A 3D Radiative Transfer Solver for Atmospheric Heating Rates – the **TenStream** solver

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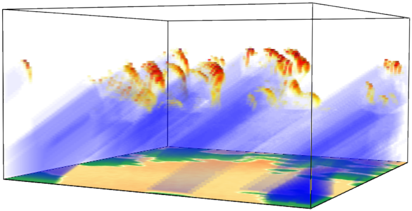
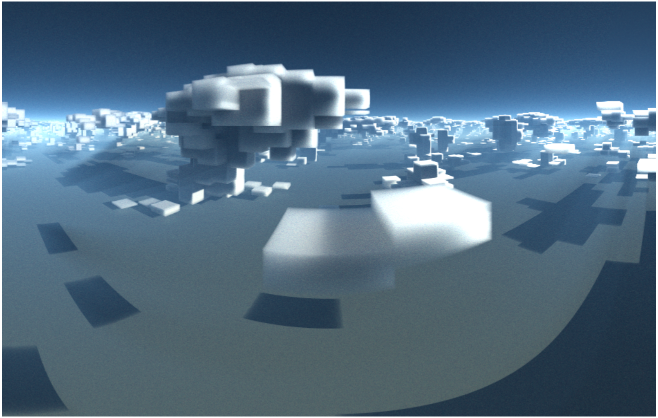


April 13, 2016

Why care for 3D radiation now? – a matter of resolution

Weather models today

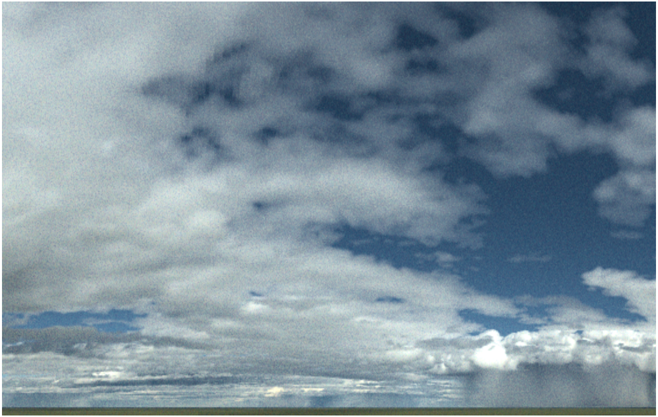


Visualization done with libRadtran.org/**MYSTIC**

Monte carlo code for the phYSically correct Tracing of photons In Cloudy atmospheres,
Mayer, B., 2009. Radiative transfer in the cloudy atmosphere (EPJ Web of Conferences)
EULAG-LES cloud data from Katrin Scheufele

Why care for 3D radiation now? – a matter of resolution

Next-gen models



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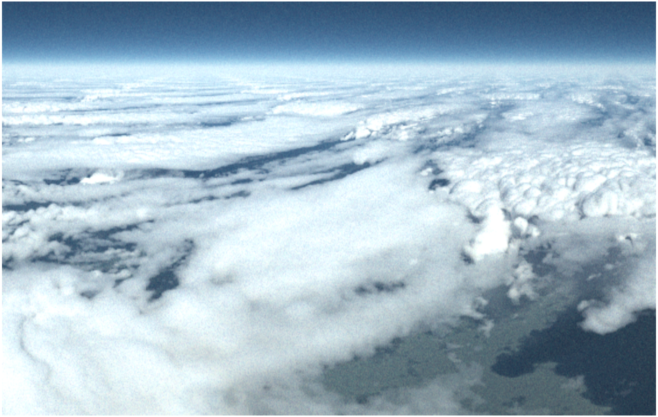

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$HD(CP)^2$ project (www.hdcp2.eu)

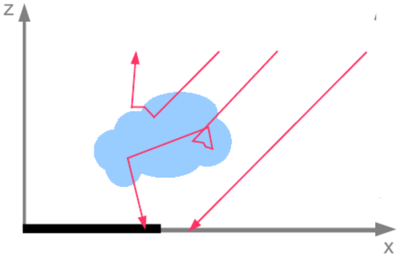
$HD(CP)^2$

High definition clouds and precipitation
for advancing climate prediction

- run hindcasts over Central Europe
- 100m horizontal resolution
- grids consisting of 10.000 x 15.000 x 300 voxels
- first develop a model capable of running it (ICON)
- ...with the goal to develop improved parametrizations for weather and climate predictions

Approximations for Radiative Transfer

Radiative transfer describes photon interactions with atmosphere.
MonteCarlo modelling of scattering and absorption:



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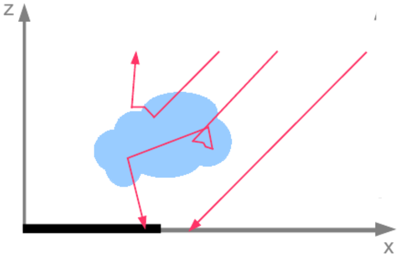

simplify to solve:

- Plane Parallel approx.
- Independent Column approx.

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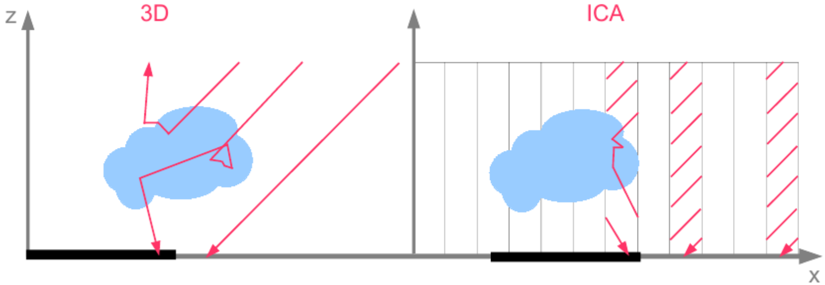
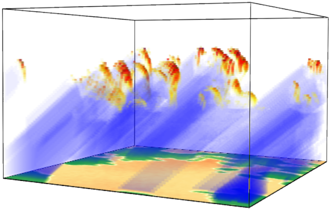


simplify to solve:

- Plane Parallel approx.
- Independent Column approx.
- Twostream solvers
- diagonal band-matrix (5)

The Tenstream solver

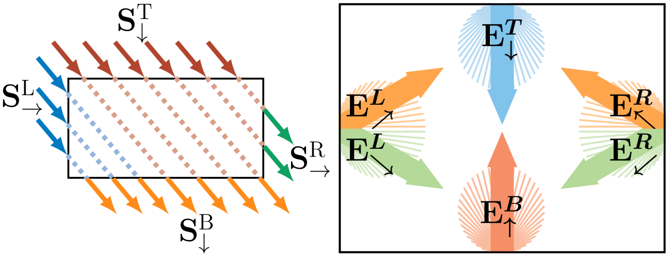
A new concept for a solver – what do we want?



I3RC cloud scene, benchmark heating rate calculation with MYSTIC (MonteCarlo code)

- accurately approximate 3D effects
- has to be several orders of magnitude faster than state of the art 3D solvers
- parallelizable on modern machines

Finite Volume formalism:
Discretize energy transport – spatially and by angle

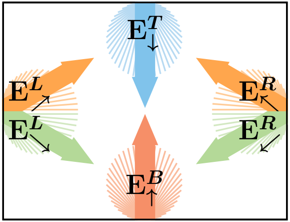


(a) direct streams (θ=40°) (b) diffuse streams

Fabian Jakub and Bernhard Mayer, 2015. A three-dimensional parallel radiative transfer model for atmospheric heating rates for use in cloud resolving models – The TenStream solver (JQSRT)

The TenStream solver

From one grid box to many:



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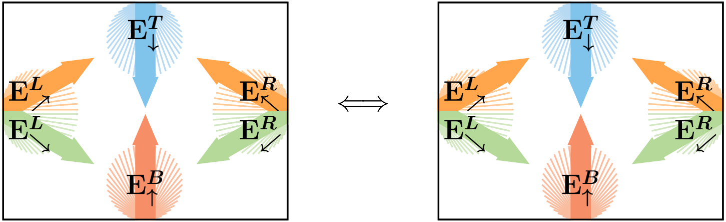

The TenStream solver

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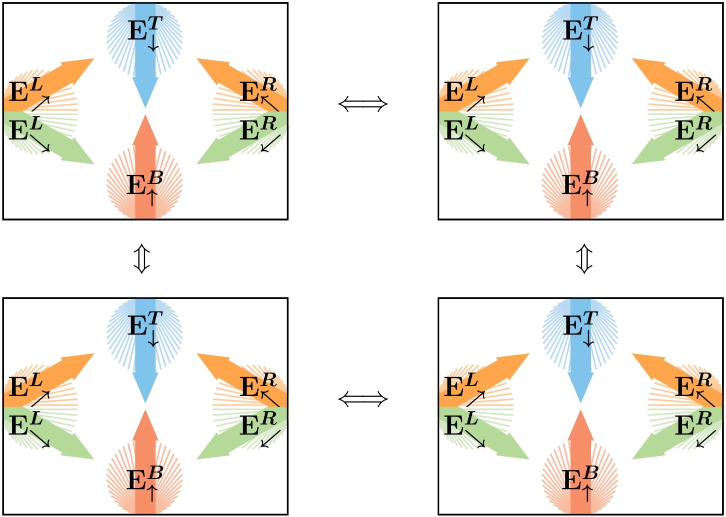

The TenStream solver

Setup equation system for one voxel:

$$\begin{bmatrix} E_{\uparrow}^{T} \\ E_{\downarrow}^{B} \\ E_{\swarrow}^{L} \\ E_{\searrow}^{R} \\ E_{\nwarrow}^{L} \\ E_{\nearrow}^{R} \\ S_{\downarrow}^{B} \\ S_{\rightarrow}^{R} \end{bmatrix} = \begin{bmatrix} \gamma_1 & \gamma_2 & \gamma_3 & \gamma_3 & \gamma_4 & \gamma_4 & \beta_{01} & \beta_{11} \\ \gamma_2 & \gamma_1 & \gamma_4 & \gamma_4 & \gamma_3 & \gamma_3 & \beta_{02} & \beta_{12} \\ \gamma_5 & \gamma_6 & \gamma_7 & \gamma_8 & \gamma_9 & \gamma_{10} & \beta_{03} & \beta_{13} \\ \gamma_5 & \gamma_6 & \gamma_8 & \gamma_7 & \gamma_{10} & \gamma_9 & \beta_{04} & \beta_{14} \\ \gamma_6 & \gamma_5 & \gamma_9 & \gamma_{10} & \gamma_7 & \gamma_8 & \beta_{05} & \beta_{15} \\ \gamma_6 & \gamma_5 & \gamma_{10} & \gamma_9 & \gamma_8 & \gamma_7 & \beta_{06} & \beta_{16} \\ 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{00} & \alpha_{10} \\ 0 & 0 & 0 & 0 & 0 & 0 & \alpha_{01} & \alpha_{11} \end{bmatrix} \begin{bmatrix} E_{\uparrow}^{B} \\ E_{\downarrow}^{T} \\ E_{\swarrow}^{R} \\ E_{\searrow}^{L} \\ E_{\nwarrow}^{R} \\ E_{\nearrow}^{L} \\ S_{\downarrow}^{T} \\ S_{\rightarrow}^{L} \end{bmatrix}$$

Couple voxels in 3 dimensions. . .

Setup equation system for one voxel:

$$
\begin{bmatrix} E^{T}_{\uparrow} \\ E^{B}_{\downarrow} \\ E^{L}_{\swarrow} \\ E^{R}_{\searrow} \\ E^{L}_{\nwarrow} \\ E^{R}_{\nearrow} \\ S^{B}_{\downarrow} \\ S^{R}_{\rightarrow} \end{bmatrix}
=
\begin{bmatrix}
\gamma_1 & \gamma_2 & \gamma_3 & \gamma_3 & \gamma_4 & \gamma_4 & \beta_{01} & \beta_{11} \\
\gamma_2 & \gamma_1 & \gamma_4 & \gamma_4 & \gamma_3 & \gamma_3 & \beta_{02} & \beta_{12} \\
\gamma_5 & \gamma_6 & \gamma_7 & \gamma_8 & \gamma_9 & \gamma_{10} & \beta_{03} & \beta_{13} \\
\gamma_5 & \gamma_6 & \gamma_8 & \gamma_7 & \gamma_{10} & \gamma_9 & \beta_{04} & \beta_{14} \\
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0 & 0 & 0 & 0 & 0 & 0 & \alpha_{00} & \alpha_{10} \\
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\end{bmatrix}
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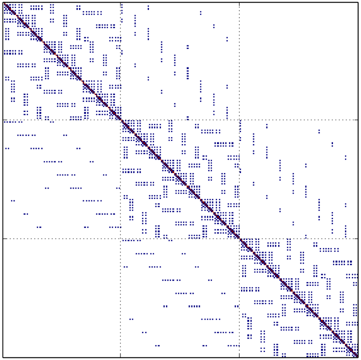
$$

Couple voxels in 3 dimensions...

...gives huge but sparse matrix.

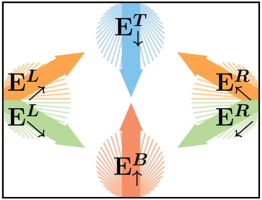


$\Longrightarrow$ solve with iterative methods, multigrid in PETSc!

Energy transport coefficients

We need to determine the energy transport

from one stream to another:



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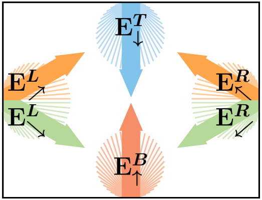
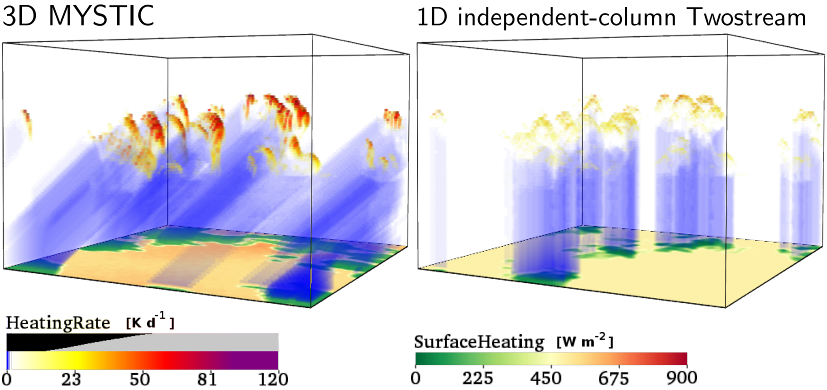


$\rightarrow$ solve radiative transfer equation

with MonteCarlo method

…and put them into LookUpTable

Does it work?



Computations done with libRadtran (Library for Radiative Transfer, libradtran.org)

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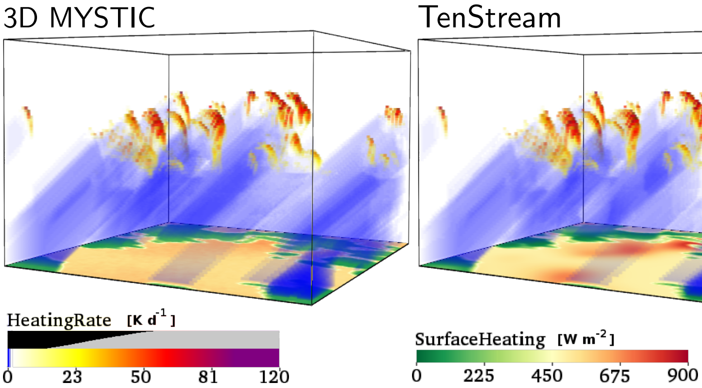

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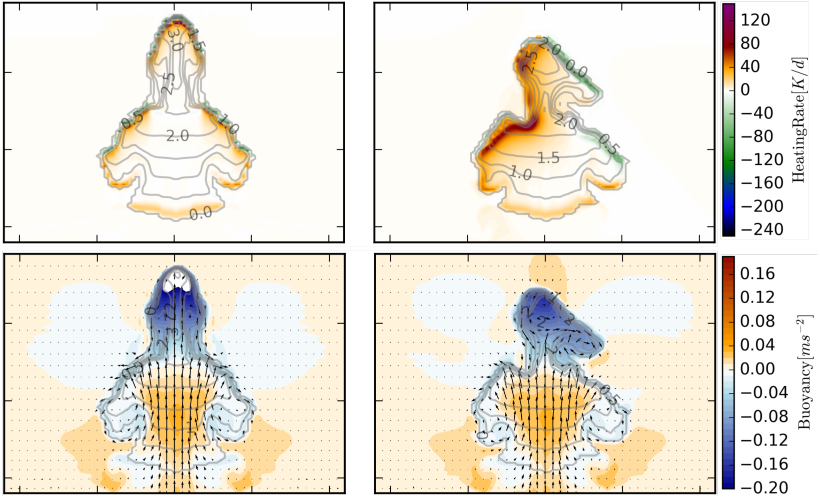
Warm-bubble experiments



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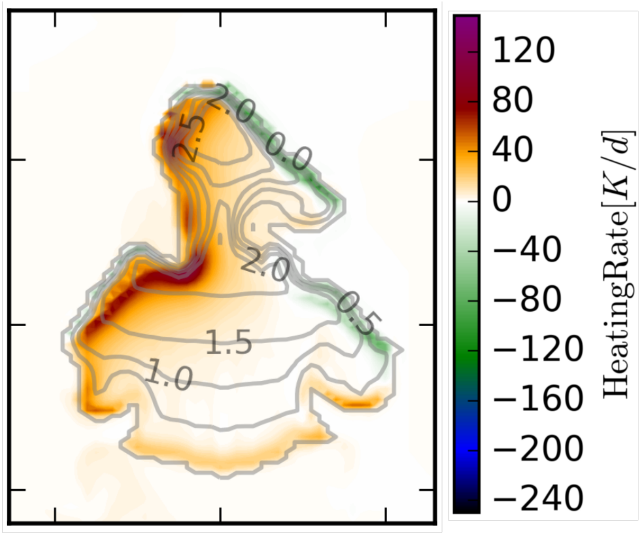
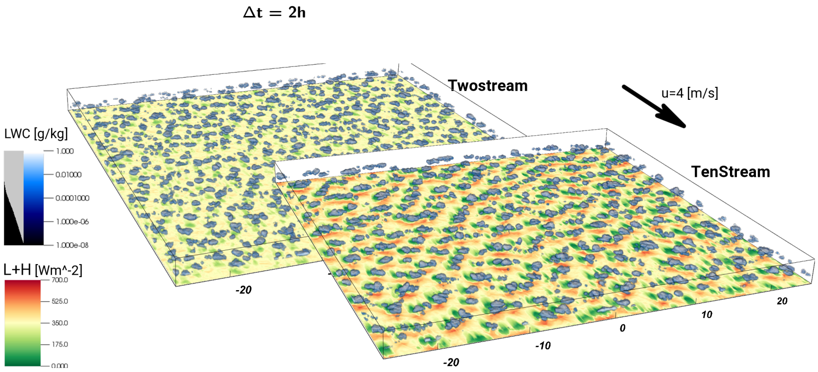


Shallow cumulus experiments



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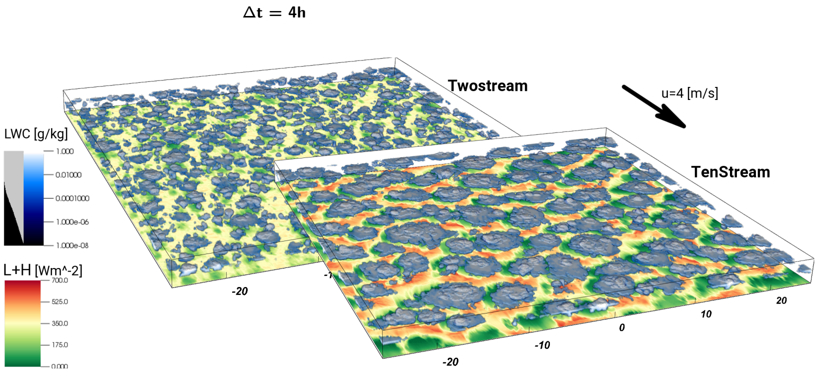

Current state and a glimpse at whats to come..

Conclusions

- New 3D RT solver — the TenStream
- Successful integration in UCLA-LES
- Solver runtime increased by factor 5-10
- Total model runtime increased by factor 3

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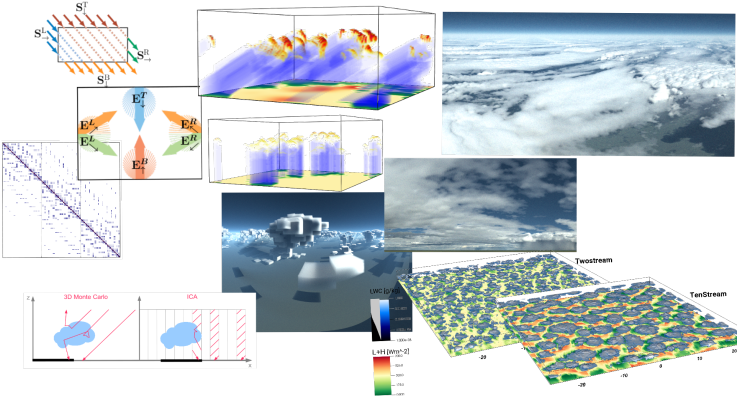
Outlook

- Determine 3D-radiation $\leftrightarrow$ cloud interaction
- Implement in icosahedral model ICON
- Make algorithm ready for large scale computations – $\mathrm{HD(CP)}^2$-Project

Thank you!



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