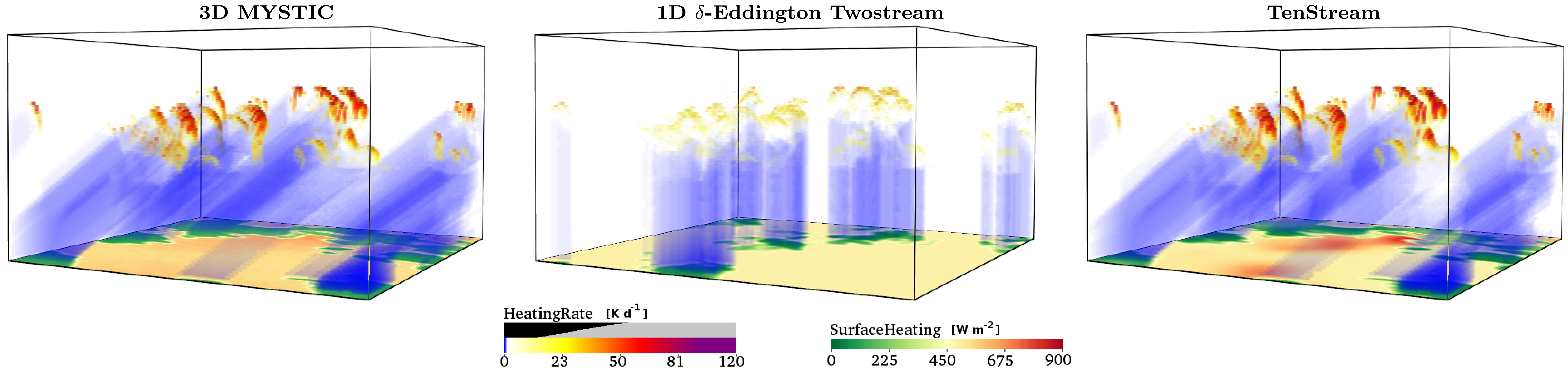
F. Jakub, F. Negwer and B. Mayer
Meteorological Institute, Physics Department

HD(CP)²
High definition clouds and precipitation for advancing climate prediction

Computational Challenges of 3D Radiative Transfer in High Resolution Simulations

3D MYSTIC | **1D δ-Eddington Twostream** | **TenStream**

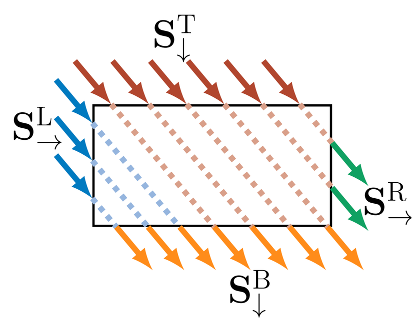


- 3D-MonteCarlo (MYSTIC) solver as benchmark
- Solar first order 3D effects are cloud-side illumination and horizontally displaced cloud shadows at the surface
- Full 3D solvers are several orders of magnitude slower than 1D approximations → not feasible for NWP/LES

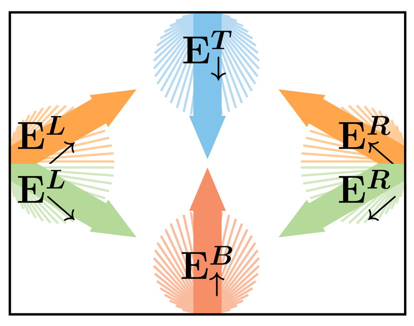
- 1D Radiative Transfer solvers, as implemented in almost any atmospheric model, neglect horizontal energy transfer
- Each vertical column is solved independently from each other (Independent Column Approximation, ICA)
  → not valid for high resolution simulations

- We developed the TenStream [1, 2] solver for comparatively fast yet accurate radiative transfer calculations
- Coupling with neighboring boxes handles horizontal energy transfer
- MPI-Parallelization realized with PETSc
- Available at `github.com/tenstream`

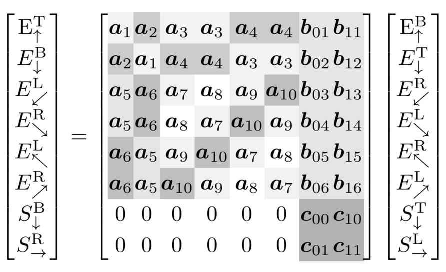
Concept for the TenStream Solver



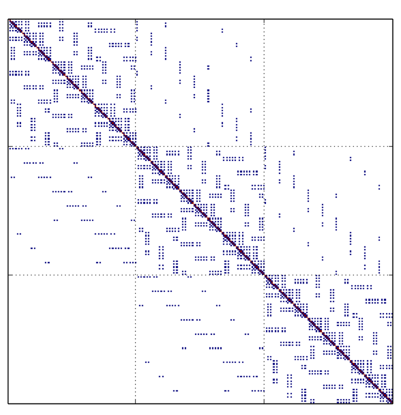
Discretize radiation streams angularly and spatially → at least 3 streams for direct radiation (fixed angle)



Diffuse angular discretization assumes Lambertian surface. Two streams (up- and downward), as in 1D solver. Additional streams sidewards enable for horizontal energy transfer

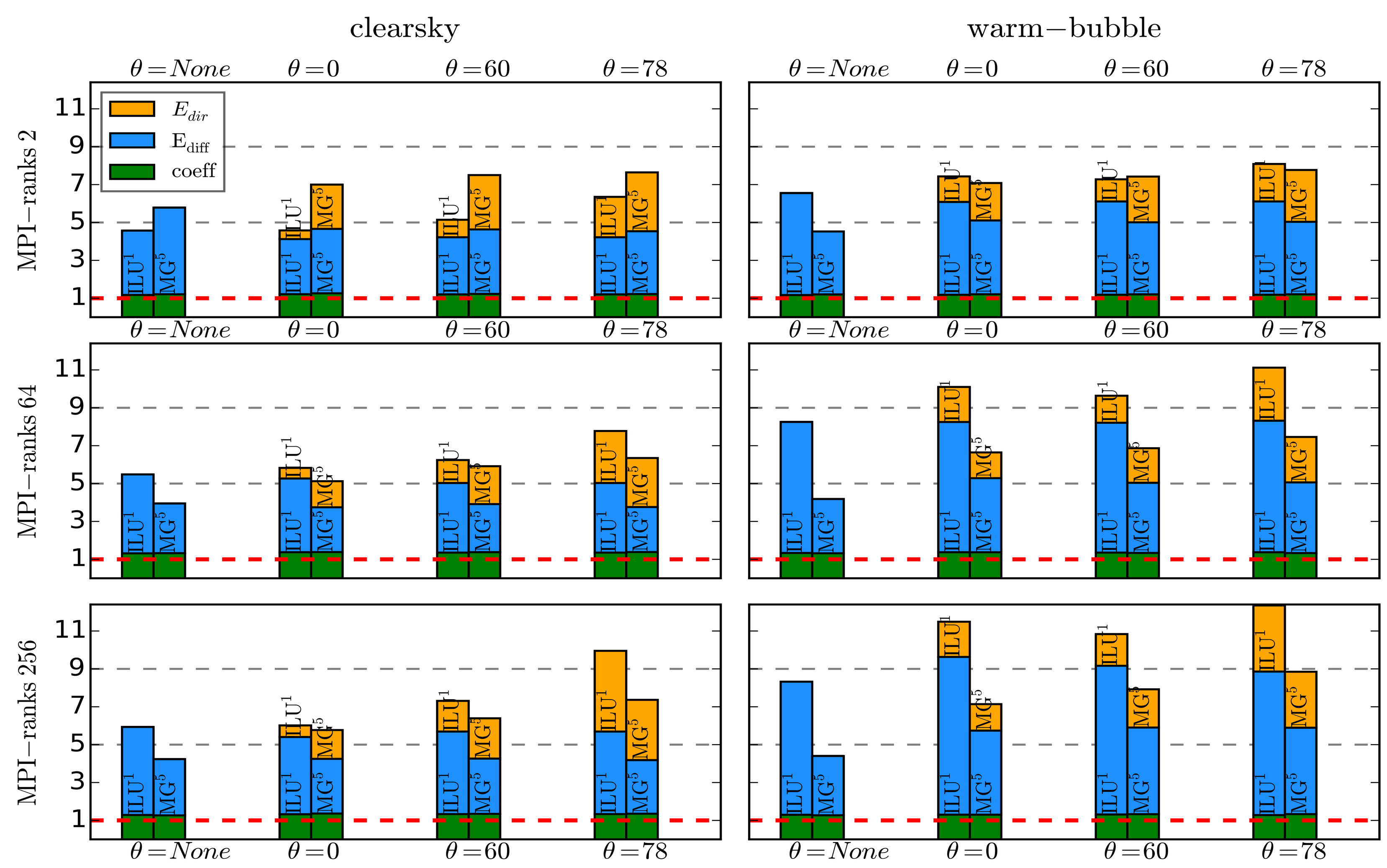


Use MonteCarlo to compute transport coefficients for single boxes and couple to neighbors
→ huge but sparse matrix



Solve eq. system with parallel iterative methods (PETSc):
BCGS + Incomplete-LU (ILU) or
GMRES + Algebraic Multigrid (GAMG)

Strong Scaling (constant problem size)

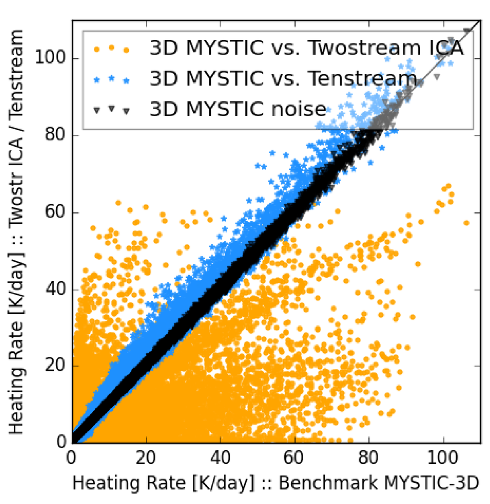


Timings for the radiative transfer routines (normalized to Twostream timings) for a weakly- and strongly forced simulation with varying preconditioner (Multigrid or ILU), solar zenith angle θ and number of cores:

- Reuse of last-timestep solution as initial guess improves performance
  → Performance depends on complexity (rate of change between radiation calls) of scene
- Use algebraic multigrid matrix preconditioner for parallel scalability
- Tenstream solver is a **factor of 5 to 10** more expensive than 1D δ-Eddington Twostream

Solver Accuracy

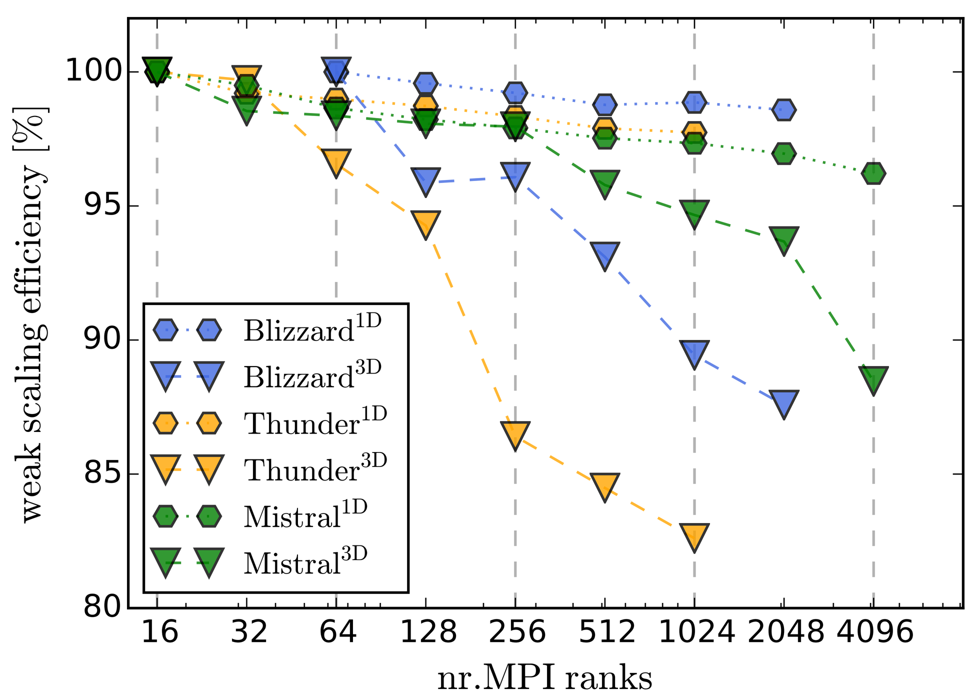
Atmospheric heating rates compared for above pictured Cumulus-scene (from I3RC):



- TenStream computes accurate Heating Rates (by magnitude and at the correct location)
- Compared to 1D ICA, reduce rel. RMSE for HeatingRates from **176%** to **31%** and bias from **−12.8%** to **−0.04%**
- Surface heating rel. RMSE reduced from **62%** to **18%** and bias from **4.4%** to **−1%**

Weak Scaling (constant work per CPU)

Weak–scaling parallel efficiency for Twostream and TenStream solver (GAMG preconditioning) on:



- Blizzard – IBM Power6 Supercomputer at DKRZ, Hamburg
- Mistral – Intel Haswell Supercomputer at DKRZ,Hamburg
- Thunder – Linux Cluster at ZMAW,Hamburg

→ Multigrid Solvers show excellent parallel scaling of > 80%

References

[1] F. Jakub and B. Mayer. "A Three-Dimensional Parallel Radiative Transfer Model for Atmospheric Heating Rates for use in Cloud Resolving Models–the TenStream solver." JQSRT (2015).
[2] F. Jakub and B. Mayer. "3D Radiative Transfer in Large-Eddy Simulations – Experiences coupling the TenStream solver to the UCLA–LES" GMD (2016).
[3] F. Jakub, On the Impact of Three Dimensional Radiative Transfer on Cloud Evolution. LMU (2016)
[4] C. Klinger, B. Mayer, F. Jakub, T. Zinner, S. Park, and P. Gentine. Effects of 3D Thermal Radiation on Cloud Development. ACP (2017)
[5] F. Jakub and B. Mayer. "The Role of 1D and 3D Radiative Heating on the Organization of Shallow Cumulus Convection and the Formation of Cloud Streets" ACP (2017)