Introducing cloud horizontal overlap at NWP scales (1-10 km) in a fast 3D radiative transfer model

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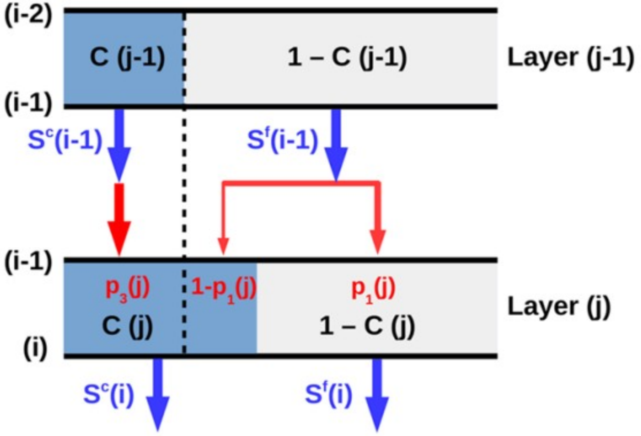
Background

- Interactions between radiation and clouds are a source of significant uncertainty in both numerical weather prediction (NWP) and climate models
- The classical method to calculate radiation in NWP and climate models is the twostream approximation combined with an independent column approach
- In order to account for the sub-grid scale structure, the cloud fraction is used as an input for a cloud overlap model, which significantly improves the twostream method



→ Črnivec and Mayer (2019)

Background

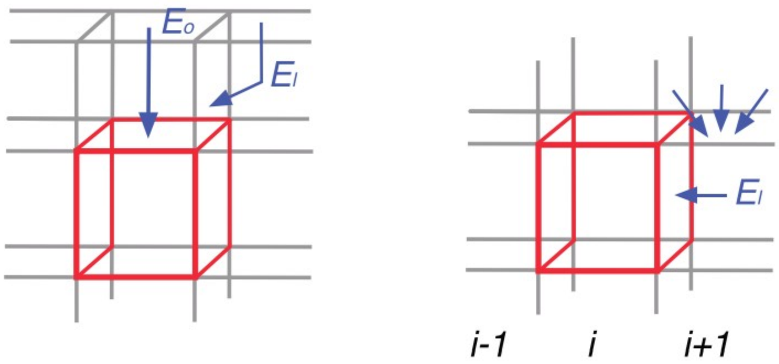
- With increased resolution it is expected that 3D effects will play an increasingly important role
- Idea: Introduce horizontal cloud overlap to a solver capable of simulating horizontal photon transport
- This idea was implemented using a combination of two existing solvers: *Neighboring Column Approximation* (Klinger and Mayer 2016, 2020) and the twostream maximum random overlap solver *twomaxrnd* (Črnivec and Mayer, 2019), which are both part of the *libradtran* software package for radiative transfer calculations

The neighbouring column approximation (NCA)

→ Klinger and Mayer (2016, 2020)

- 1. step: Calculation of vertical thermal irradiances by a 1D radiation scheme
  (Schwarzschild solver without vertical cloud overlap)

- 2. step: Calculation of horizontal fluxes using the results from neighbouring columns



$$E_{top,j+1} = (1 - w(\tau_{j+1}, \zeta)_0) \cdot E_{dn,0,j+1} + w(\tau_{j+1}, \zeta)_0 \, \frac{\sum_{l=2}^{n_{side}} E_{dn,l,j+1}}{n_{side}}$$

$$E_{bot,j} = (1 - w(\tau_{j-1}, \zeta)_1) \cdot E_{up,1,j} + w(\tau_{j-1}, \zeta)_1 \, \frac{\sum_{l=2}^{n_{side}} E_{up,l,j}}{n_{side}}.$$

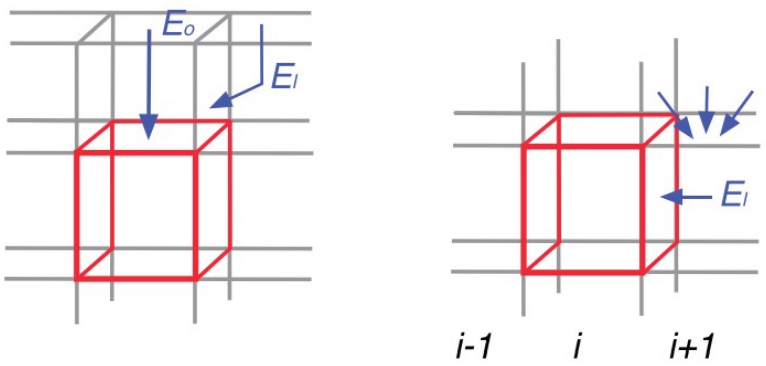
$$E_{l,side} = w_{1,l} \cdot E_{l,j} + w_{2,l} \cdot E_{l,j+1}$$

→ figure from Klinger and Mayer (2020)

Extending NCA to include horizontal overlap

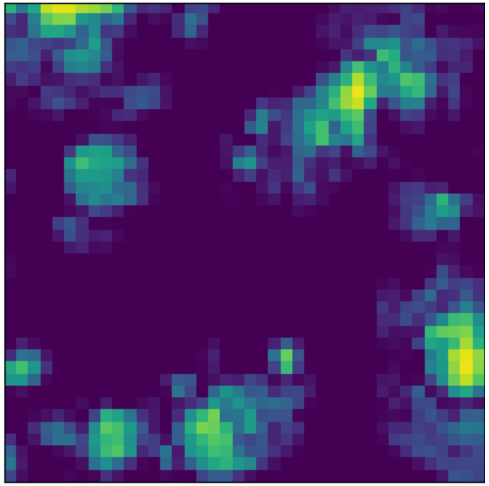
- 1. step: Calculation of vertical irradiances by a 1D radiation scheme
  (here a twostream maximum random overlap solver)

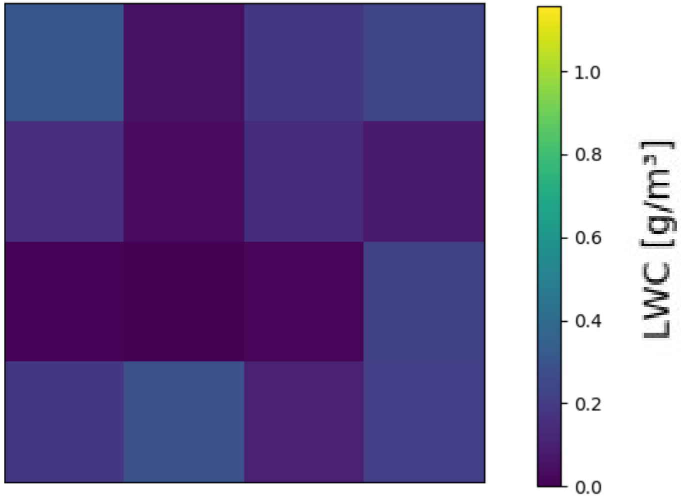
- 2. step: Calculation of horizontal fluxes using the results from neighbouring columns. The formulas for the horizontal contributions are modified in order to accommodate the different irradiances from the cloudy and cloud-free regions



→ figure from Klinger and Mayer (2020)

Setup

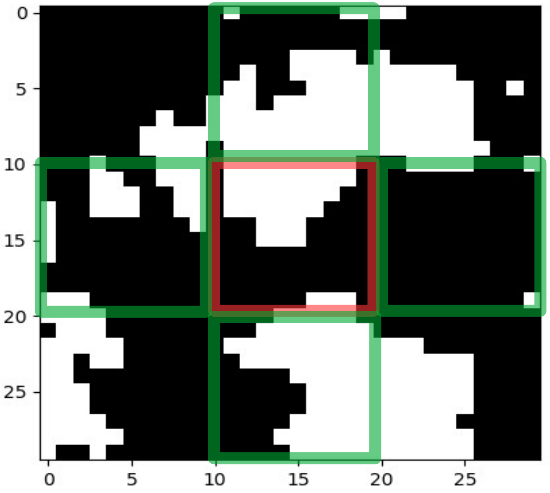


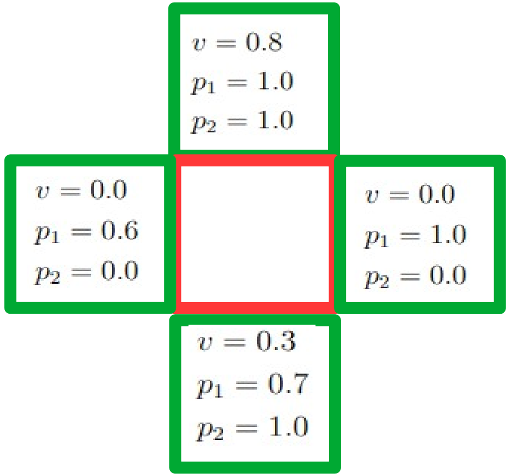


- LES cloud field (horizontal resolution 200 m)
  → Benchmark simulations with the Monte Carlo model *MYSTIC*

- NWP cloud field (horizontal resolution 2 km)
  → Simulations with *twomaxrnd* and the hybrid model *NCA-twomax*

Horizontal overlap in a LES cloud field



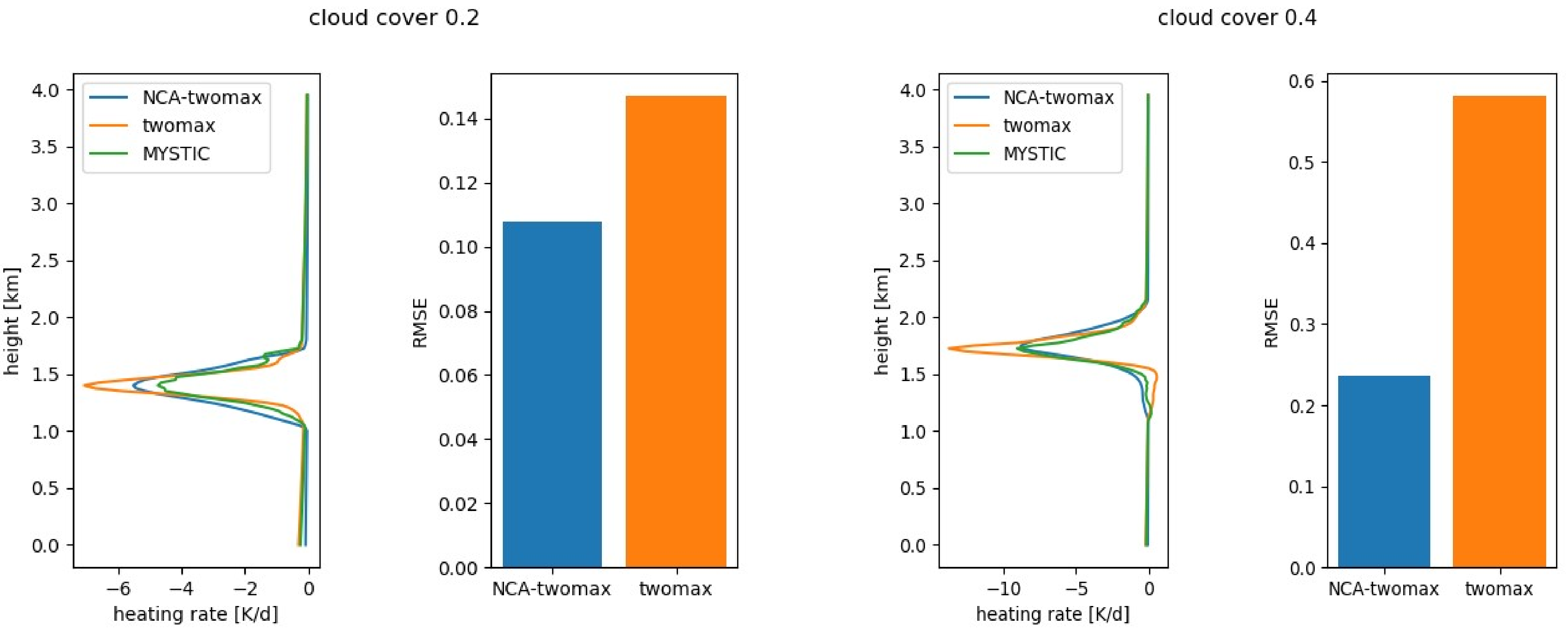


$$p_1 = \frac{1 - c_0 - c_1 + v}{1 - c_0}, p_2 = \frac{v}{c_0}$$

$$v \in [max(0, c_0 + c_1 - 1), min(c_0, c_1)]$$

- Calculation of the overlap coefficients $\boldsymbol{p_1}$ and $\boldsymbol{p_2}$ between the red and the adjacent green domains in dependence of the variable $\boldsymbol{v}$, which represents the actual overlap between the neighbors. Here $\boldsymbol{c_0}$ and $\boldsymbol{c_1}$ are the cloud fractions of the border area of the red and green domains.

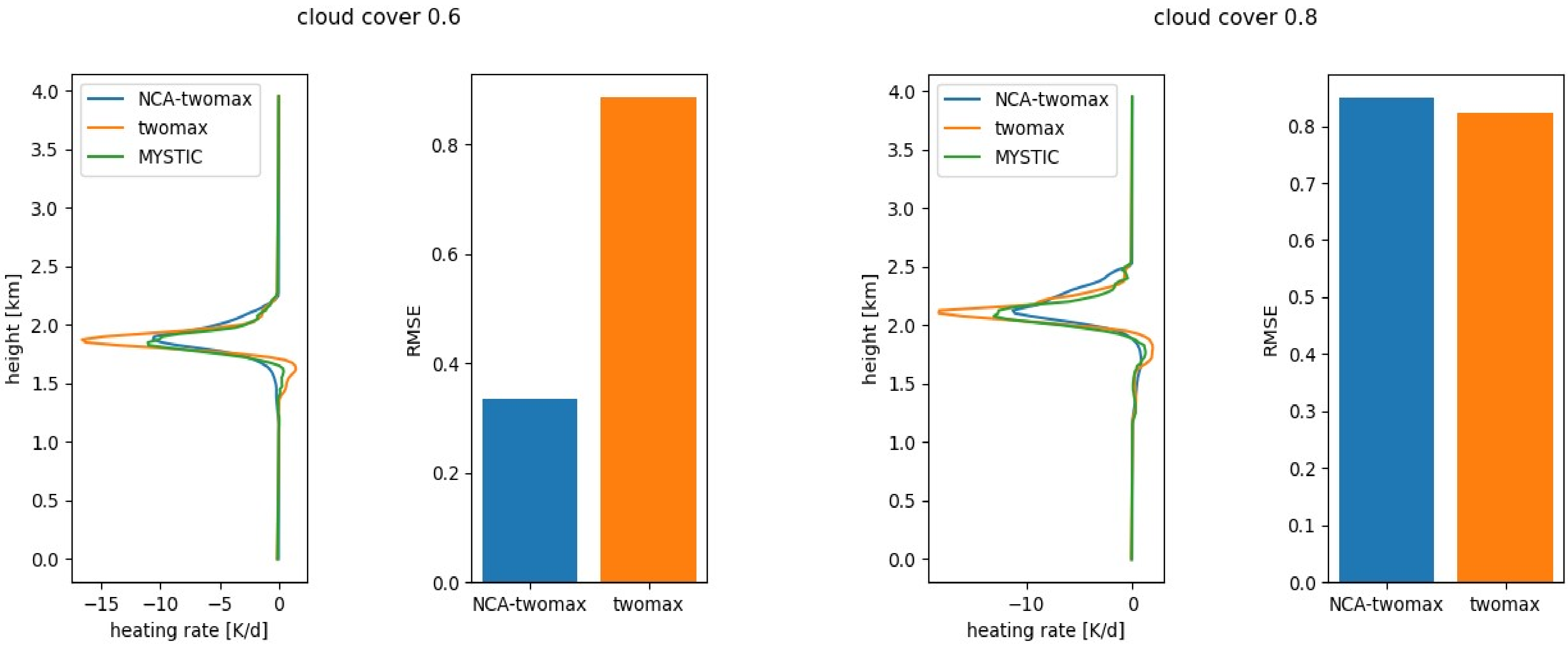
Results



- Results for the vertical profile of the horizontally-averaged heating rate for two different cumulus cloud scenes

- The RMSE was calculated with respect to the results of the benchmark model *MYSTIC*

Results


cloud cover 0.6
cloud cover 0.8
NCA-twomax
twomax
MYSTIC
height [km]
heating rate [K/d]
RMSE
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−15
−10
−5
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
NCA-twomax
twomax

Outlook

- Testing many different cloud scenes
- Allowing for the inclusion of *Tripleclouds* as a vertical solver
- Analysis of LES data for optimization of overlap coefficients
- Implementation of horizontal overlap into other solvers