B4 - Workpackage 2: Radiative heating and cooling at cloud scale and its impact on dynamics

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1 Summary

Paving the way towards an improved radiation parameterization for NWP models a set of radiative transfer calculations was carried out for a realistically evolving LES shallow cumulus cloud field comprising a wide range of total cloud cover and optical thickness, varying solar zenith angle (SZA) and surface albedo. The benchmark 3-D and supplement ICA experiments were performed on highly-resolved LES cloud field using the Monte Carlo radiation model. In order to imitate poor representation of shallow cumulus in NWP models, cloud optical properties were horizontally averaged over the cloudy part of the boxes with dimensions comparable to NWP horizontal grid spacing and the δ-Eddington two-stream method with maximum-random overlap assumption for partial cloudiness was applied (abbreviated to "1D" experiment). The ICA experiment is found to be steadily more accurate than the 1-D experiment (with respect to the same 3-D benchmark). This highlights the importance of an improved representation of subgrid-scale cloud structure even at the resolution of today's regional limited-area models (such as COSMO-DE with horizontal grid spacing of 2.8 km). The Tripleclouds method, originally developed by Shonk and Hogan (2008), is an approach to better represent cloud horizontal heterogeneity. Optimizations of this method are currently being explored within B4 - Workpackage 2.

2 Quantifying radiative biases in NWP models

Input shallow cumulus cloud fields

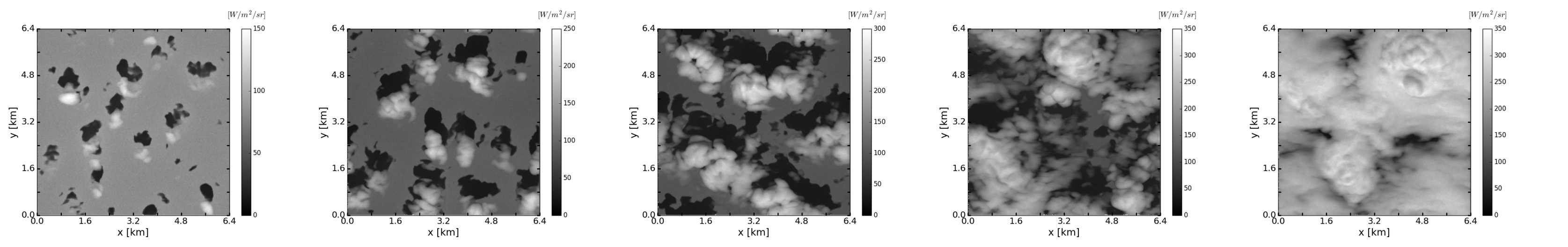

Figure 1: A set of shallow cumulus cloud fields used as input for radiative transfer calculations (visualized with the 3-D radiation model MYSTIC, Mayer, 2009).

Results

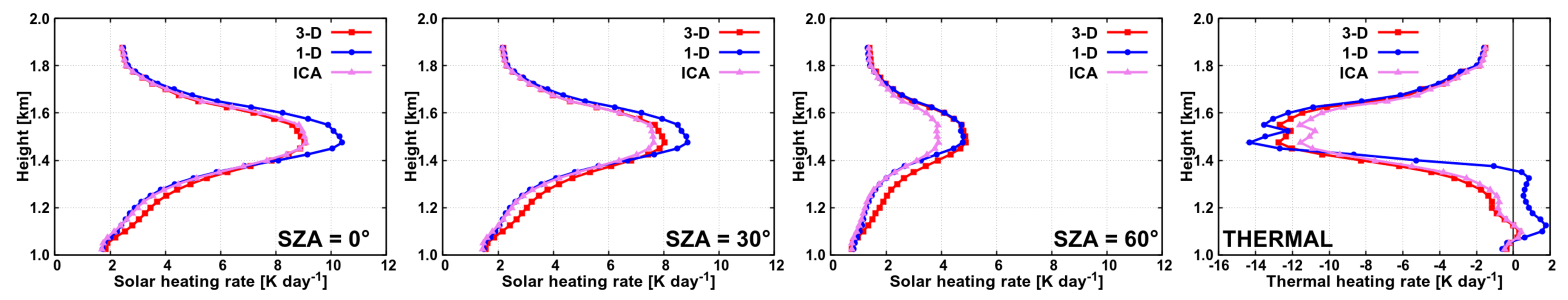

Figure 2: Solar and thermal heating rate in the cloud layer for a cumulus cloud field with a total cloud cover of 52.3 % in the trio (3-D, 1-D, ICA) of experiments with land albedo.

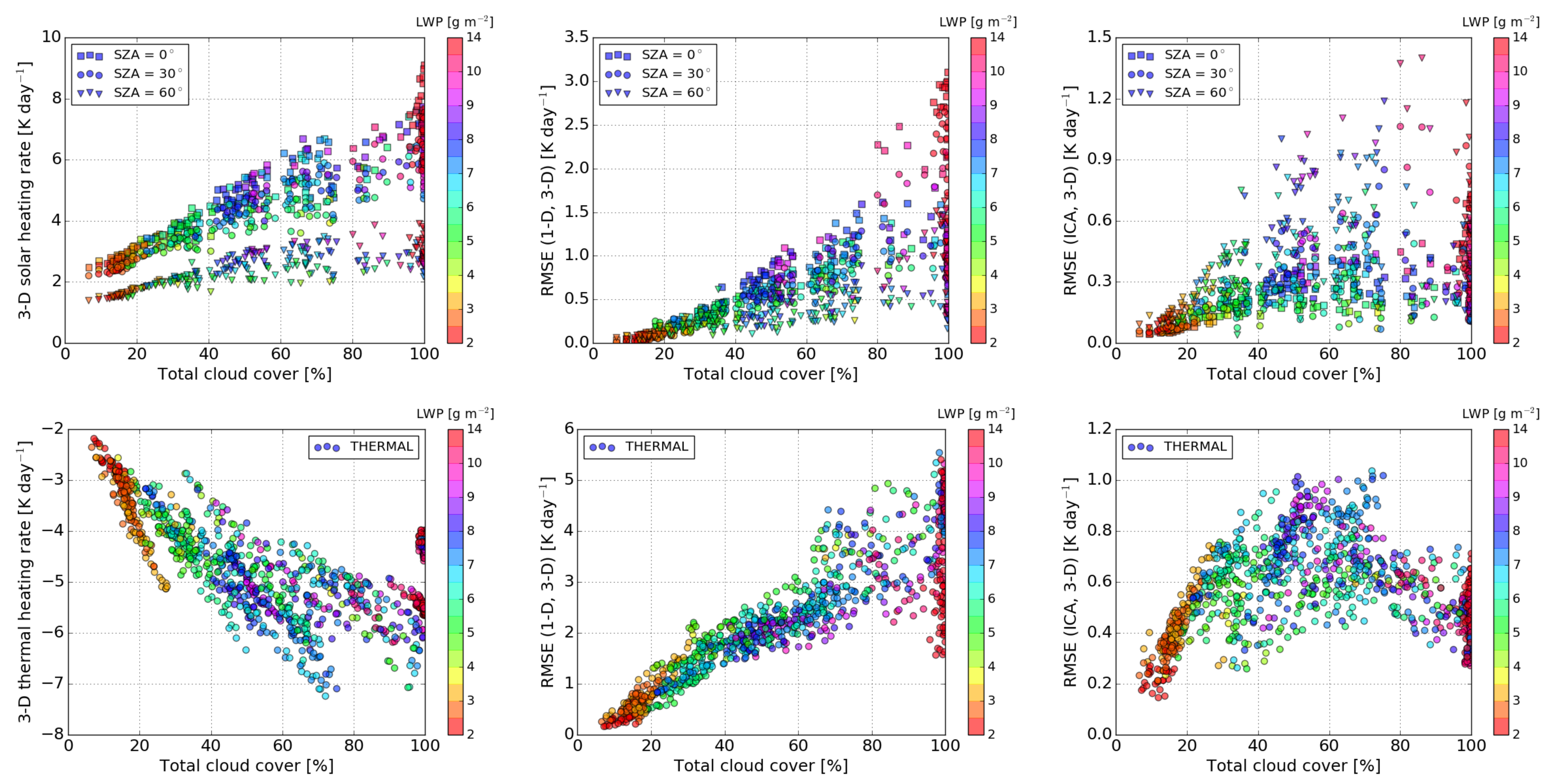

Figure 3: Solar (top row) and thermal (bottom row) heating rate in the cloud layer in the trio (3-D, 1-D, ICA) of experiments with land albedo. Left panels show the 3-D heating rate averaged over the height of the cloud layer, middle panels show the root mean square error (RMSE) between the pair (1-D, 3-D) of heating rate profiles, whereas right panels show the RMSE between the pair (ICA, 3-D) of heating rate profiles.

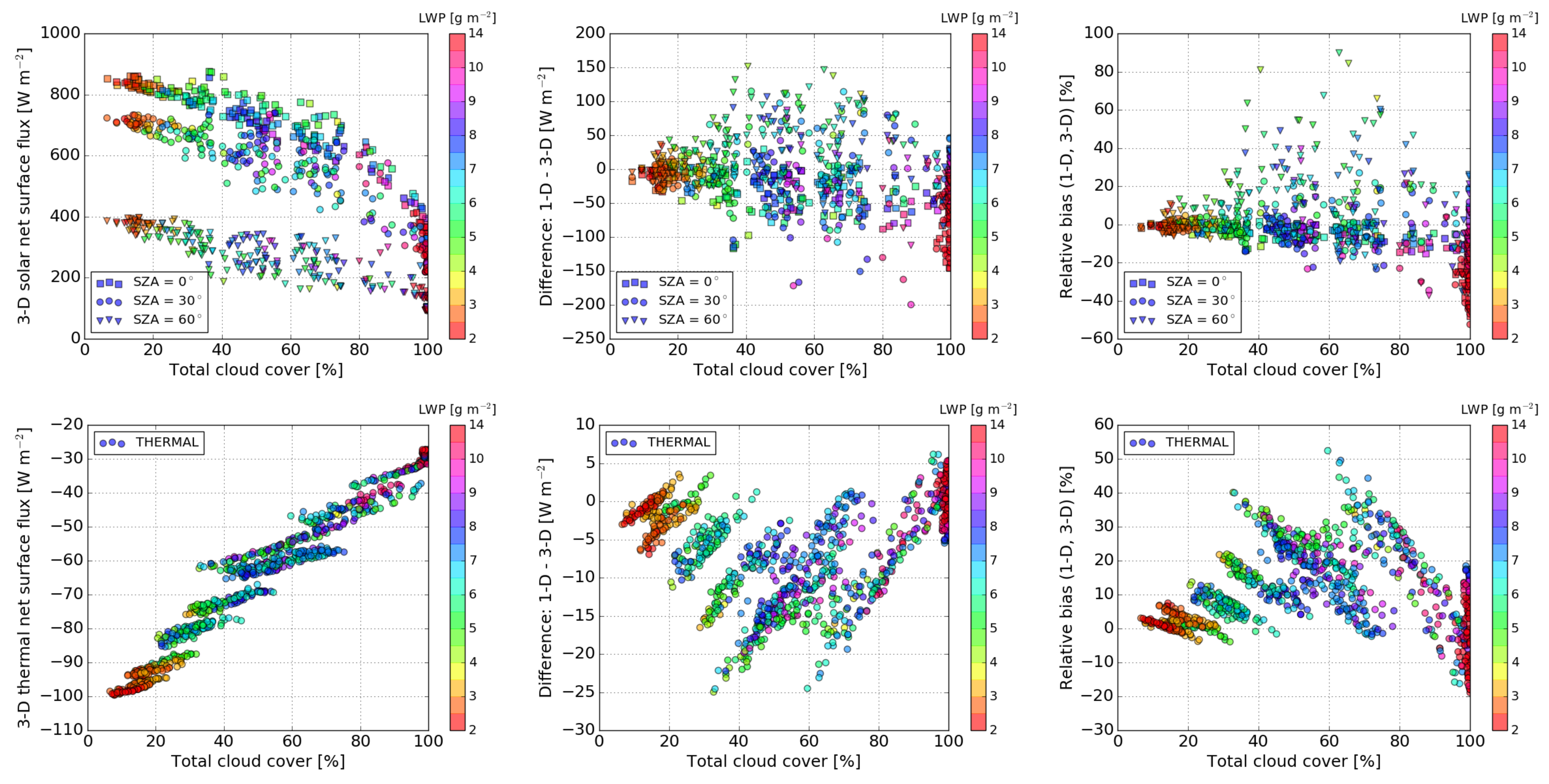

Figure 4: Solar (top row) and thermal (bottom row) net surface flux in the experiments with land albedo. Left panels show the outcome of the 3-D experiment, middle panels show the difference between the 1-D and 3-D experiment, whereas right panels show the relative bias of the 1-D experiment.

3 The Tripleclouds method

Underlying idea behind the Tripleclouds

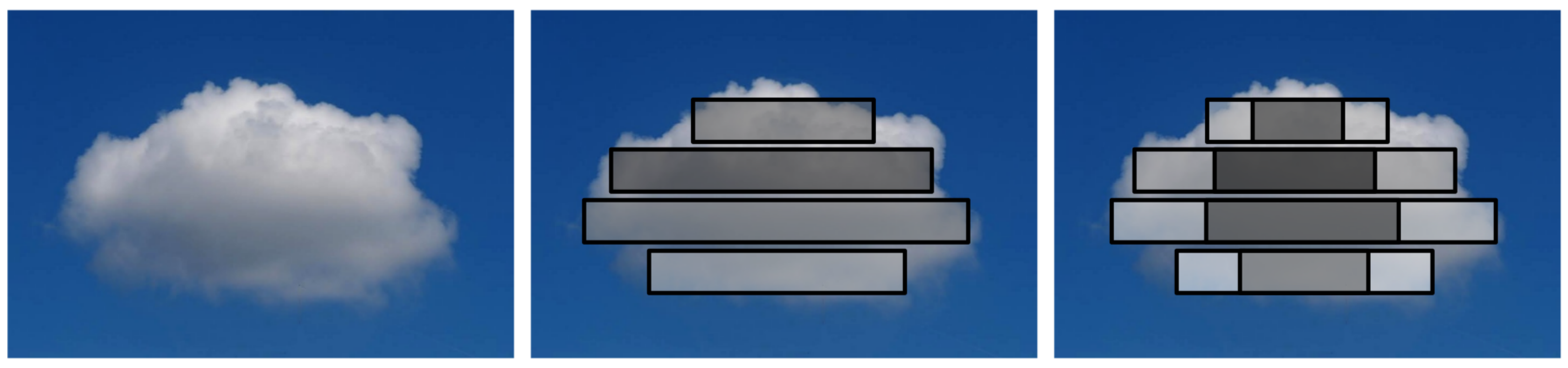

Figure 5: Underlying idea behind the Tripleclouds method, which uses two regions at each height (right schematic) to represent the cloud as opposed to one (middle schematic) as is conventionally done in radiation schemes of NWP models. One region represents the optically thicker cloud core (hereafter denoted as "CK" region) and the other region represents the optically thinner cloud sides (hereafter denoted as "CN" region). Further, vertical overlap rules need to be extended if cloud at each height is splitted into two parts. Our version of the Tripleclouds method assumes maximal overlap of adjacent CK-regions as well as maximal overlap of adjacent cloudy regions as a whole. Cloudy layers separated by at least one cloud-free layer overlap randomly.

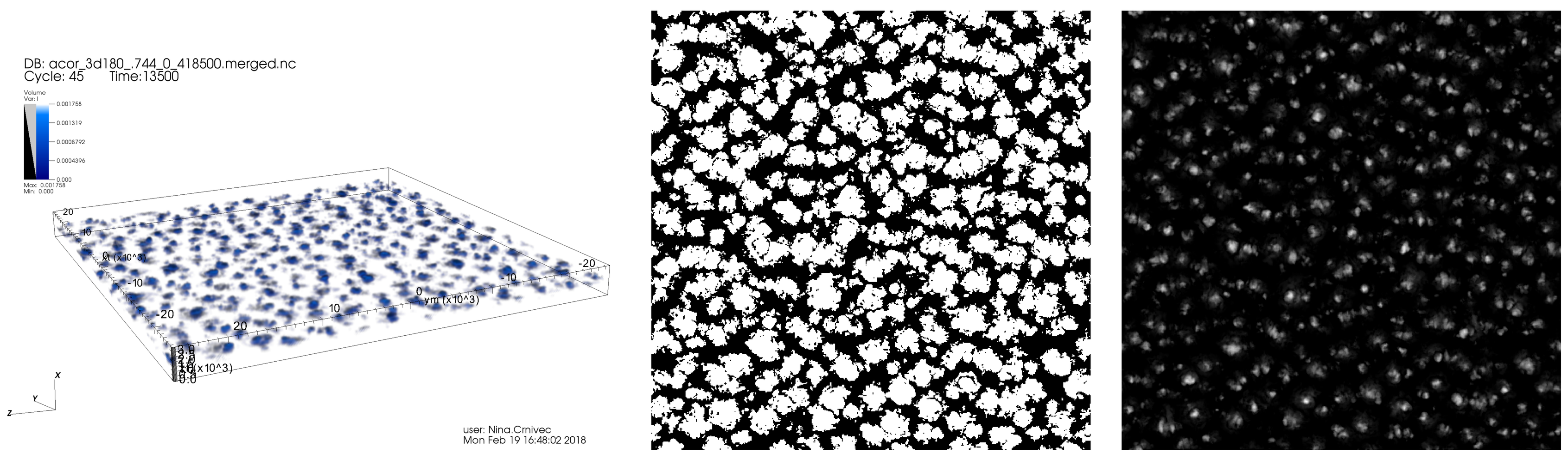

Figure 6: Shallow cumulus cloud field with a total cloud cover of 54.8 % used as input for radiative transfer calculations. The left panel shows its visualization with VisIt, the middle panel shows the cloud mask. The right panel shows vertically integrated optical thickness, demonstrating that optically thick convective cores are surrounded by relatively large cloudy regions with lower optical thickness.

Splitting the liquid water content (LWC) into two parts

Mass conservation constraint:

$$LWC = \frac{LWC_{CN} + LWC_{CK}}{2} \qquad (1)$$

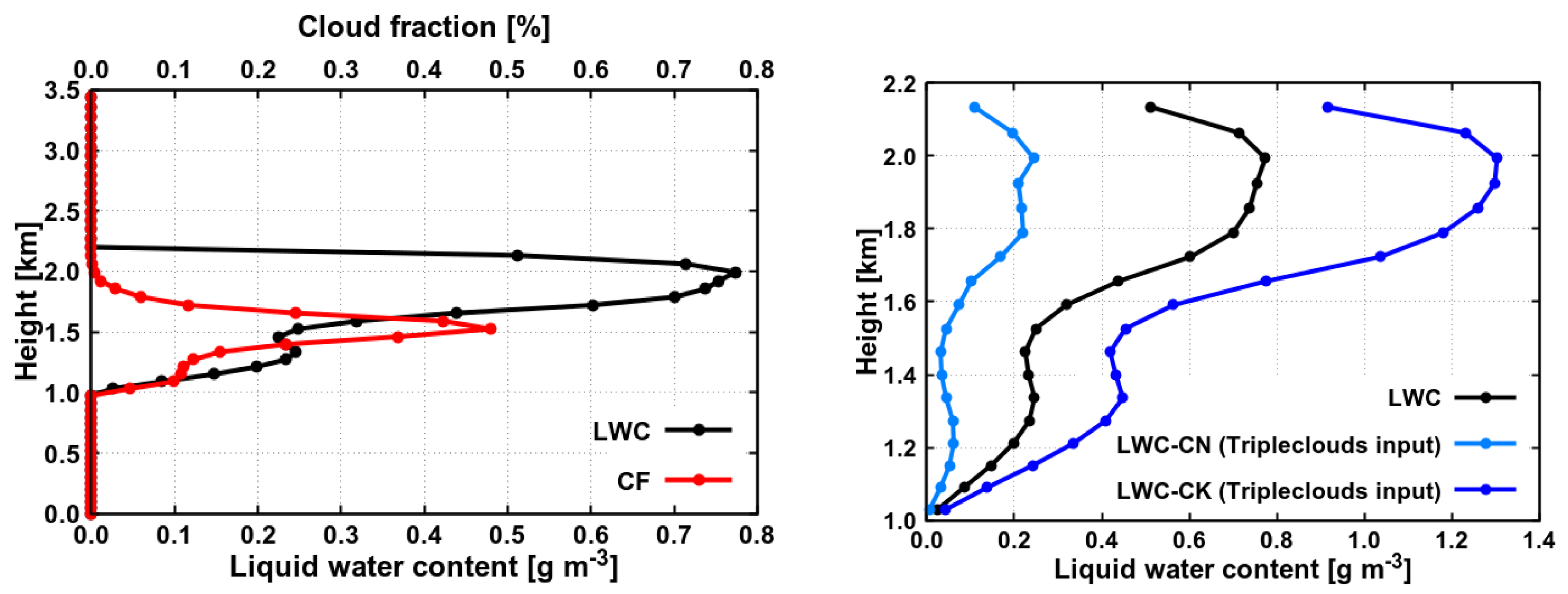

Figure 7: Left panel: Vertical profiles of averaged LWC and cloud fraction for a cumulus cloud field with a total cloud cover of 54.8 %. These profiles are used as input for the classic δ-Eddington two-stream method with maximum-random overlap assumption for partial cloudiness. Right panel demonstrates the split of averaged LWC into CN- and CK-components, which are used as input for the Tripleclouds method. The split assumes that the two cloudy regions are of equal size and that LWC at each height is normally distributed.

Results

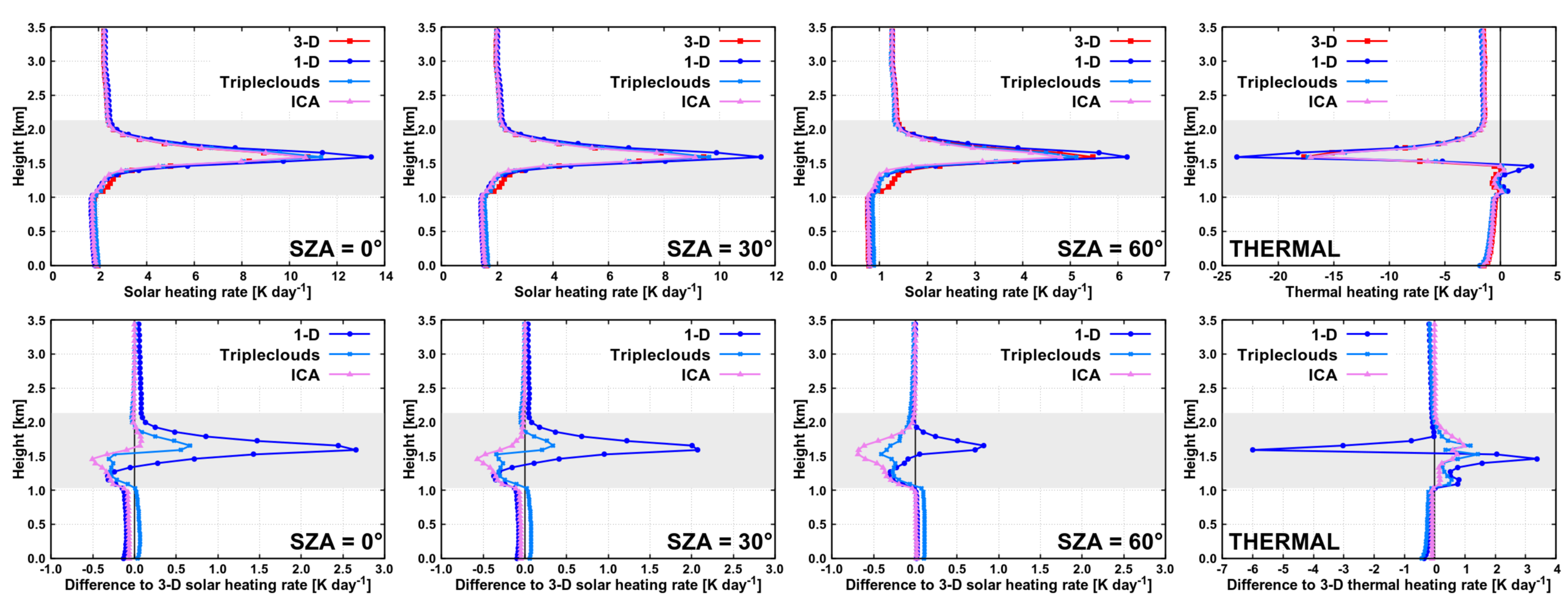

Figure 8: Solar and thermal heating rate for a cumulus cloud field with a total cloud cover of 54.8 % in the four experiments (3-D, 1-D, Tripleclouds, ICA) with land albedo. The grey-shaded area denotes the layer where clouds are present. The Tripleclouds method is profoundly more accurate than the 1-D experiment and in some occasions even more accurate than the ICA experiment (with respect to the same 3-D benchmark).

4 References

(1) Črnivec, N. and Mayer, B.: Quantifying the bias of radiative heating rates in NWP models for shallow cumulus clouds. *Atmos. Chem. Phys.*, submitted.

(2) Mayer, B.: Radiative transfer in the cloudy atmosphere. *Eur. Phys. J. Confer.*, 1, 75-99, 2009.

(3) Shonk, J. K. P. and Hogan, R. J.: Tripleclouds: An efficient method for representing horizontal inhomogeneity in 1D radiation schemes by using three regions at each height. *J. Climate*, 21, 2352-2370, 2008.