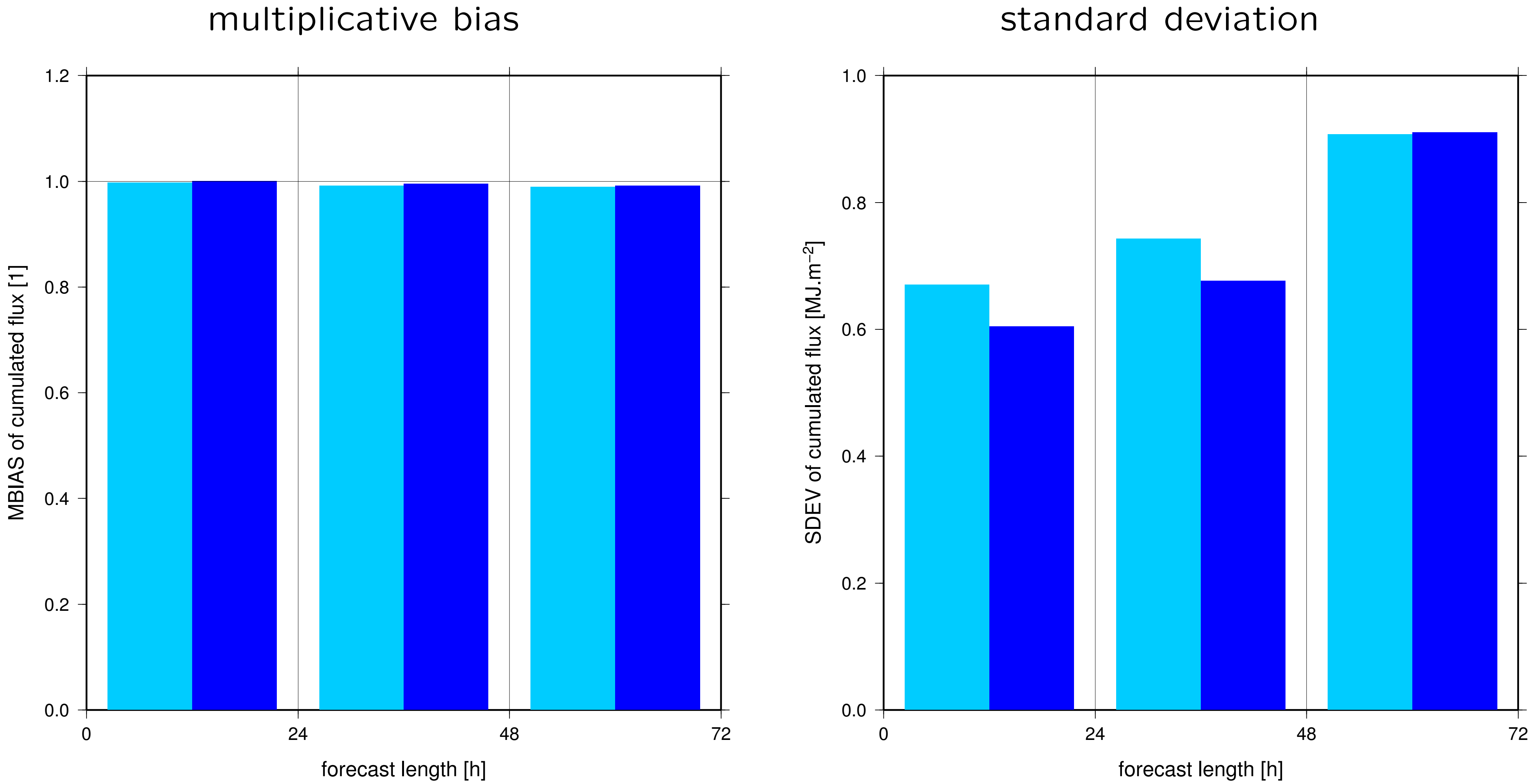
- oper suite:
  - ALARO-1 version A settings
  - new 2m diagnostics of temperature and humidity in stable conditions, affecting also obs operator in surface CANARI
  - diagnostics of sunshine duration based on gridbox averaged unscaled direct solar flux

- double suite:
  - activated on 29-Jun-2016, still running
  - correct diagnostics of 10m wind when lowest model level falls below measurement height
  - new parameterization of shallow convection on the turbulence side, based on mass flux approach
  - exponential-random cloud overlap with same decorrelation depth in microphysics and radiation; in diagnostics scaled by factor 0.4
  - diagnostics of surface direct solar flux applying delta-scaling in clearsky part of gridbox
  - diagnostics of sunshine duration taking into account subgrid variability of surface direct solar flux

Scores of daily downward SW flux (30-Jun-2016 to 07-Sep-2016, 19 CZ stations)



Scores of daily downward LW flux
(30-Jun-2016 to 07-Sep-2016, 1 CZ station)



CHMI oper suite
CHMI double suite

Publications, code info, future challenges

Publications

- SW ACRANEB2 paper (QJRMS):
  - submitted on 08-Jan-2015
  - revised on 17-Apr-2015 and 22-Jul-2015
  - accepted on 11-Aug-2015
  - **published in January 2016, DOI:10.1002/qj.2653**

- LW ACRANEB2 paper (QJRMS):
  - submitted on 17-Jun-2016
  - **in a review process**

- direct consequence of writing the papers was **significant improvement** of ACRANEB2 scheme:
  - thoroughful verification against SW and LW narrowband references helped to identify the weak points, some of them are cured already
  - sometimes it is easier to redo the things cleanly rather than to advocate the dirty way they are done

ACRANEB2 radiation in official cy40t1 (ACRANEB2 baseline version)

- new fits of gaseous transmissions based on HITRAN 2008 line parameters, Serdyuchenko et al. 2014 ozone absorption cross-sections, and MT_CKD model version 2.5.2 of water vapour e-type continuum
- parameterized non-random spectral overlaps between gaseous pairs
- parameterized saturation of Rayleigh scattering
- liquid clouds: Stephens 1978
- ice clouds: Edwards et al. 2007 with optical saturation based on Rockel et al. 1991 high resolution data
- cloud optical parameters fitted directly against LWC and IWC
- intermittent update of LW gaseous transmissions and of bracketing weights
- angular dependency of direct surface albedo tuned against results of Gardner and Sharp 2010 for snow, and of Yang et al. 2008 for land

ACRANEB2 radiation in official cy43t1 (ALARO-1 version A; backphased to cy40t1_bf5)

- liquid clouds: Hu and Stamnes 1993
- ice clouds: SW – Key et al. 2002, LW – Yang et al. 2005
- cloud optical parameters fitted against R_e and D_e, that are in turn expressed via LWC and IWC respectively
- revised cloud optical saturation, different for liquid and ice clouds
- parameterized gas-cloud SW spectral overlap
- intermittent update also of SW gaseous transmissions

○ retuned bracketing

○ exponential-random cloud overlap with unified decorrelation depth

(○ – items not included in recommended tuning of ALARO-1 version A, missing in cy40t1_bf5)

ACRANEB2 extensions available at CHMI cy38t1tr_op6 (to be phased later)

- true direct solar flux, more consistent with instrumental measurements
- improved diagnostics of sunshine duration
- scaled decorrelation depth in diagnostic cloud cover (to be abandoned when unified cloud treatment is available)

Remark on recommended ALARO configurations

- at present, there are only two recommended ALARO configurations:

  1. ALARO-0 baseline version with old ACRANEB
  2. ALARO-1 version A with **successor** of ACRANEB2 baseline version

- cross combinations (e.g. in multi-physics EPS) are strongly deprecated, since they are neither sufficiently tested nor tuned, likely to be problematic (strong biases can trigger unrealistic model feedbacks)

- one should keep in mind that ACRANEB2 **baseline** version was never tuned with ALARO-0 or ALARO-1

- nevertheless, it was given “as is” to D. Lindstedt from SMHI, who used it in ALARO-0 climate simulations (old ACRANEB does not enable to modify concentrations of greenhouse gases without touching oxygen)

- such step was overly optimistic, since in the climate runs biases are challenge even for well tuned NWP configurations

- in climate modeling as well as in operational applications it is wiser to wait until the fresh NWP developments settle down

Future ACRANEB2 challenges

- using microphysical condensates and layer cloud fractions in radiation (requires deeper revision of ALARO-1 cloudiness)
- improving gaseous transmissions in the stratosphere (main limitations are Curtis-Godson approximation and a posteriori treatment of Voigt line shape)
- parameterizing impact of clouds on the broadband surface albedo (after Gardner and Sharp 2010)
- parameterizing 3D cloud effects in 1D radiative transfer (after Hogan and Shonk 2013)
- parameterizing optical properties of falling hydrometeors (challenge is snow)
- taking into account orographic effects on surface radiation budget (developed by HIRLAM, available via SURFEX)
- using near real time aerosol distribution and optical properties (first steps already done by HIRLAM), link of aerosols with microphysics

Limitations of 1D radiative transfer

- plane parallel approximation with inclusion of partial cloud cover, combined with delta-two stream and adding method has proved extremely successful in NWP
- however, in high horizontal resolutions (kilometric and finer), truly 3D radiative transfer becomes an issue
- it is most critical in the short range deterministic forecasts, where the exact localization of radiative heating is important
- for the time being it is not clear what the NWP solution will look like
- Monte Carlo algorithms are awfully expensive
- 3D solvers of radiative transfer equation are complicated and costly
- all 3D methods require a lot of communications, causing scalability problems

How much time is left for 1D radiative transfer in the short range NWP?

What will replace it?

My apology for ALARO-1 WD being only in September