3D Radiation in Cloud Resolving Models

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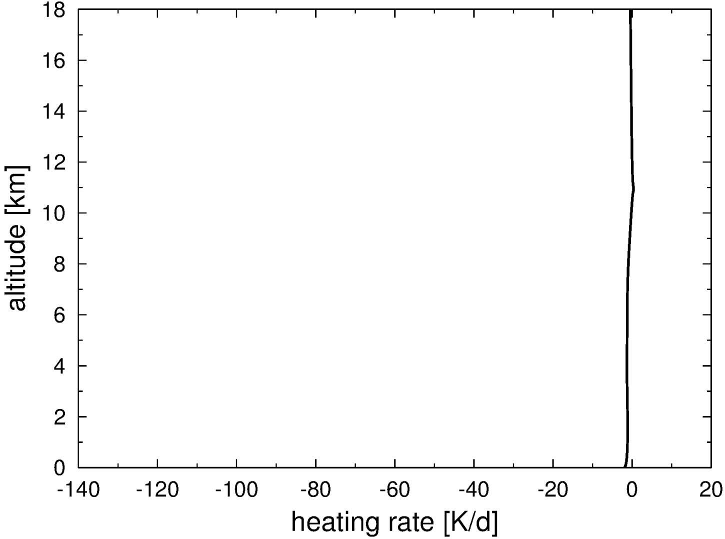
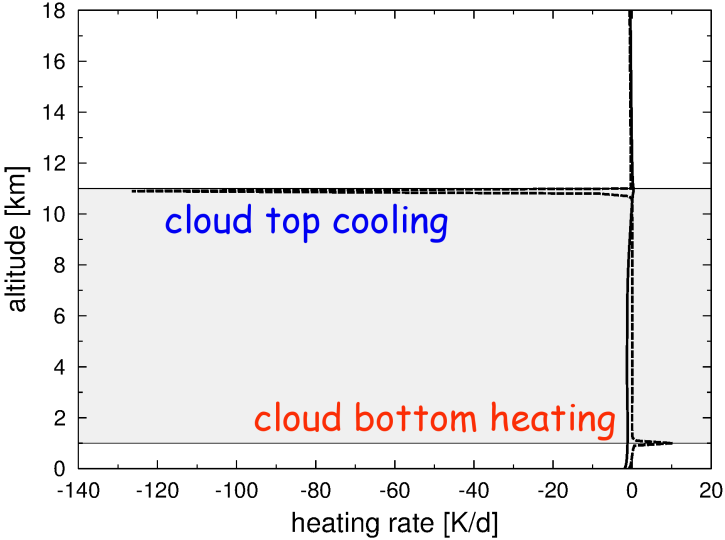
May 22, 2018

Radiative Heating and Cooling: Thermal (1D)



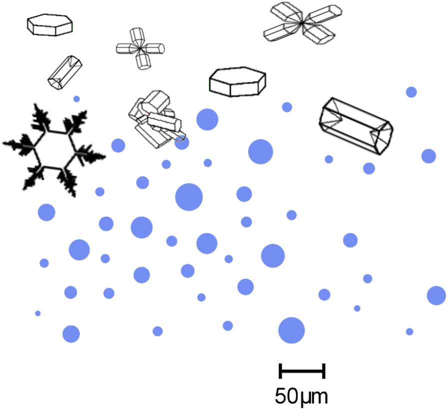
Radiative Heating and Cooling: Thermal (1D)



Potential Effects of Radiation on Clouds

- Droplet growth affected by absorption/emission of radiation
- Effect of heating/cooling rates on dynamics
- Differential heating of the surface (cloud shadows)

Radiative Heating and Cooling: Microscopic View



Radiative Heating and Cooling: Microscopic View

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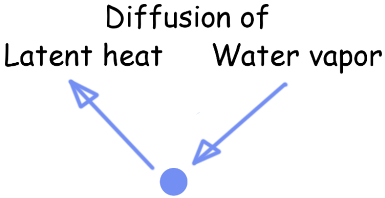

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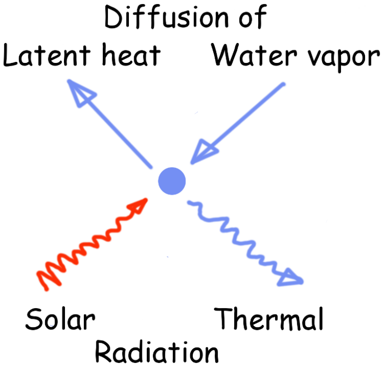


Previous work on the effect of radiation on droplets

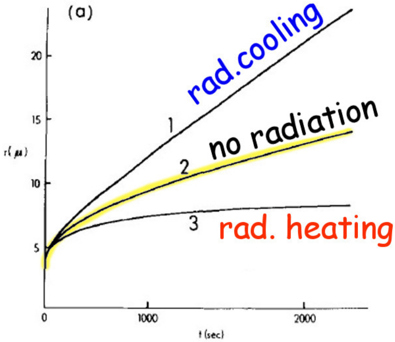
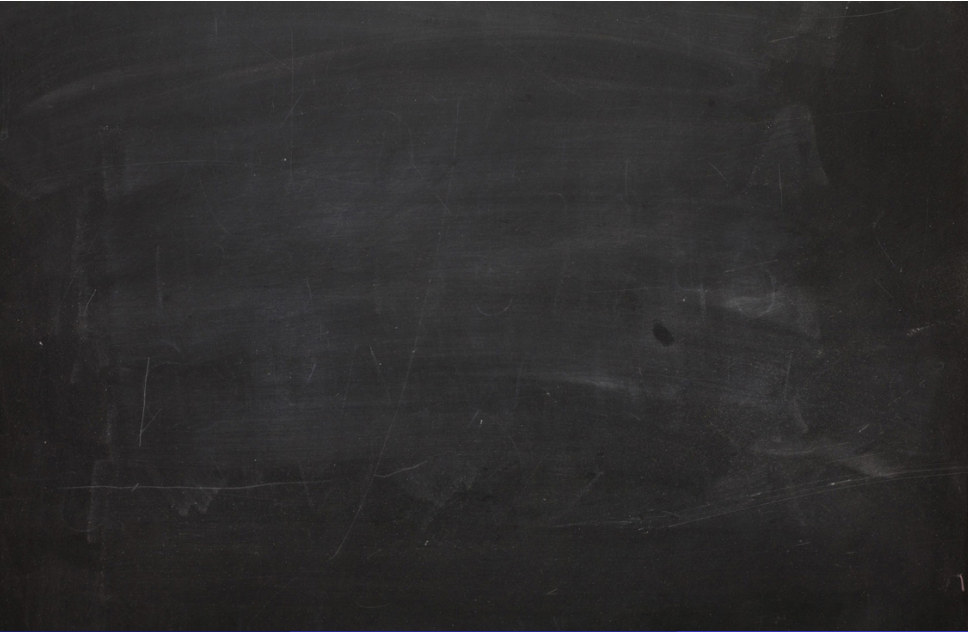


Figure 3. Some droplet growth curves for different values of s, F, m and T.

Curve	s (10^{-4})	F (W m^{-2})	m (10^{-12}g)	T (K)
1		−30		
2	5	0	1	280
3		30		

Maxwell, 1890
Roach, 1976
Barkstrom, 1978
Harrington et al, 2000
Marquis and Harrington, 2005
...

Analytical 3D Thermal Heating and Cooling Rates



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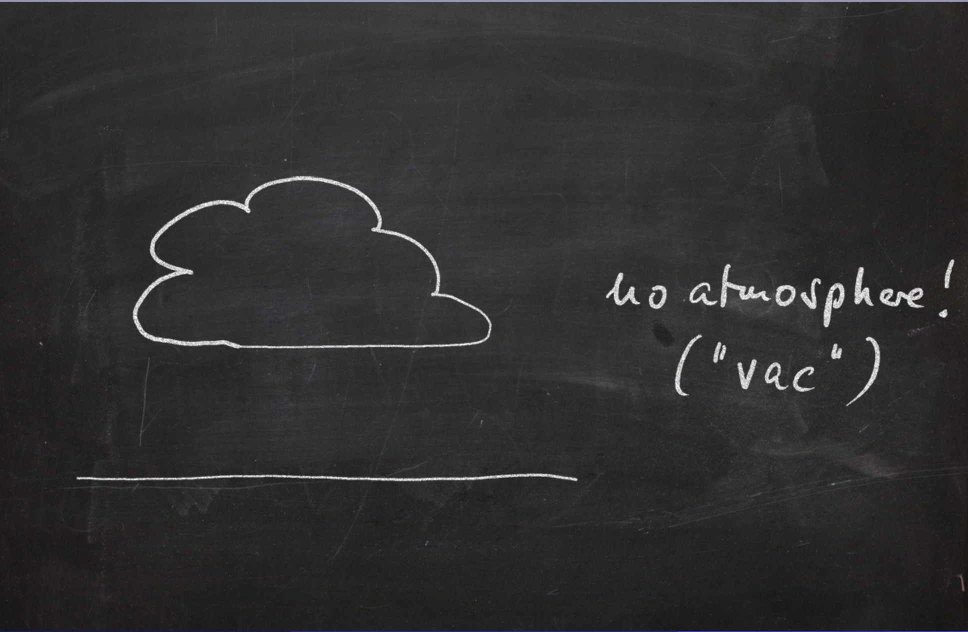

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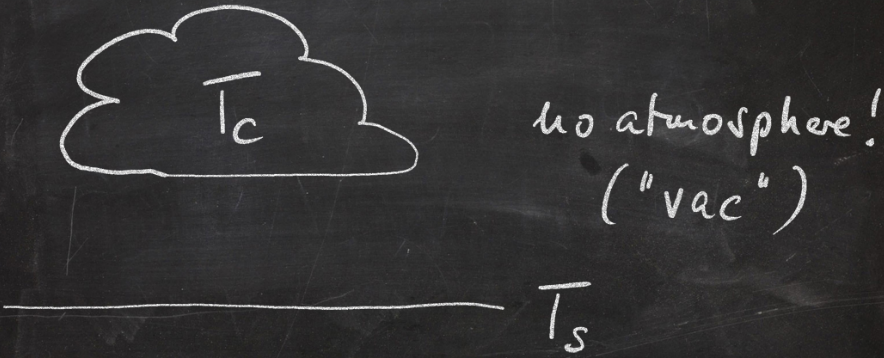

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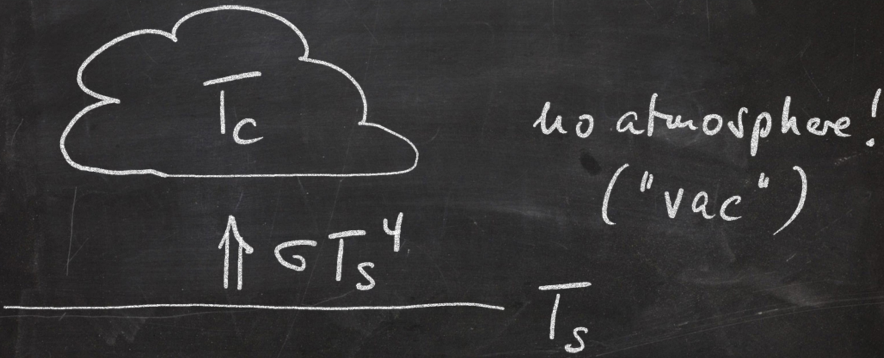

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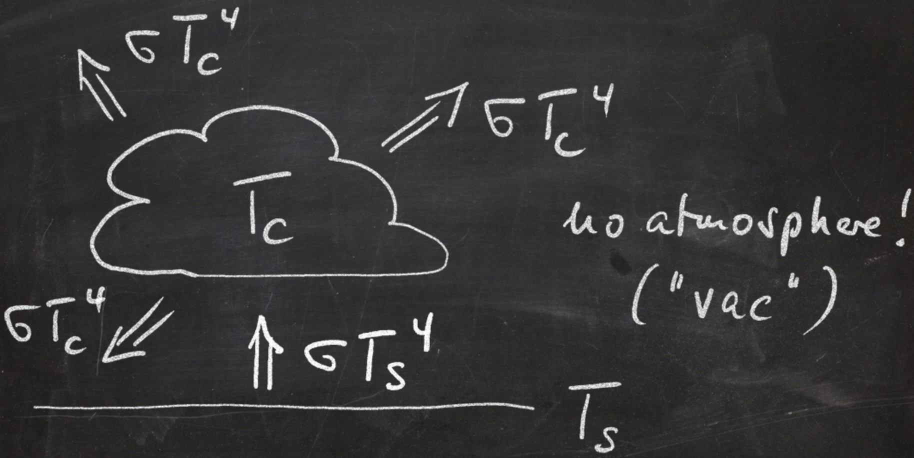

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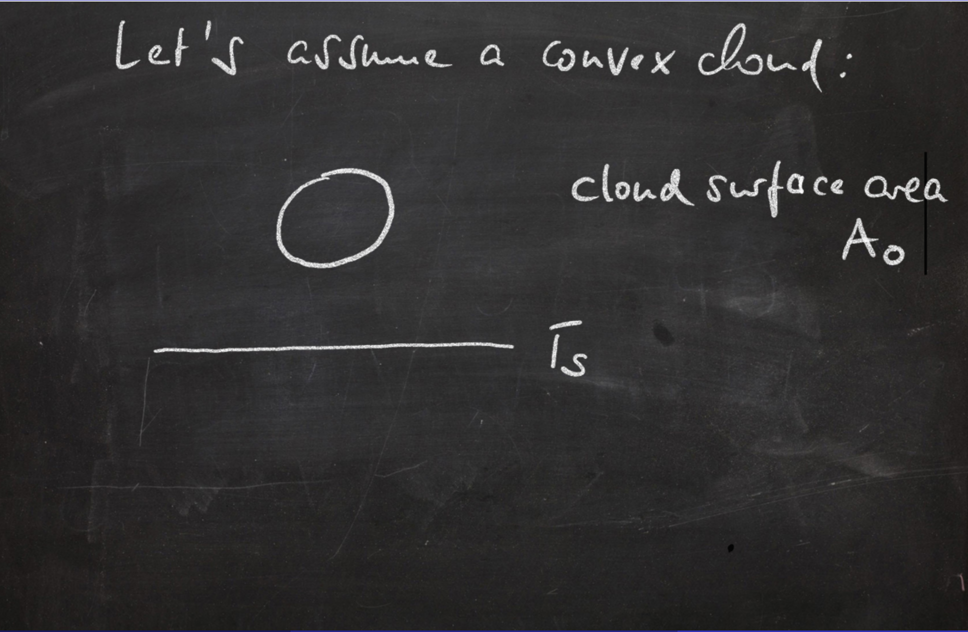
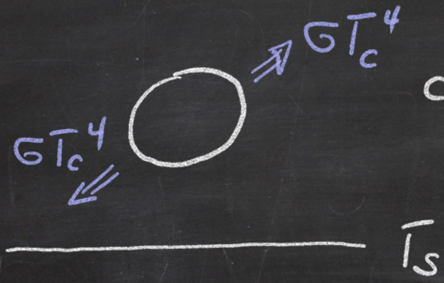


Analytical 3D Thermal Heating and Cooling Rates

Let's assume a convex cloud:



cloud surface area A_0

$$\dot{Q}_{em,vac} = A_0 \cdot \sigma T_c^4$$

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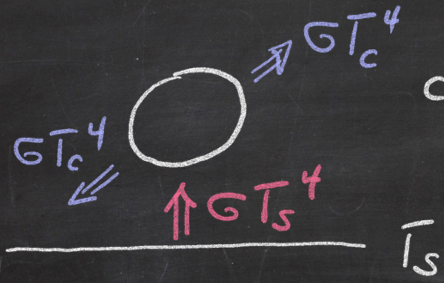

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$$\dot{Q}_{em,vac} = A_0 \cdot \sigma T_c^4$$

$$\dot{Q}_{abs,vec} = \frac{1}{2} A_0 \sigma T_S^4 \text{ (only from below)}$$

Analytical 3D Thermal Heating and Cooling Rates

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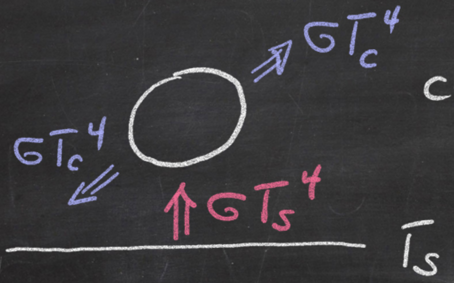


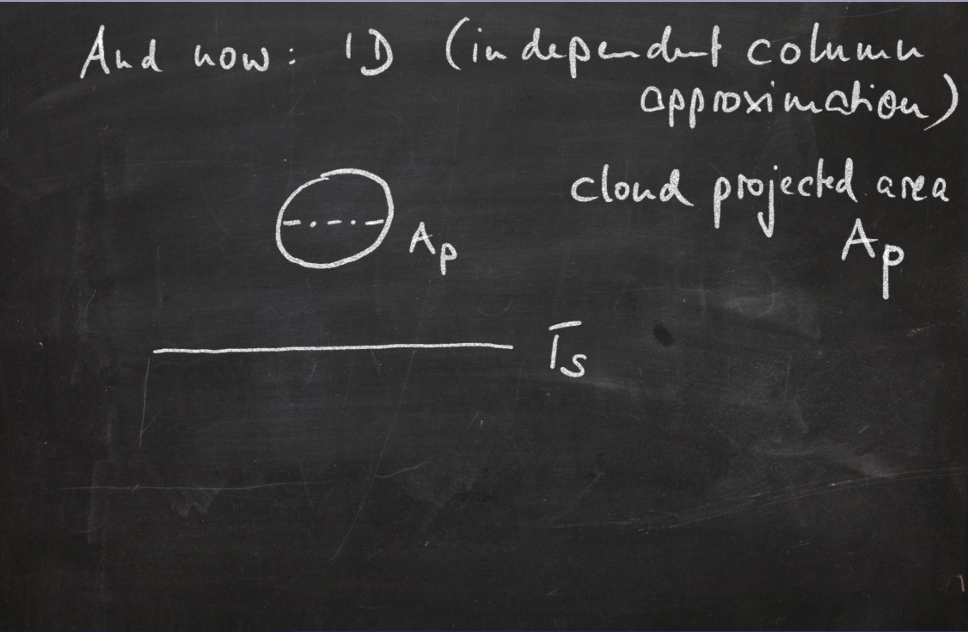
cloud surface area A_0

$$\dot{Q}_{em,vac} = A_0 \cdot \sigma T_c^4$$

$$\dot{Q}_{abs,vac} = \frac{1}{2} A_0 \sigma T_s^4 \text{ (only from below)}$$

$$\dot{Q}_{rad,vac} = \dot{Q}_{abs,vac} - \dot{Q}_{em,vac} = A_0 \sigma \left(\frac{1}{2} T_s^4 - T_c^4\right)$$

Analytical 3D Thermal Heating and Cooling Rates



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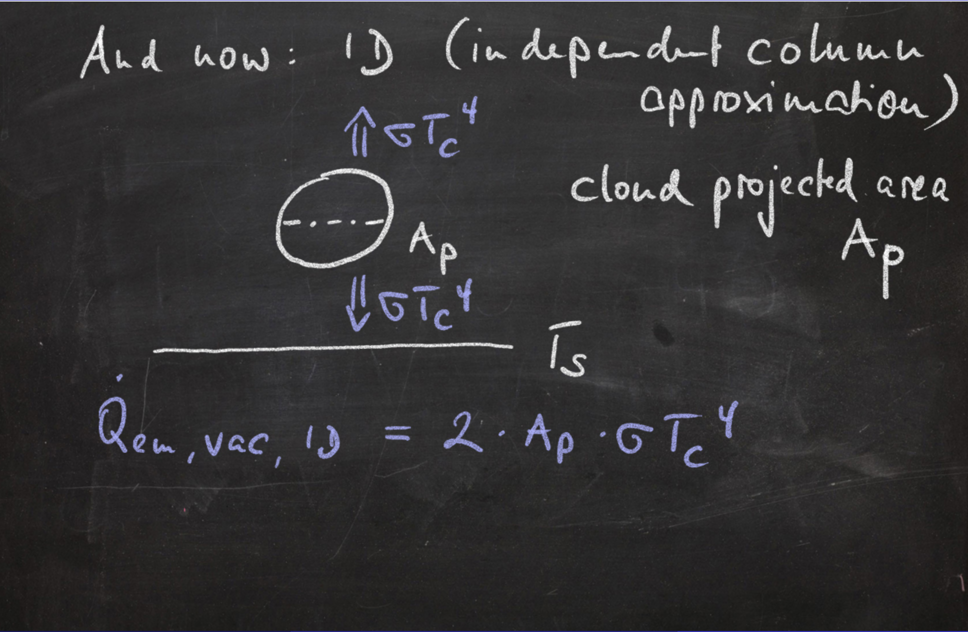

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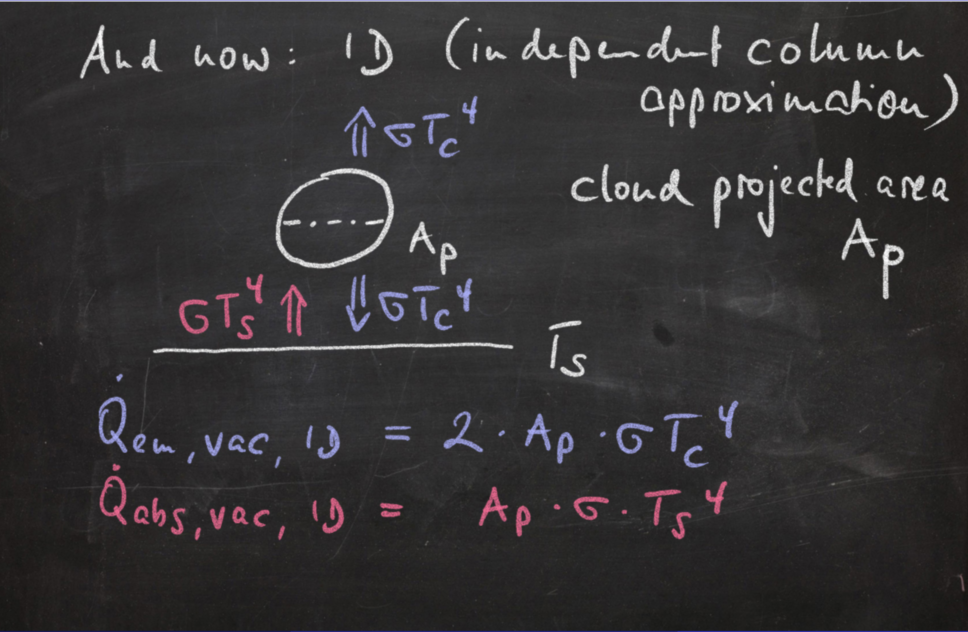

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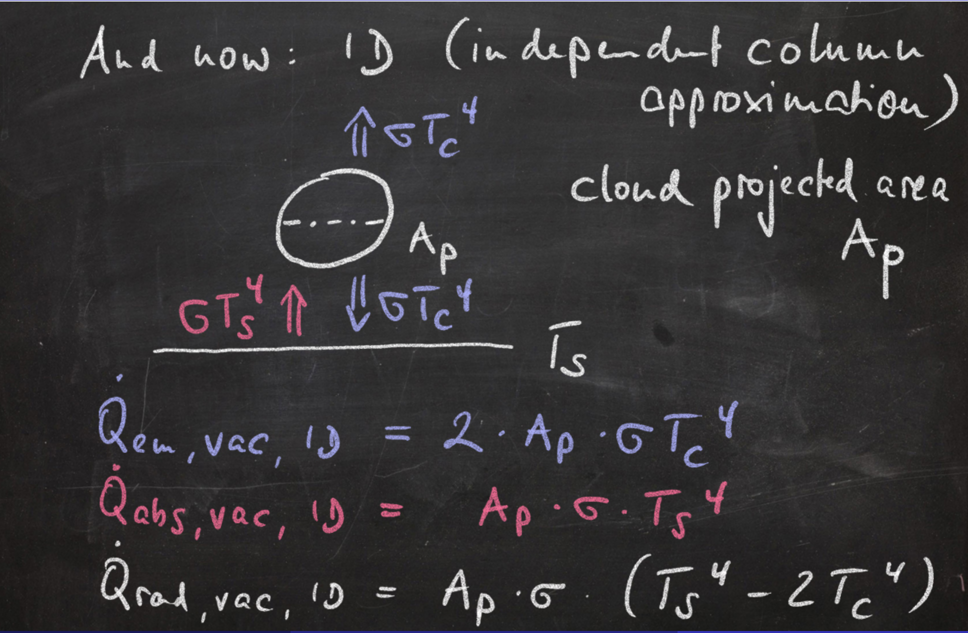

Analytical 3D Thermal Heating and Cooling Rates

For example: Cube with length d:

$$A_o = 6 d^2$$

$$A_p = d^2 = \frac{1}{6} A_o$$

$$\Rightarrow \dot{Q}_{rad,3D} = 3 \cdot \dot{Q}_{rad,1D} \;!$$

Analytical 3D Thermal Heating and Cooling Rates

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$$A_p = d^2 = \frac{1}{6} A_0$$

$$\Rightarrow \dot{Q}_{rad,3D} = 3 \cdot \dot{Q}_{rad,1D} \; !$$

Sphere instead of cube:

Factor 2 instead of 3

Analytical 3D Thermal Heating and Cooling Rates

And now atmosphere instead of vaccum:

- Only atmospheric window contributes to rad. heating / cooling

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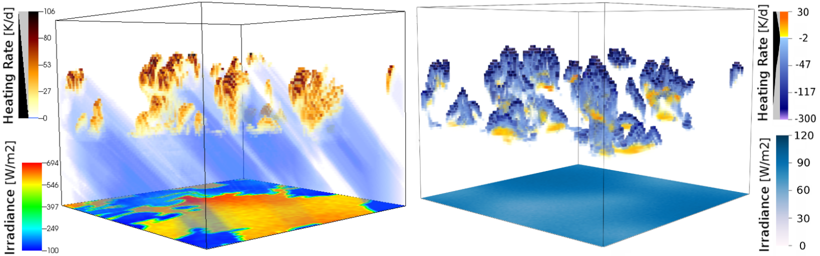
And now atmosphere instead of vaccum:

- Only atmospheric window contributes to rad. heating / cooling
- Atm. window ≈ 1/3 of integrated thermal flux σT^4

$$\Rightarrow \dot{Q}_{rad} \approx \frac{1}{3} \dot{Q}_{rad,vac}$$

Of course we can do much better than that!

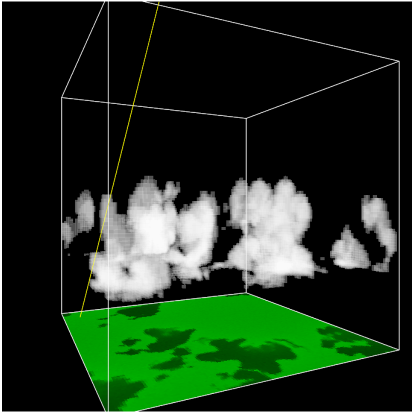


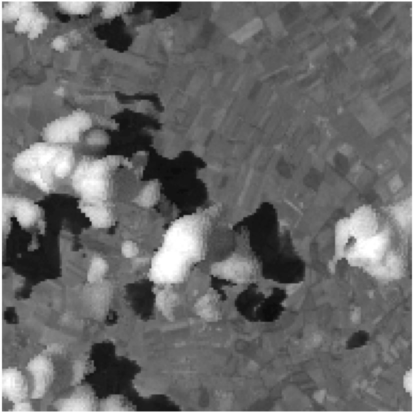
MYSTIC simulation: Carolin Klinger, Fabian Jakub, HD(CP)2

Monte Carlo Code for the physically correct tracing of photons in cloudy atmospheres, e.g. Mayer, 2009

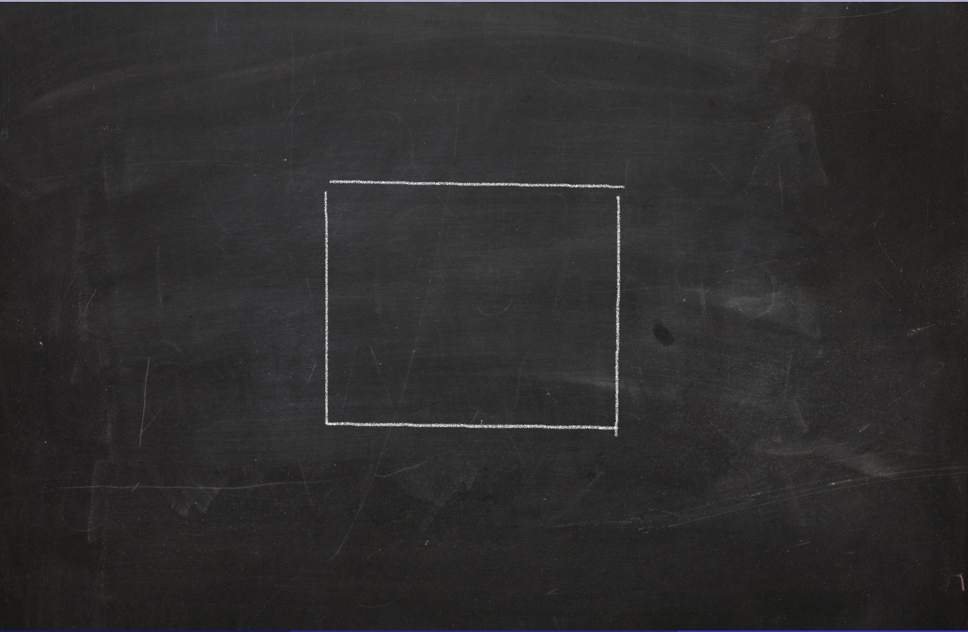
Monte carlo code for the phYSically correct Tracing of photons In Cloudy atmospheres

Mayer, 2009; Buras, Emde, Klinger, ...





The Tenstream Solver (Mayer and Jakub, 2015 a,b)



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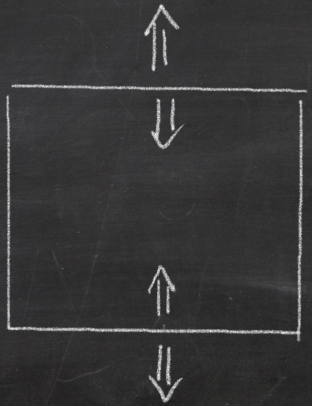

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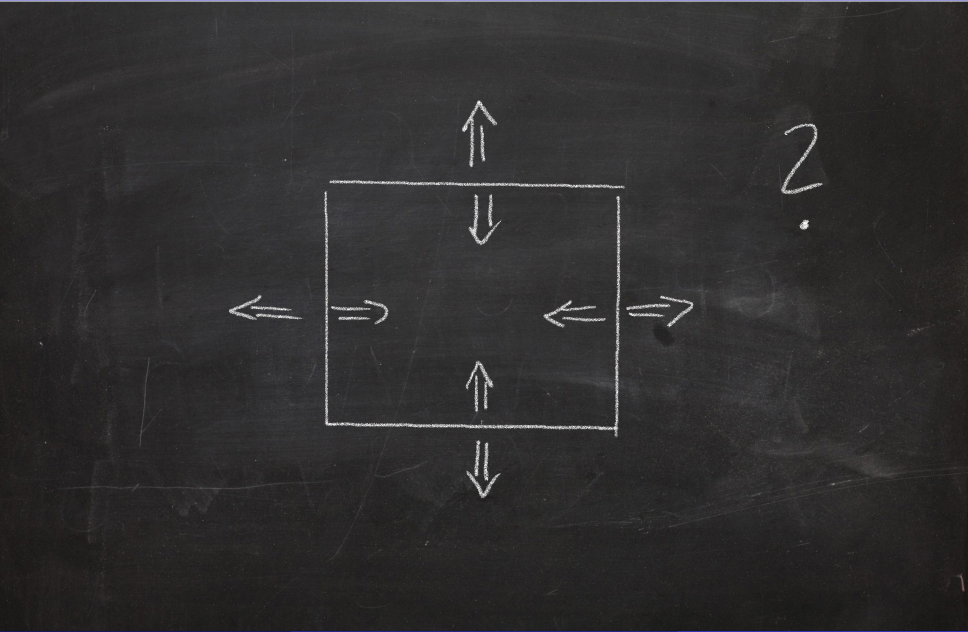

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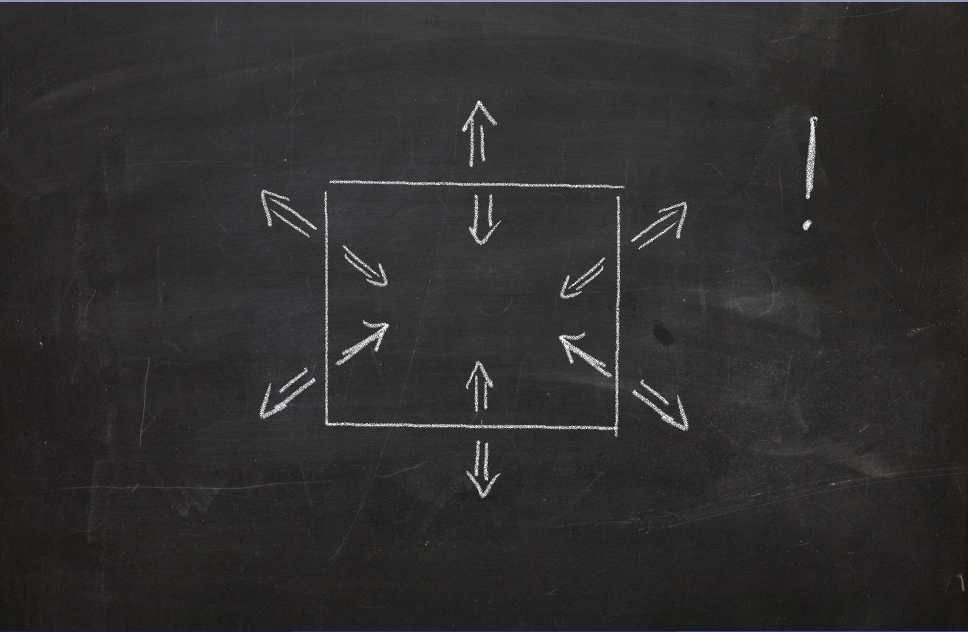

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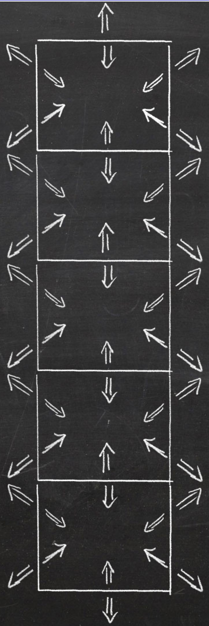

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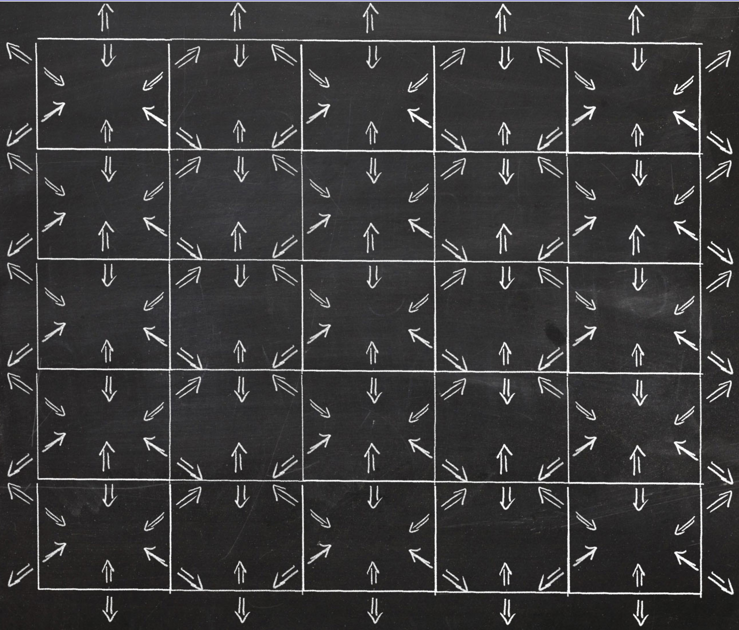

The Neighboring Column Approximation (Klinger and Mayer, 2016)

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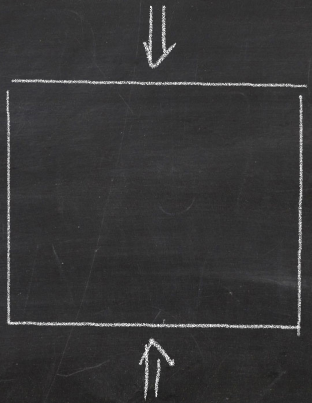

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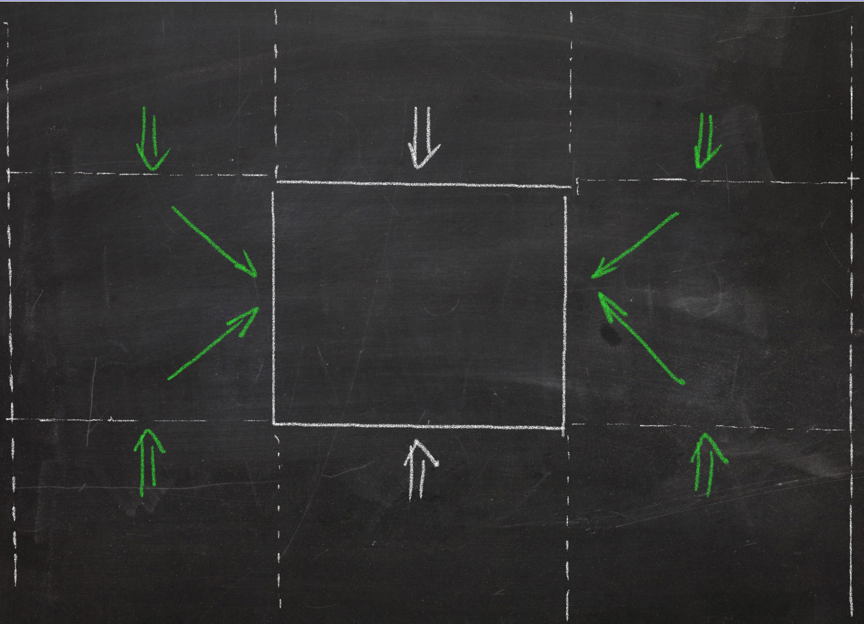
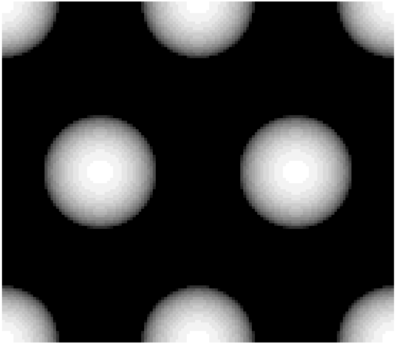


3D (MYSTIC) Heating Rates for Spherical Clouds



cloud cover: 30.4%

lwc = 0.5 g/m^3, r_{eff} = 10 μm

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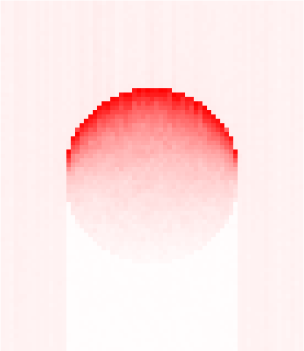

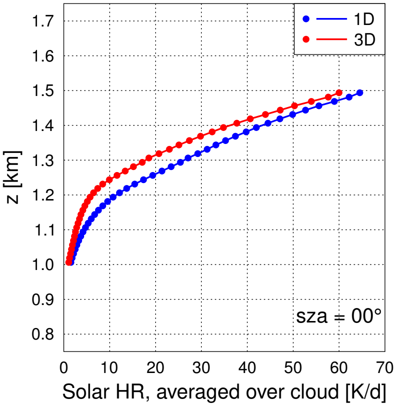

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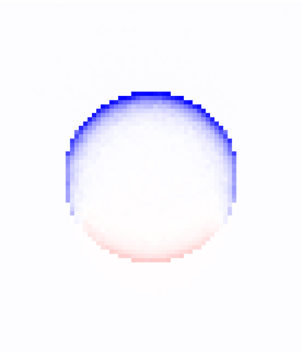

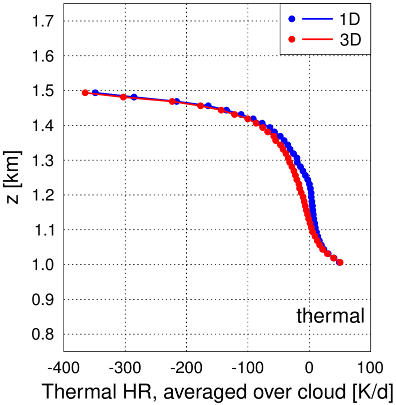

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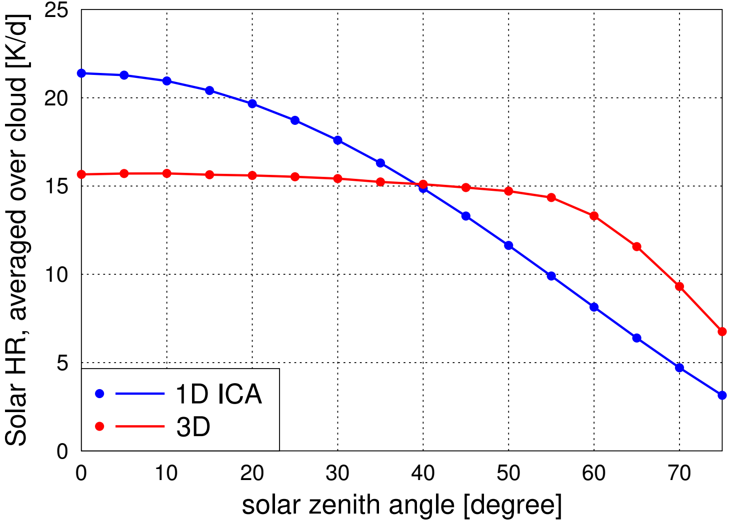

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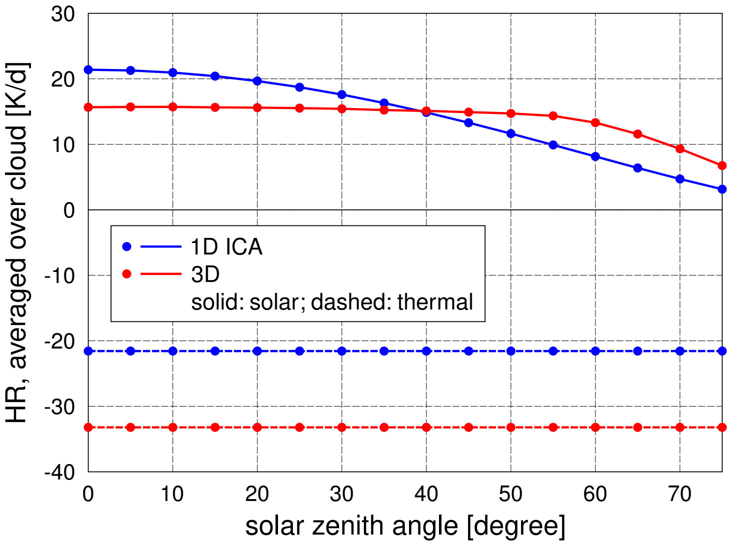

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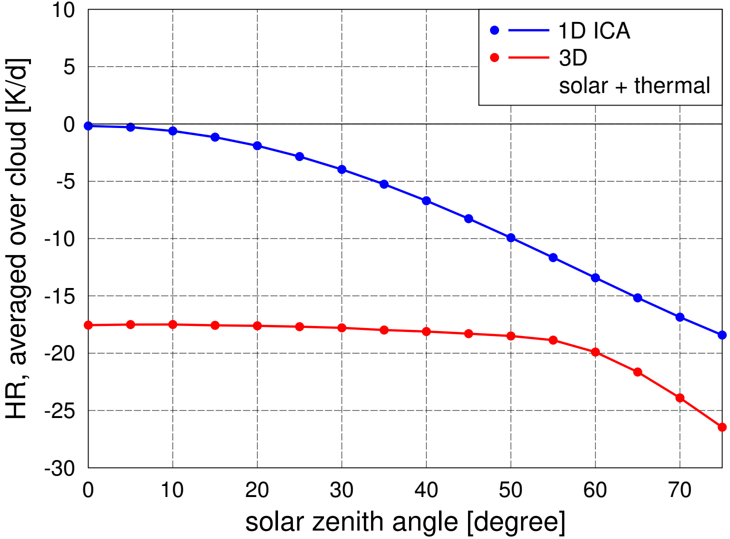
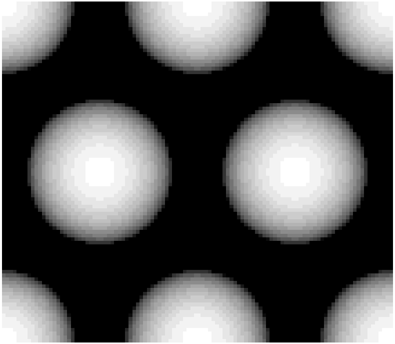


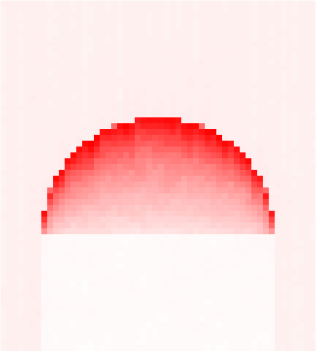
3D (MYSTIC) Heating Rates for Half Spheres

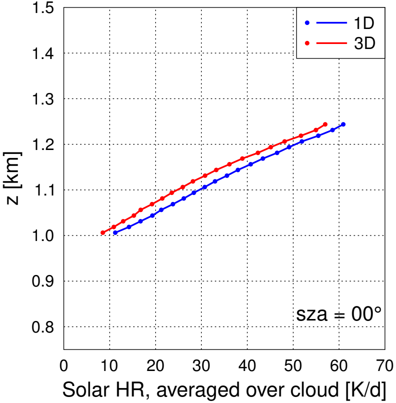


cloud cover: 49.8%

lwc = 0.5 g/m^3, r_{eff} = 10 μm

3D (MYSTIC) Heating Rates for Half Spheres





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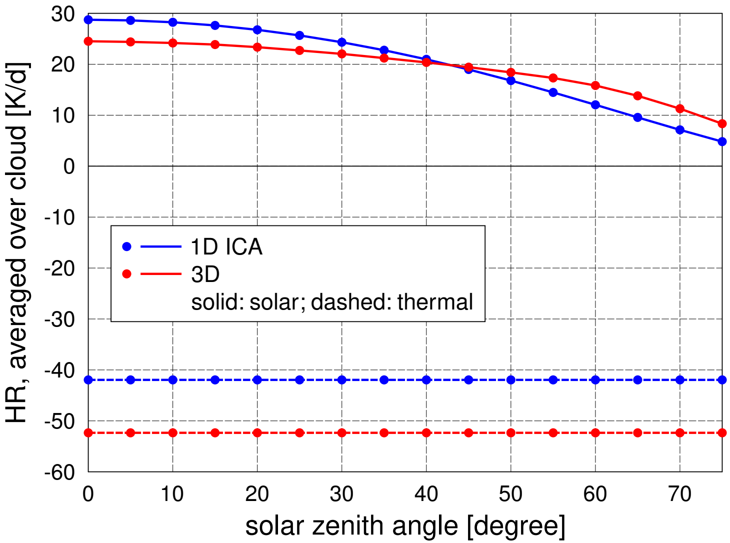

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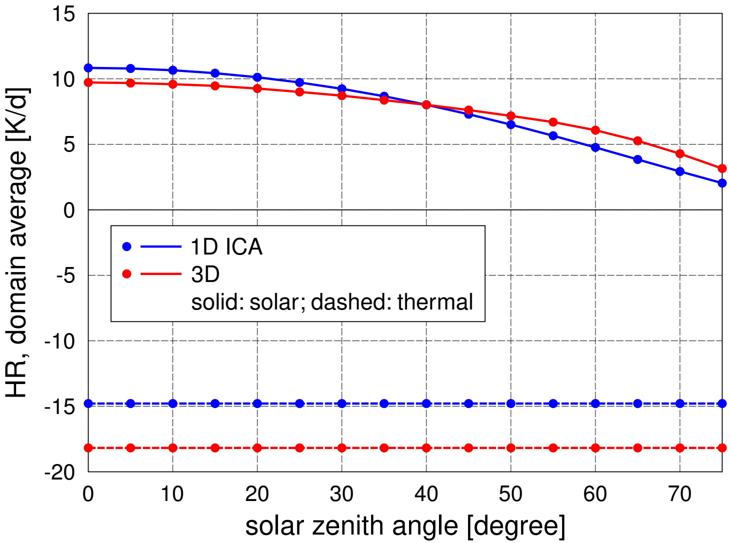


Effects: Cloud Streets (Jakub and Mayer, 2017)

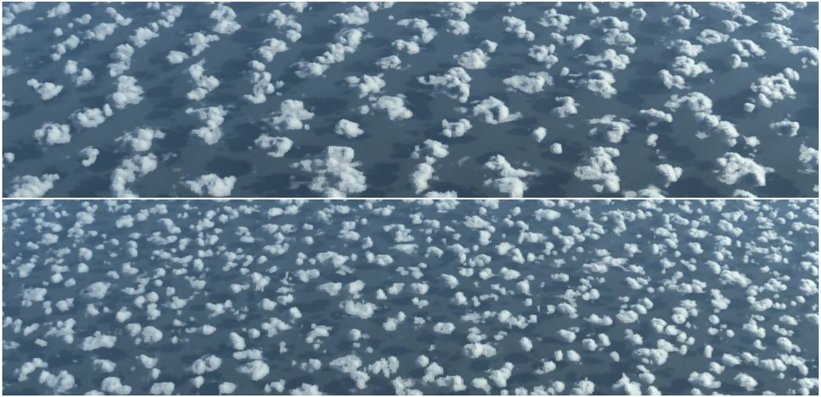
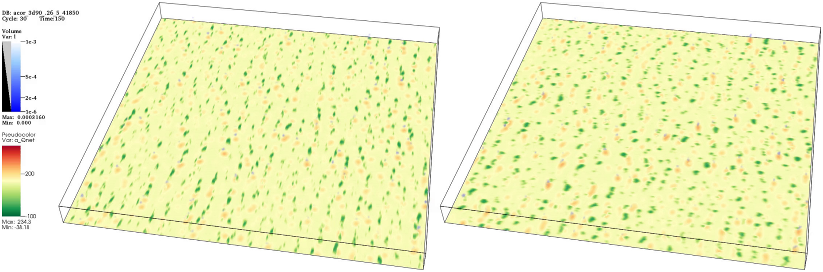


Figure 1. Virtual photograph of LES simulations at a cruising altitude of 15 km. Top panel: cloud formation of a simulation driven by 3D radiation (TenStream with sun in the east, i.e. right ($\varphi = 90°$)). Lower-panel: cloud formation of a simulation which was performed with 1D radiation (Two-stream). The specific model setup is the same as referenced in fig. 2 i.e., no background wind and a continental land surface. The simulations differ with respect to cloud size distributions and the organization in cloud streets, the cloud fraction though is the same (27 %). The visualization was performed with a physically correct rendering with MYSTIC (MonteCarlo solver in libRadtran (Mayer, 2009, Emde et al. 2015)).

SZA = 60°

Effects: Cloud Streets (Jakub and Mayer, 2017)



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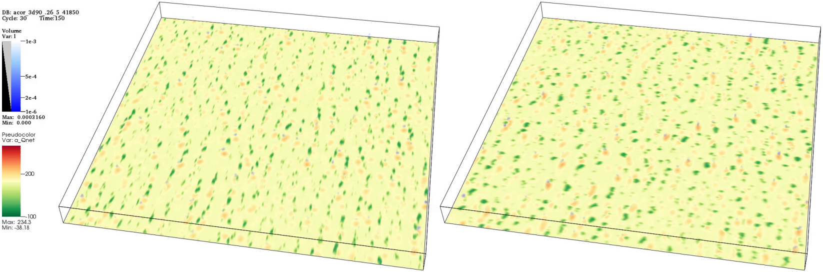
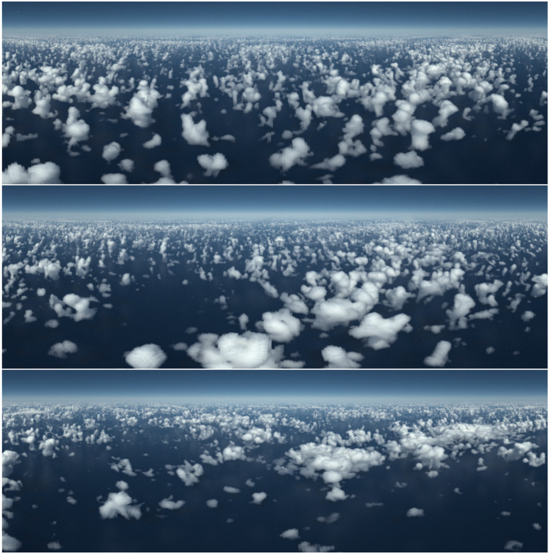


Sun in the South vs. Sun in the West

Effects: Atmospheric Heating and Cooling (Klinger et al, 2017)

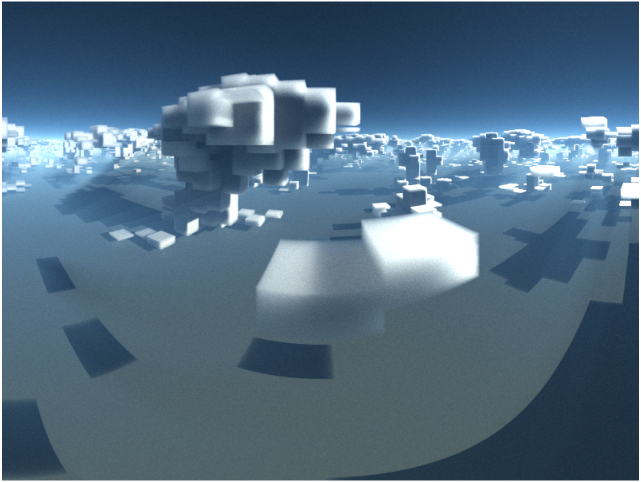


const. cooling

3D avg

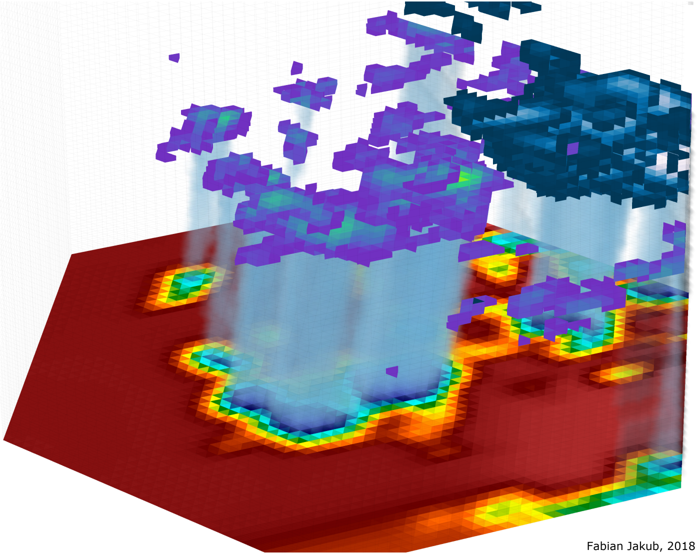
3D

Challenges: Effects at the NWP scale



Visualization of 2km “convection-permitting” model output with MYSTIC

Challenges: New NWP models – Unstructured Grids



Fabian Jakub, 2018

Summary of 3D Radiation

- Strong differences between 3D and 1D heating rates in high resolution radiative transfer and cloud models
- Reasonably fast parameterizations available
- Effect on clouds in high resolution models demonstrated
- Work on microphysics effect ongoing
- How much remains at low resolution and how to parameterize it?
- And how to parameterize subgridscale effects?

Effect of Radiation on Clouds

Schumann et al. (2002), Wapler and Mayer (2008),
Wissmeier et al (2013): **Cloud shadows**

Klinger and Mayer (2014, 2016), Klinger et al (2017):
Atmospheric heating and cooling: thermal radiation

Jakub and Mayer (2015a, 2015b, 2017):
Atmospheric heating and cooling: Solar and thermal radiation