Cirrus Clouds triggered by Radiation

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Content

- Introduction
  - Motivation, Cirrus clouds, Radiation Transfer
- Model Description
- Results
  - Reference Case
  - Sensitivity Studies → Stability, wind-shear, RHi
- Conclusion

Motivation

Introduction

Cirrus Clouds

- High level clouds consisting purely of ice crystals.
- Ice Supersaturated Regions (ISSR) are potential cirrus formation regions.
- Homogenous freezing is probably the dominant freezing mechanism in low temperature / high altitude regimes (< 235 K) [Koop et al., 2004].
- Cover approximately 20 – 30% of earth’s surface [Wylie & Menzel, 1999]
- → Cirrus clouds are important modulators of earths radiation budged!

Introduction

Cirrus Cloud Formation

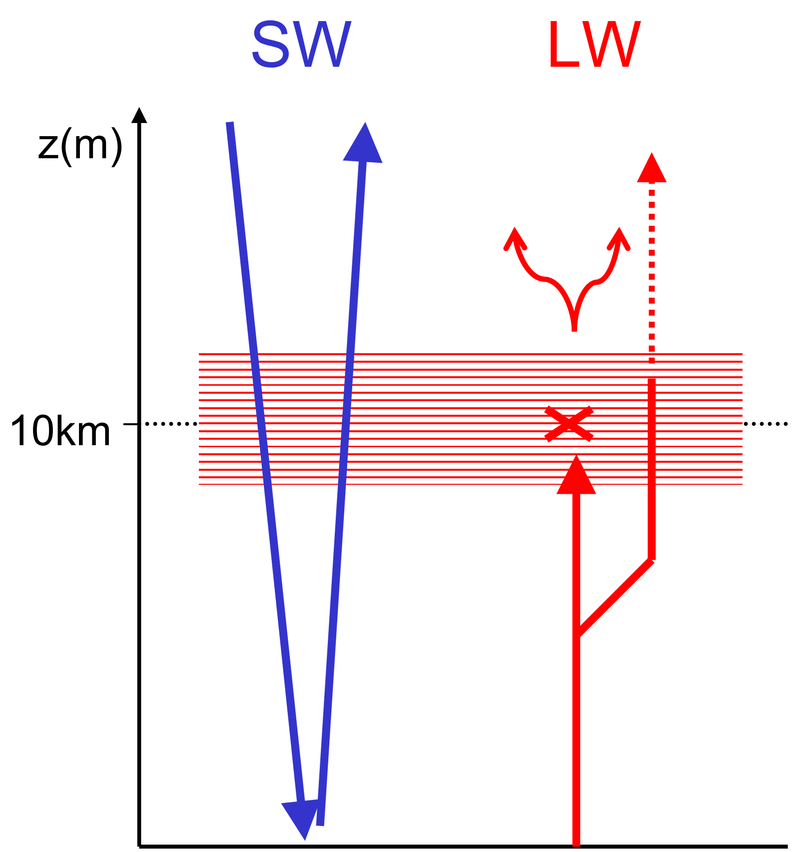
- Mainly formed by vertical updrafts
- Dynamical processes acting on various scales

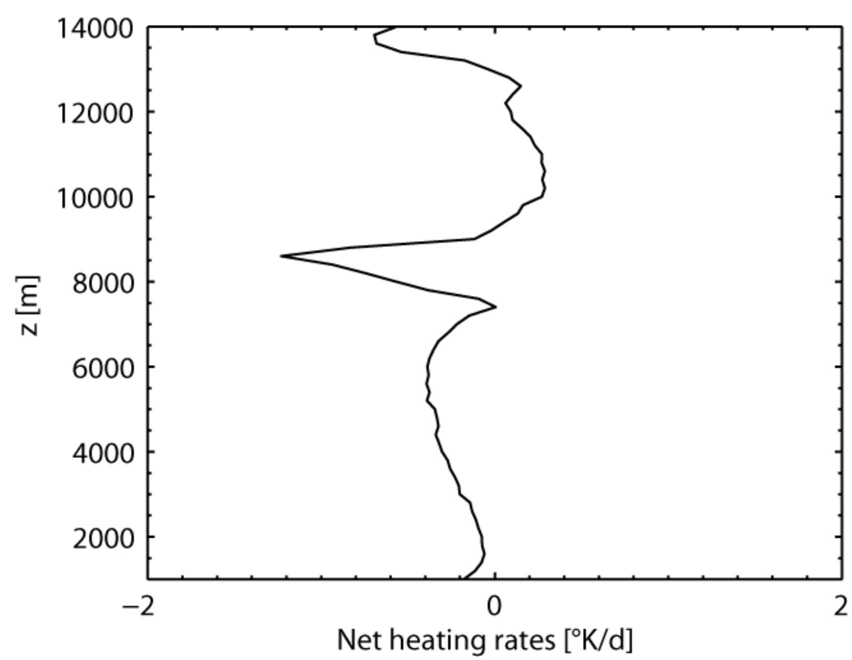
A superposition of different dynamical and microphysical processes on various scales influences the cirrus formation.

- Large-scale processes (synoptic-): e.g. frontal lifting, (radiative cooling/heating)
- Meso-scale processes: e.g. gravity waves
- Small-scale processes: e.g. microphysical processes, turbulence

Introduction

Radiation Transfer - ISSR





Cooling/heating due to radiation in ISSRs is a slow process (~ 2 K/d)

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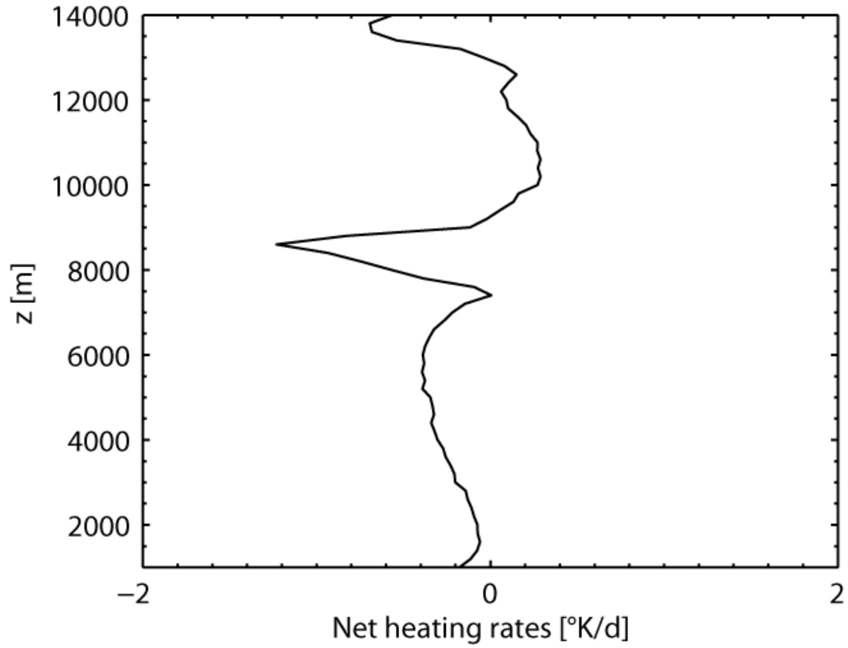
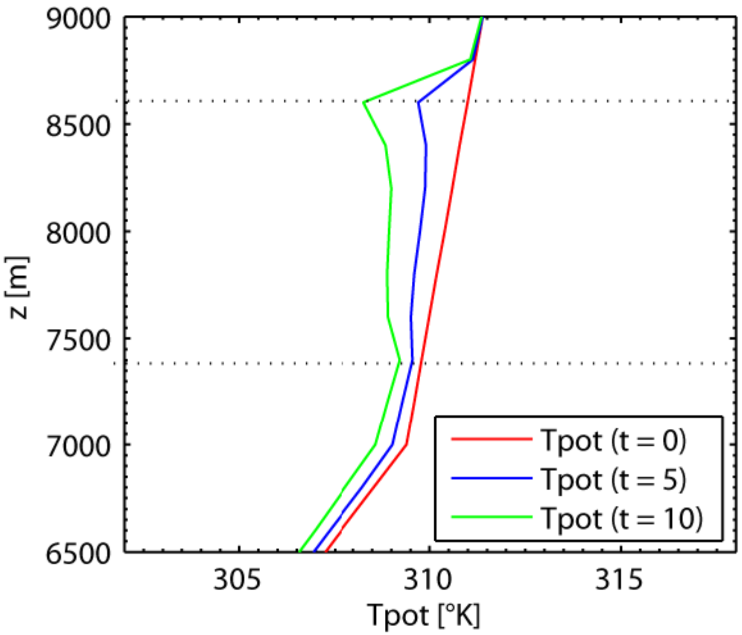
Introduction

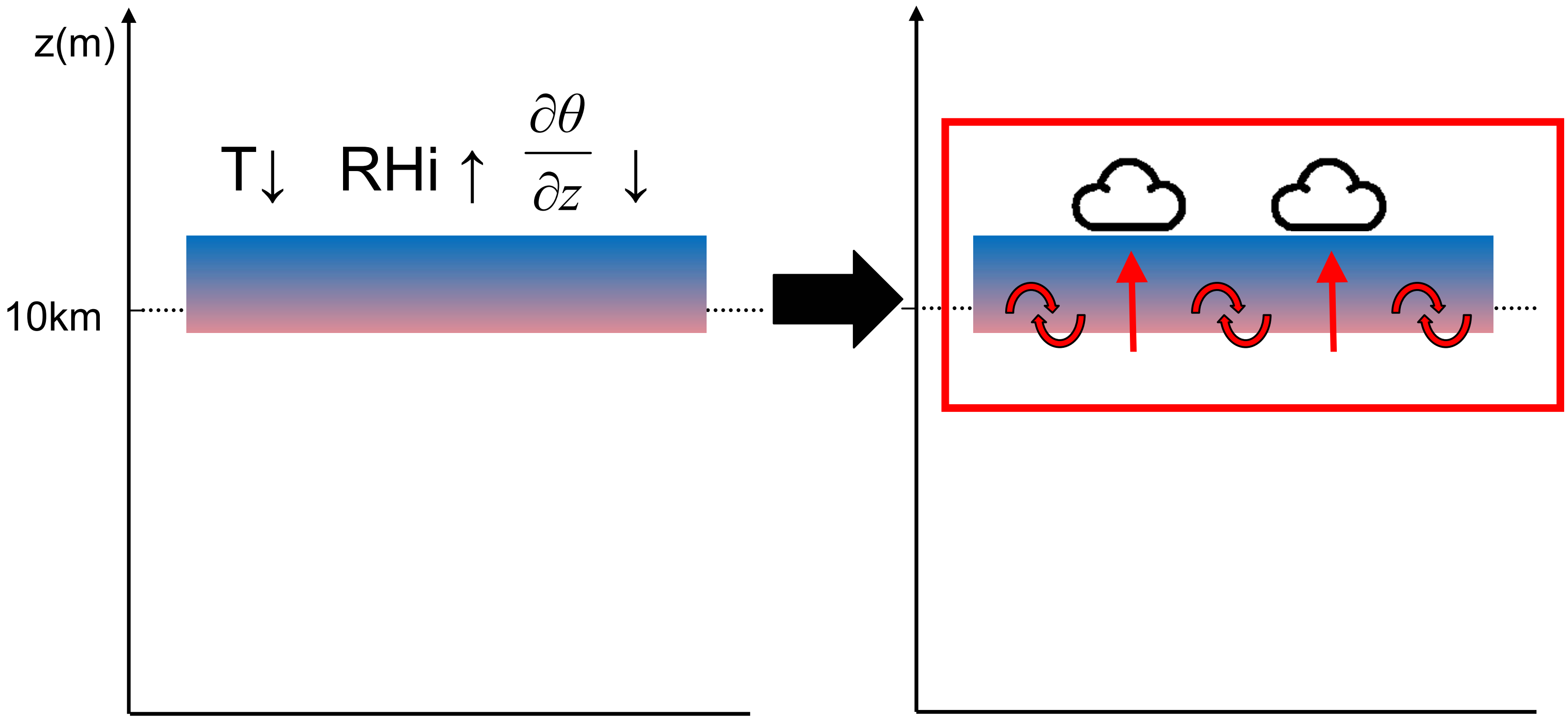
Radiation Transfer





Introduction

Radiation Transfer



$$RHi = 100\% \cdot \frac{q_v \cdot p}{\varepsilon \cdot p_{sat,i}(T)}$$

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Model Description

State of the Art

- Only few parameterization for the physical correct formation of cirrus clouds driven by synoptic scale dynamics in global climate models (e.g. ECHAM, NCAR-Model).
- The impact of mesoscale and small-scale motion on cirrus clouds is not yet regarded.
- → Exclusive consideration of synoptic scale dynamics leads to an underestimation of the frequency of occurrence of cirrus clouds [Dean et. al., 2005].

Model Description

EULAG ("Eulerian, semi-Lagrangian numerical model for fluids")

- Resolution:
  - Spatial: x: 100m, z: 50m -- Model Domain: 12.8 x 15 km
  - Temporal: 1sek (dynamics), 100ms (ice physics), 10sek (radiation)

Model Description

EULAG ("Eulerian, semi-Lagrangian numerical model for fluids")

- Resolution:
  - Spatial: x: 100m, z: 50m -- Model Domain: 12.8 x 15 km
  - Temporal: 1sek (dynamics), 100ms (ice physics), 10sek (radiation)
- Recently developed bulk ice microphysics scheme for the low temperature range (T < 235 K) including:
  - Nucleation (homogeneous/heterogeneous)
  - Deposition (growth/evaporation)
  - Sedimentation
  - Consistent double moment scheme (v_T for ice crystal number and mass concentration)

Model Description

EULAG ("Eulerian, semi-Lagrangian numerical model for fluids")

– Implemented radiation code [Fu, 1996; Fu et al., 1998]
  - Solar (SW) regime: 6 Bands
  - Longwave (LW) regime: 12 Bands
  - Uses spatial Resolution of EULAG within the Model Domain.
  - 1 km Resolution above the model domain up to z = 50km

Model Description

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  - Uses spatial Resolution of EULAG within the Model Domain.
  - 1 km Resolution above the model domain up to z = 50km
- Input: T, p, q_v, O_3, IWC, N

$$r_{eff} = \frac{\int_0^\infty \left(\frac{A}{4\pi}\right)^{3/2} \cdot f(L)dL}{\int_0^\infty \frac{A}{4\pi} \cdot f(L)dL}$$

- Output:
  - Optical depth (for every grid-cell)
  - SW and LW up-/downward fluxes (for every grid-cell)
  - SW and LW Heating Rates (for every grid-cell)

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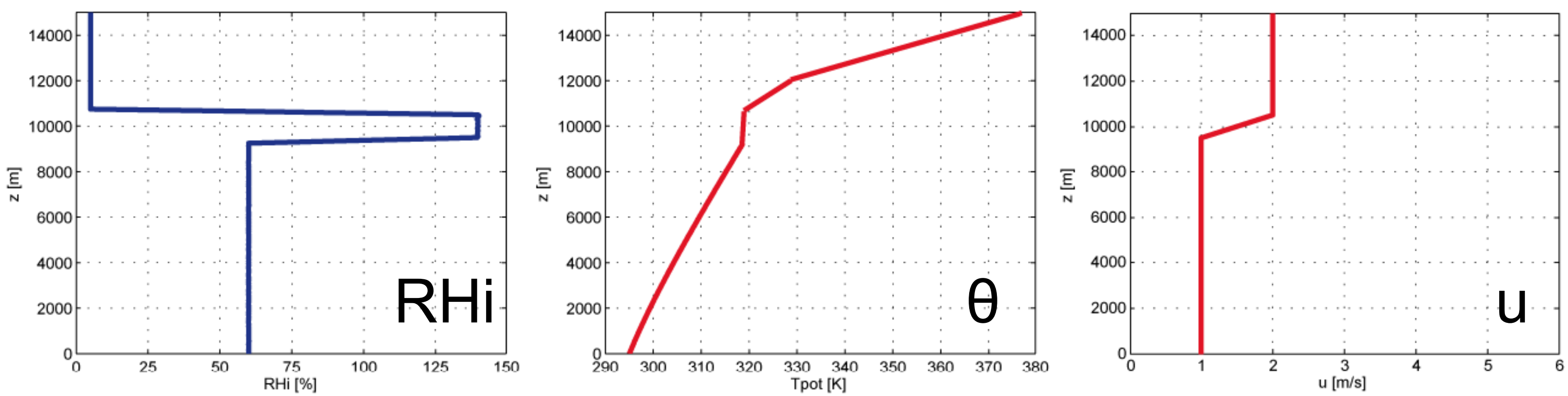
Setup

Cirrus triggered by radiation

Experimental Setup (**reference case**):

- Supersaturated region with RHi 140%
  - Altitude: 10km , Thickness: 1km

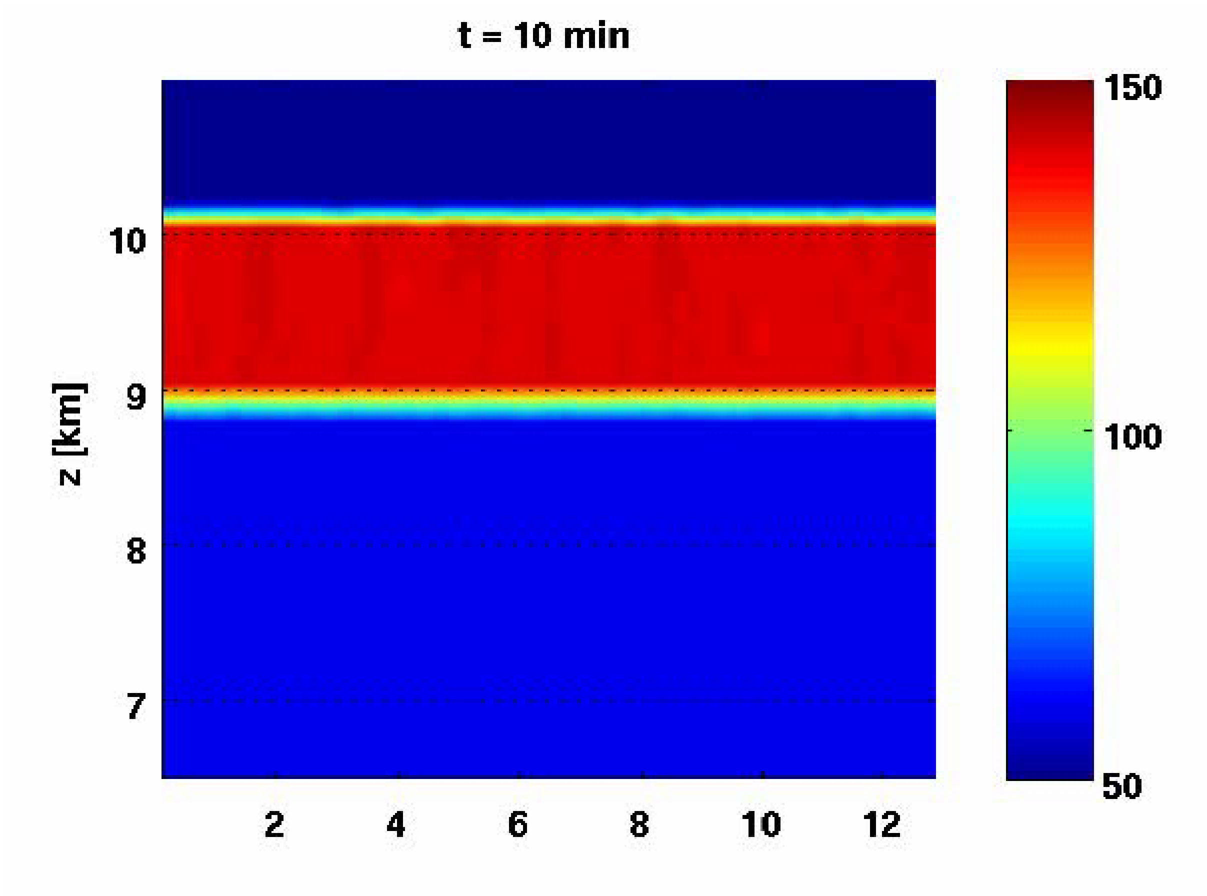


- Radiation and temperature gauss-noise (σ ~ 0.1K)
- Vertical gradient of potential Temperature: +0.4 K/km

Results – Reference Case

<u>Cirrus triggered by radiation</u>

RHi [%] / Ice water content [10^{-6} kg/m^3]



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Results – Reference Case

Cirrus triggered by radiation

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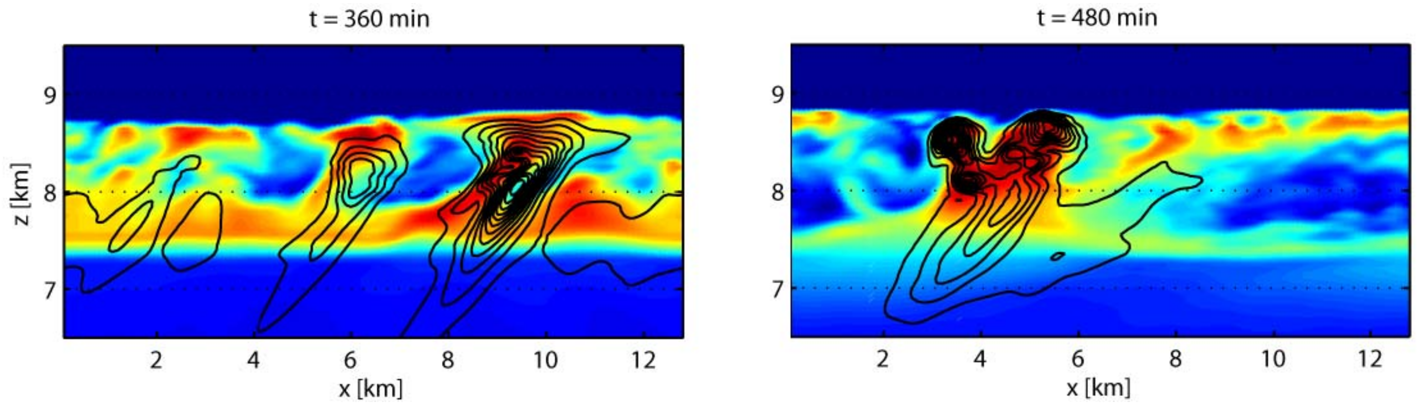
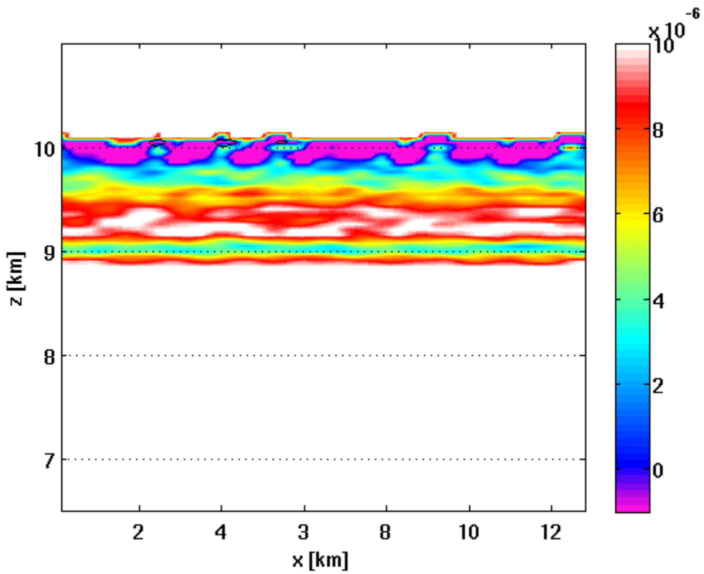
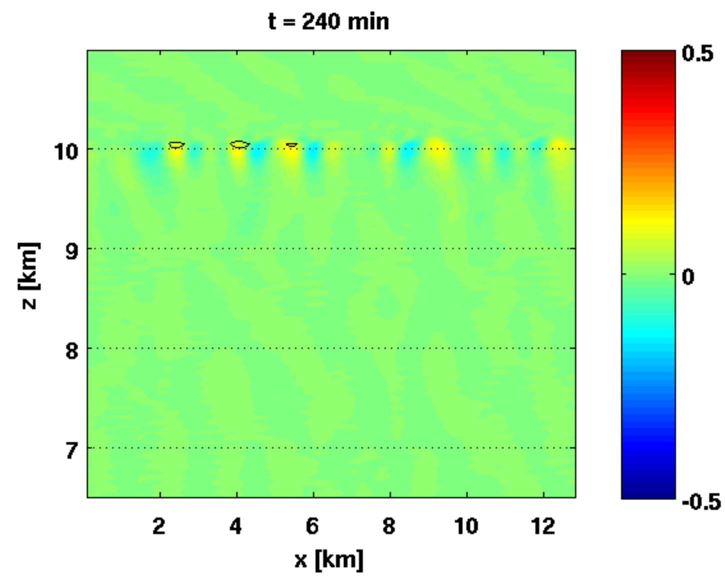


Results – Reference Case

Cirrus triggered by radiation





Negative Brunt-Vaisala Frequency (N_m^2)! → unstable

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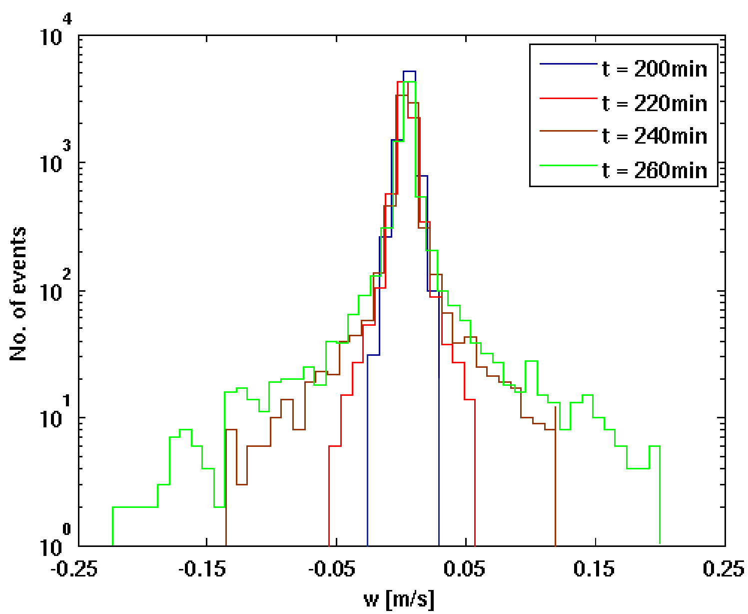
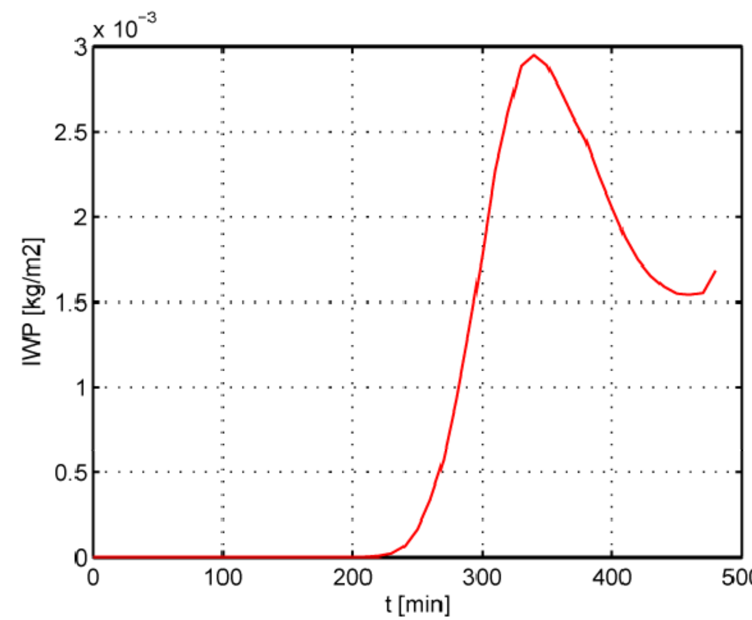
Results – Reference Case

Cirrus triggered by radiation

w [m/s]



IWP [kg/m^2]



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Results – Sensitivity Studies

Cirrus triggered by radiation

Sensitivity Studies:

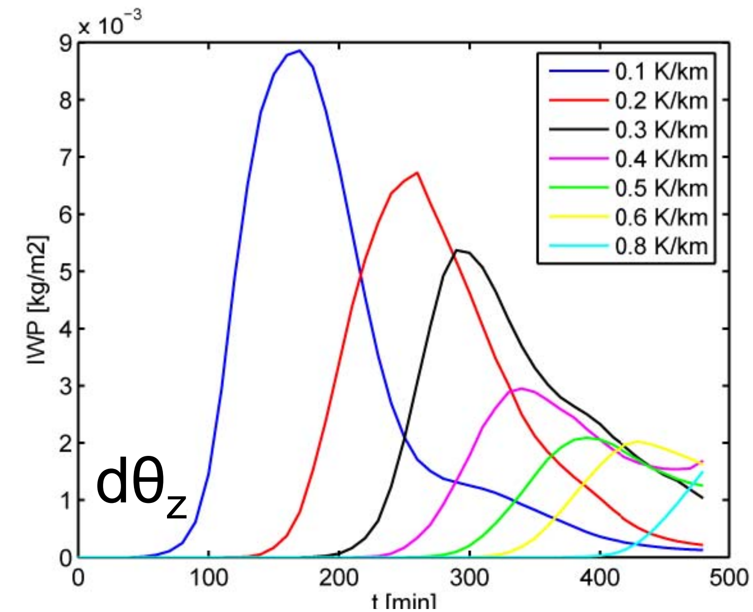
- Stability
  - static: $$\frac{\partial \theta_e}{\partial z} \geq 0$$
  - dynamical: $$Ri \geq 0.25$$ (Miles-Theorem)

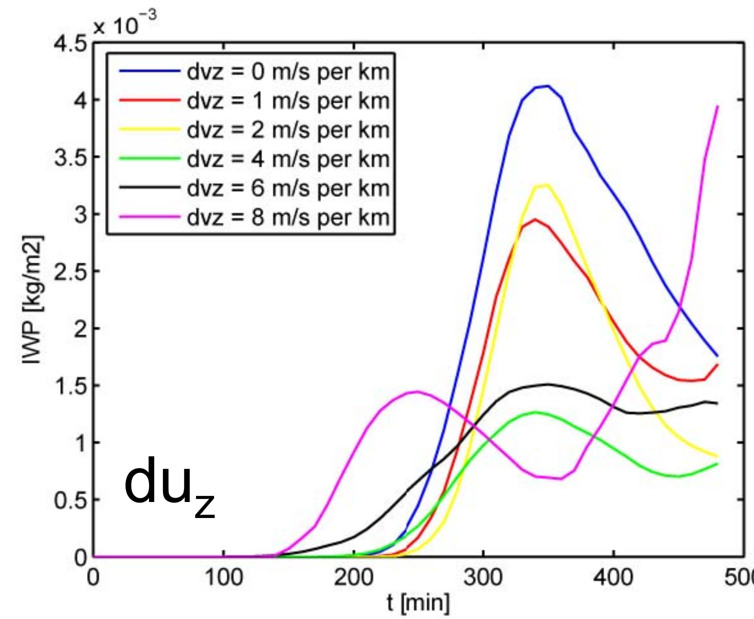
$$\rightarrow \quad Ri = \frac{N_m^{\,2}}{\left(\frac{\partial u}{\partial z}\right)^2} \quad / \quad N_m^{\,2} = \frac{g}{\theta_e}\frac{\partial \theta_e}{\partial z}$$

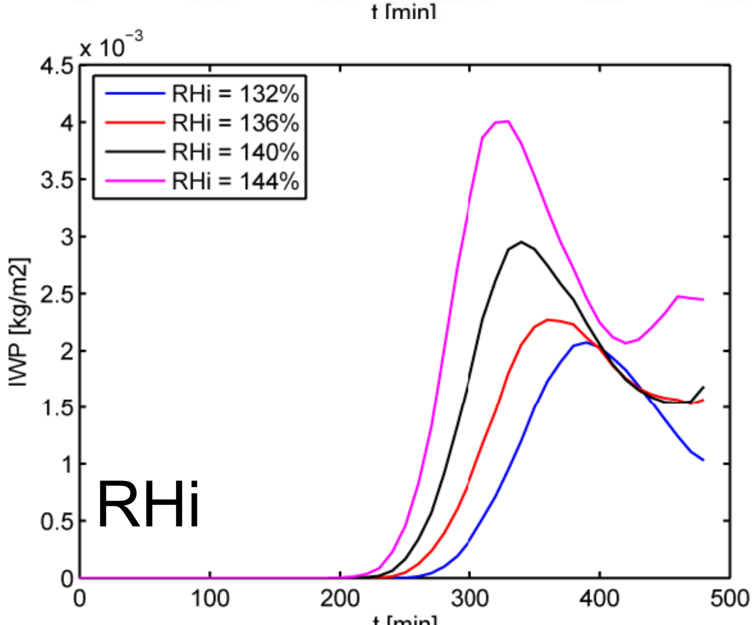
- RHi

Results

Cirrus triggered by radiation - IWP







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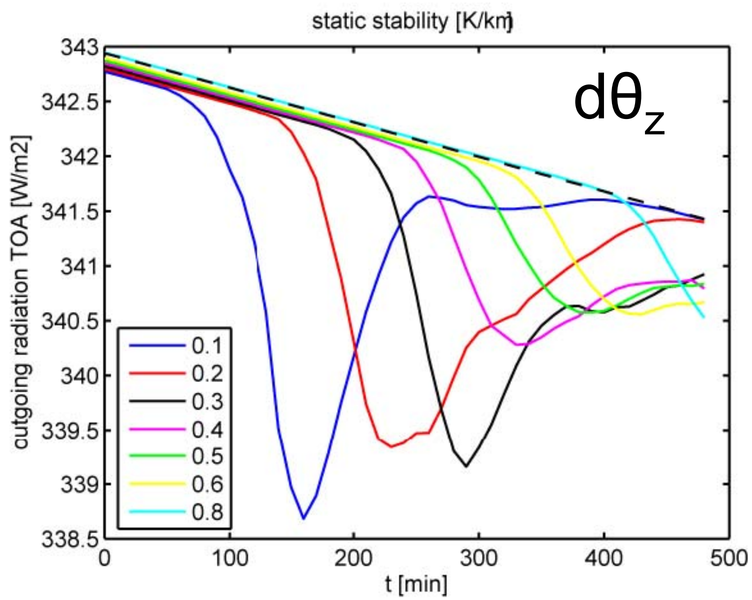
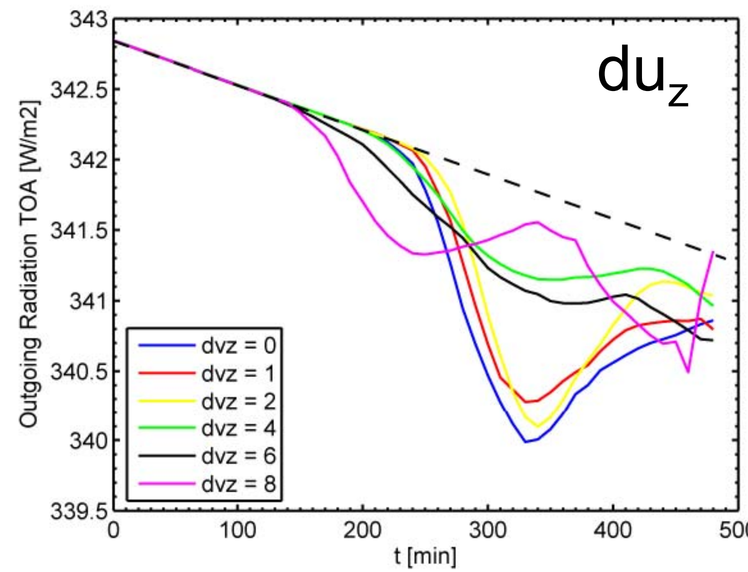
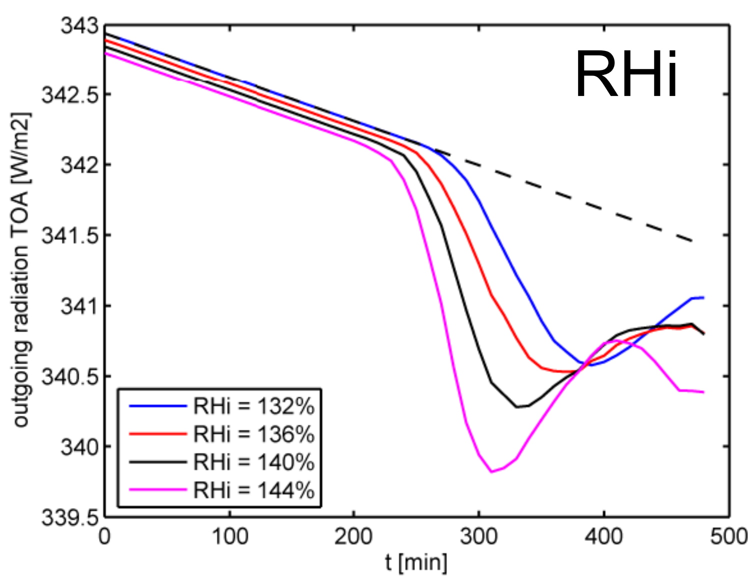
Results

Cirrus triggered by radiation – outgoing radiation TOA

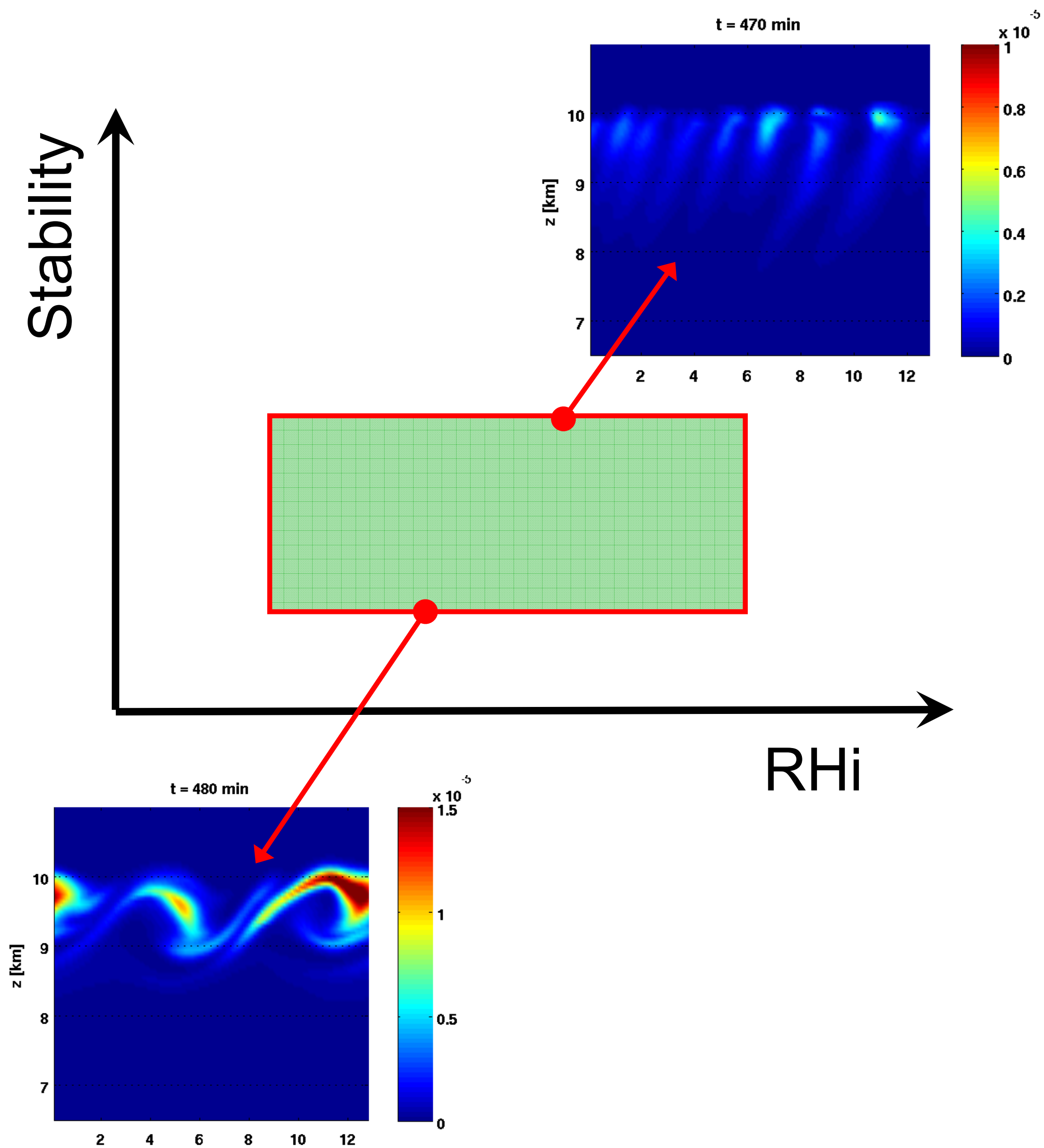






Results – Sensitivity Simulations

Cirrus triggered by radiation



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Conclusion

- 2-stream radiation transfer code implemented in EULAG
- Cooling/heating due to the emission of longwave radiation can trigger a cirrus cloud.
- The formation and evolution of this kind of cirrus clouds depends on the RHi of the ISSR and the stability (static and dynamic) of the stratification.
- The formed cirrus decrease the total outgoing radiation TOA (warming).

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Conclusion

<u>Outlook:</u>

- Development of parameterisations of these (subgrid) effects for large-scale models

Progress in this area will help to better determine the cirrus radiative forcing in the present climate and will allow more reliable predictions of cirrus clouds in a changing climate.

Thank you for listening!

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Conclusion

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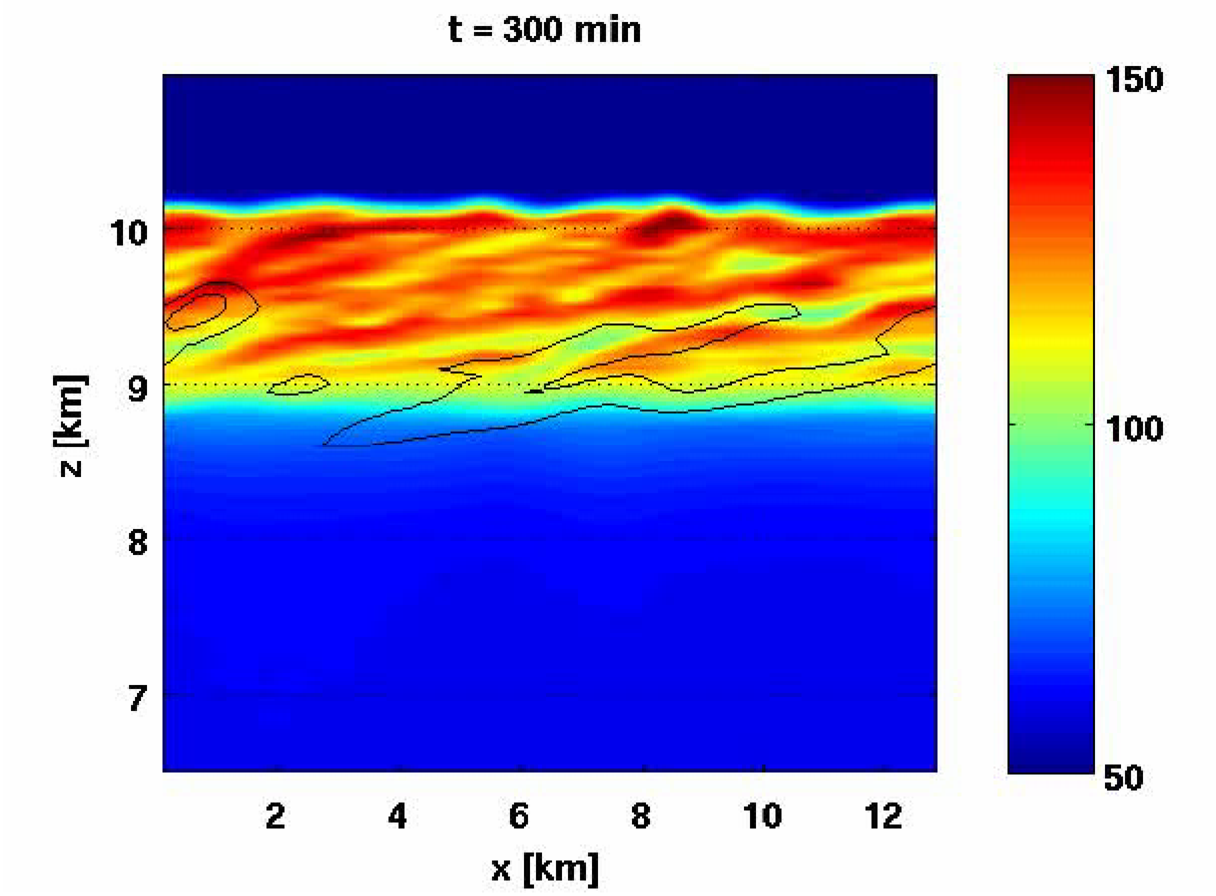
Extension



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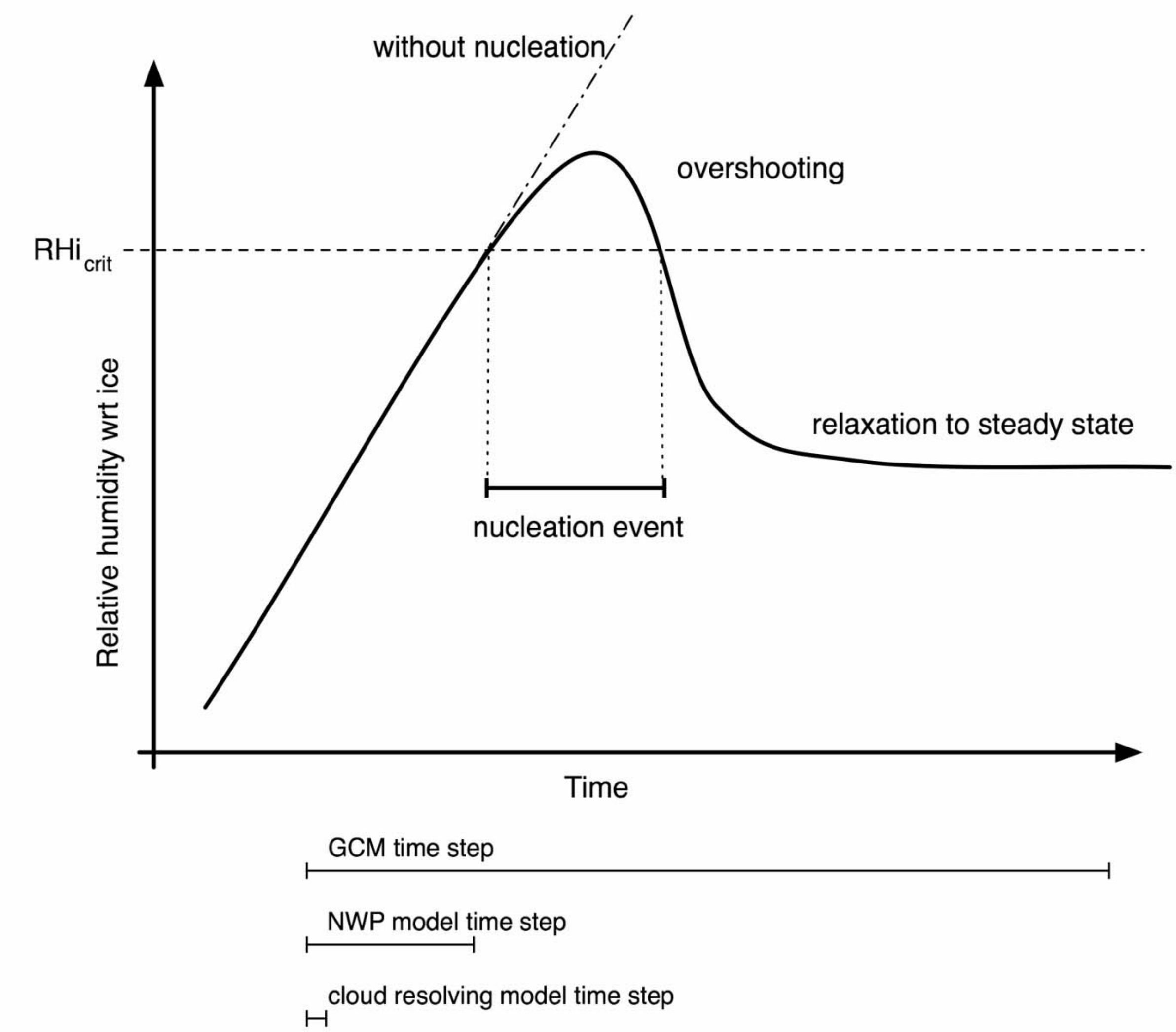

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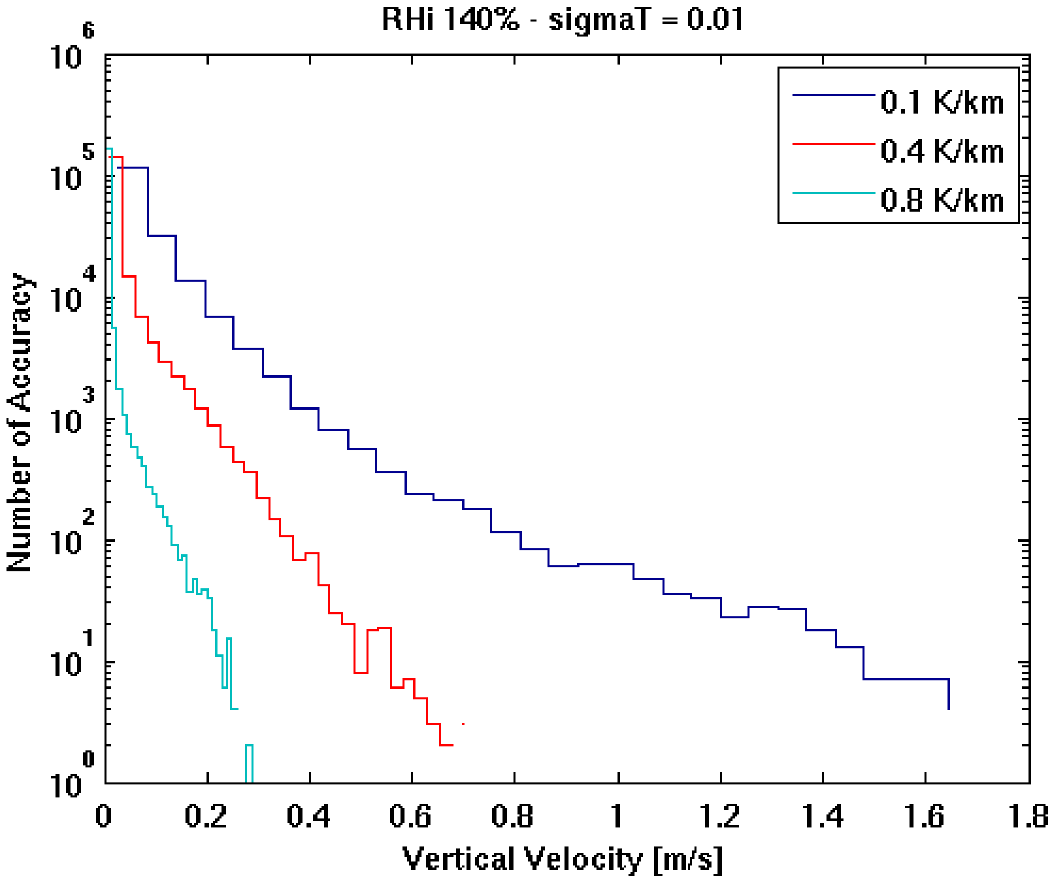

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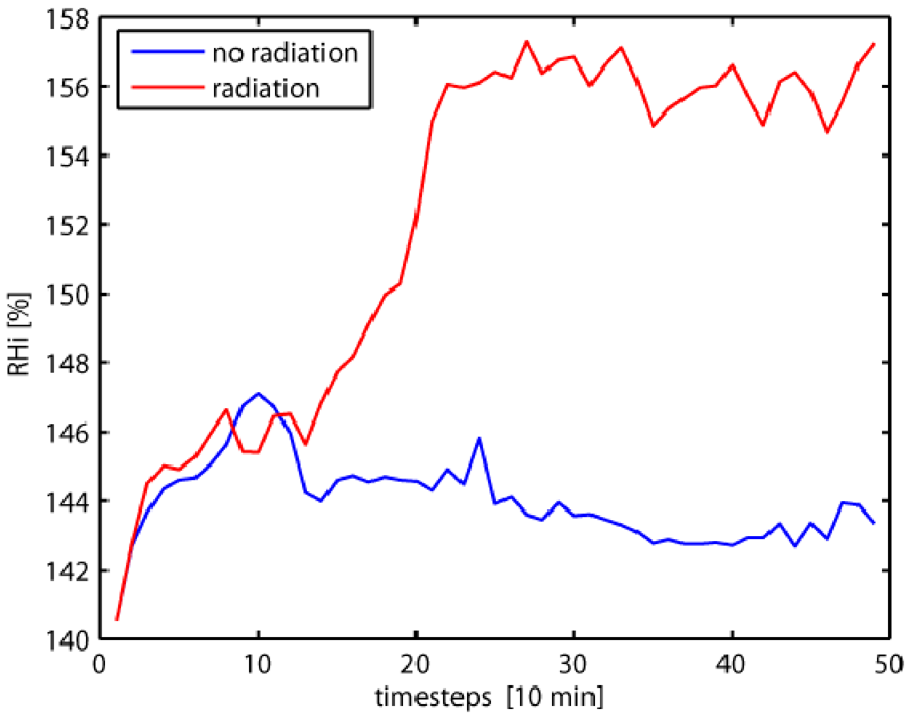

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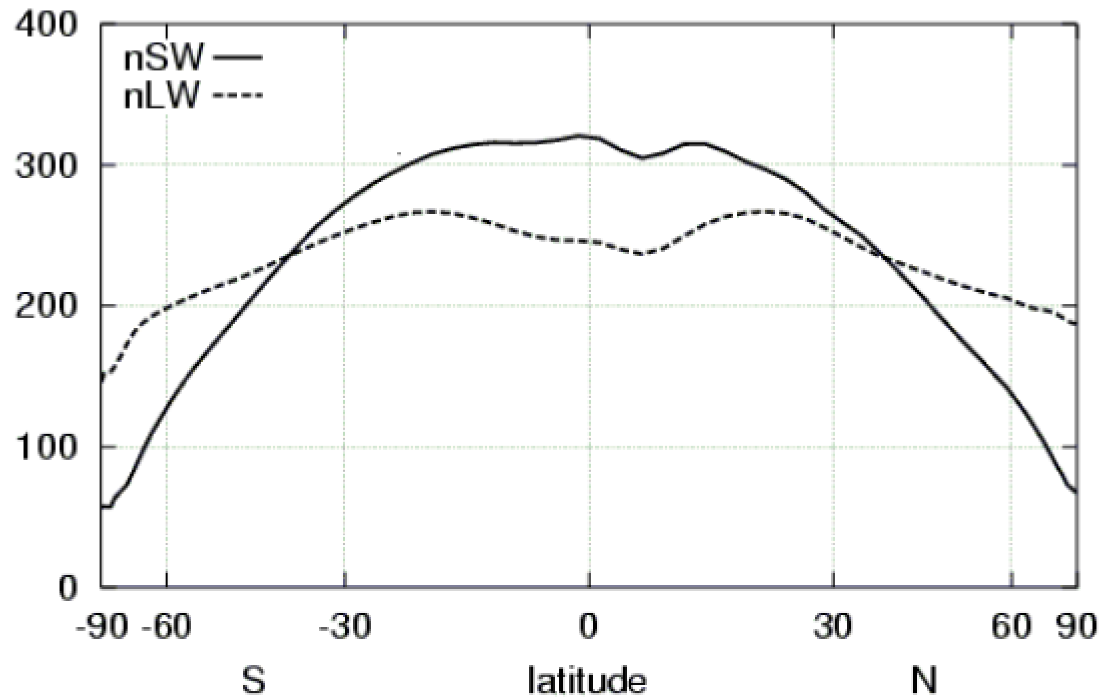

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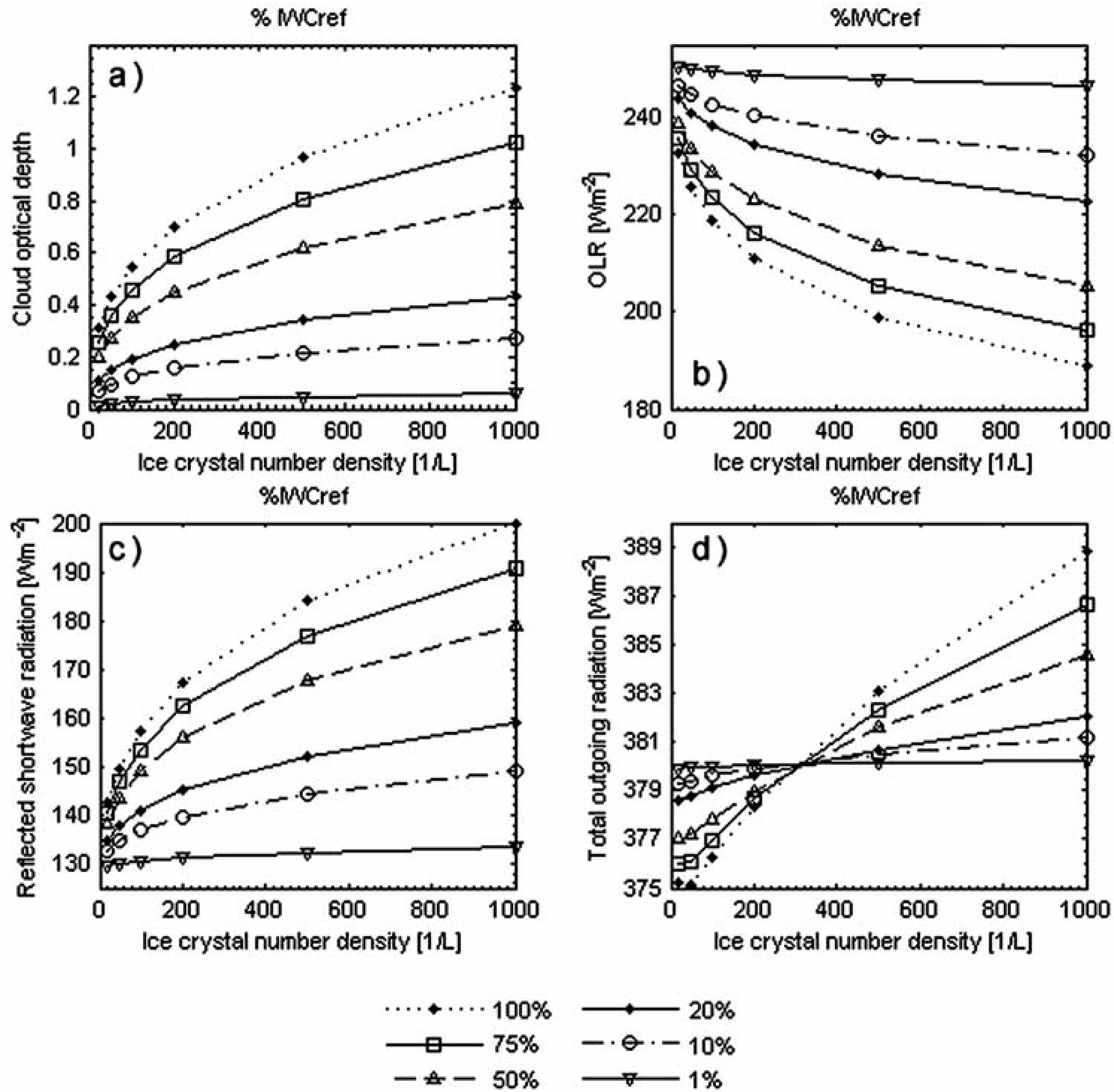


Extension

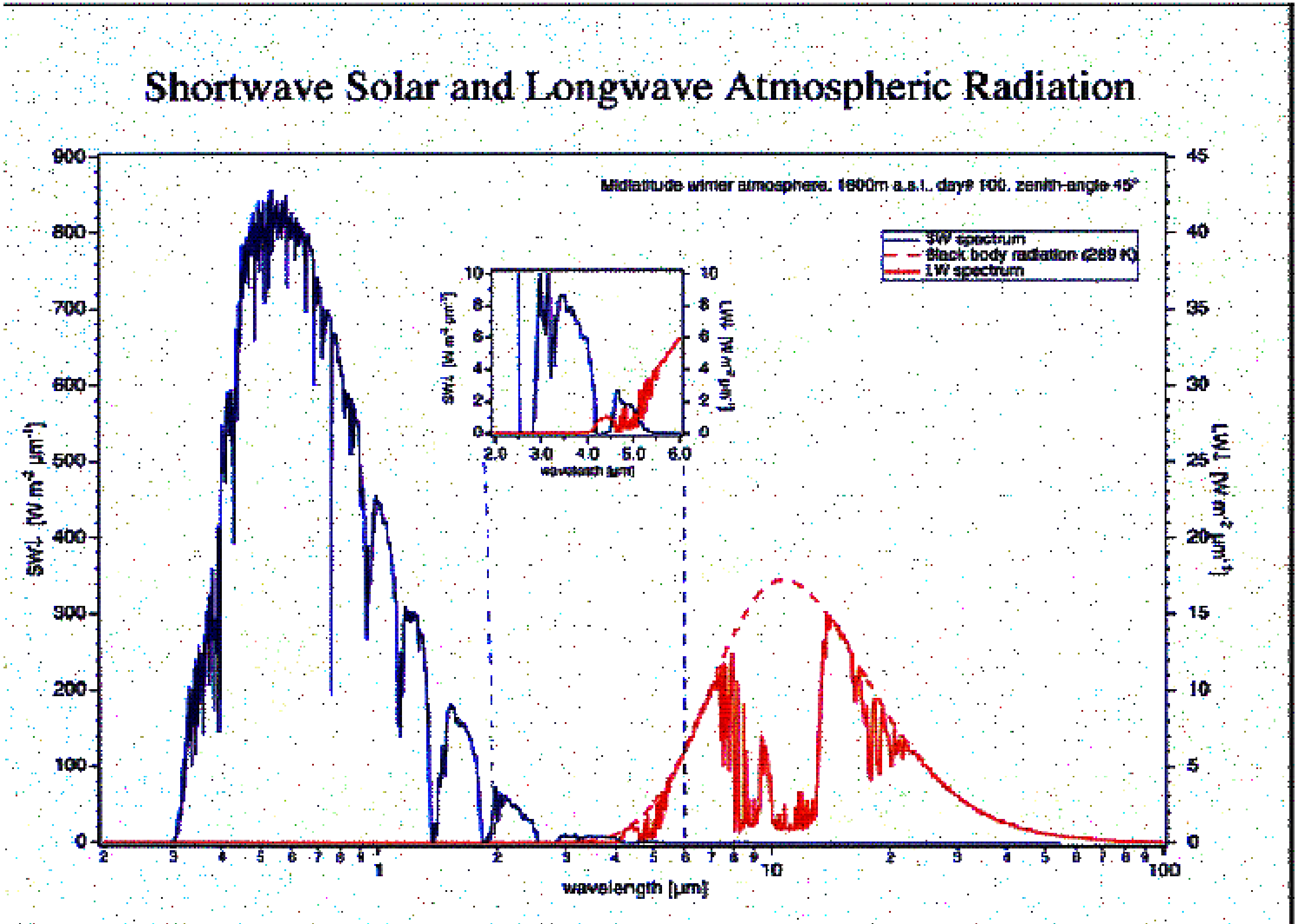
Band No.	Spectral region (μm)
1	0.2 - 0.7
2	0.7 - 1.3
3	1.3 - 1.9
4	1.9 - 2.5
5	2.5 - 3.5
6	3.5 - 4.0

Table 3.4: Wavelengths of the optical bands of the radiation code designed by Fu et al. (1998) - Solar regime

Band No.	Spectral region (μm)	(cm^{-1})
1	4.5 - 5.3	1900 - 2200
2	5.3 - 5.9	1700 - 1900
3	5.9 - 7.1	1400 - 1700
4	7.1 - 8.0	1250 - 1400
5	8.0 - 9.0	1100 - 1250
6	9.0 - 10.2	980 - 1100
7	10.2 - 12.5	800 - 980
8	12.5 - 14.9	670 - 800
9	14.9 - 18.5	540 - 670
10	18.5 - 25.0	400 - 540
11	25.0 - 35.7	280 - 400
12	35.7 - ∞	0 - 280

Table 3.5: Wavelengths and wavenumbers of the optical bands of the radiation code designed by Fu et al. (1998) - Longwave regime

Extension



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