From ice crystals to climate: clearing high clouds of uncertainty

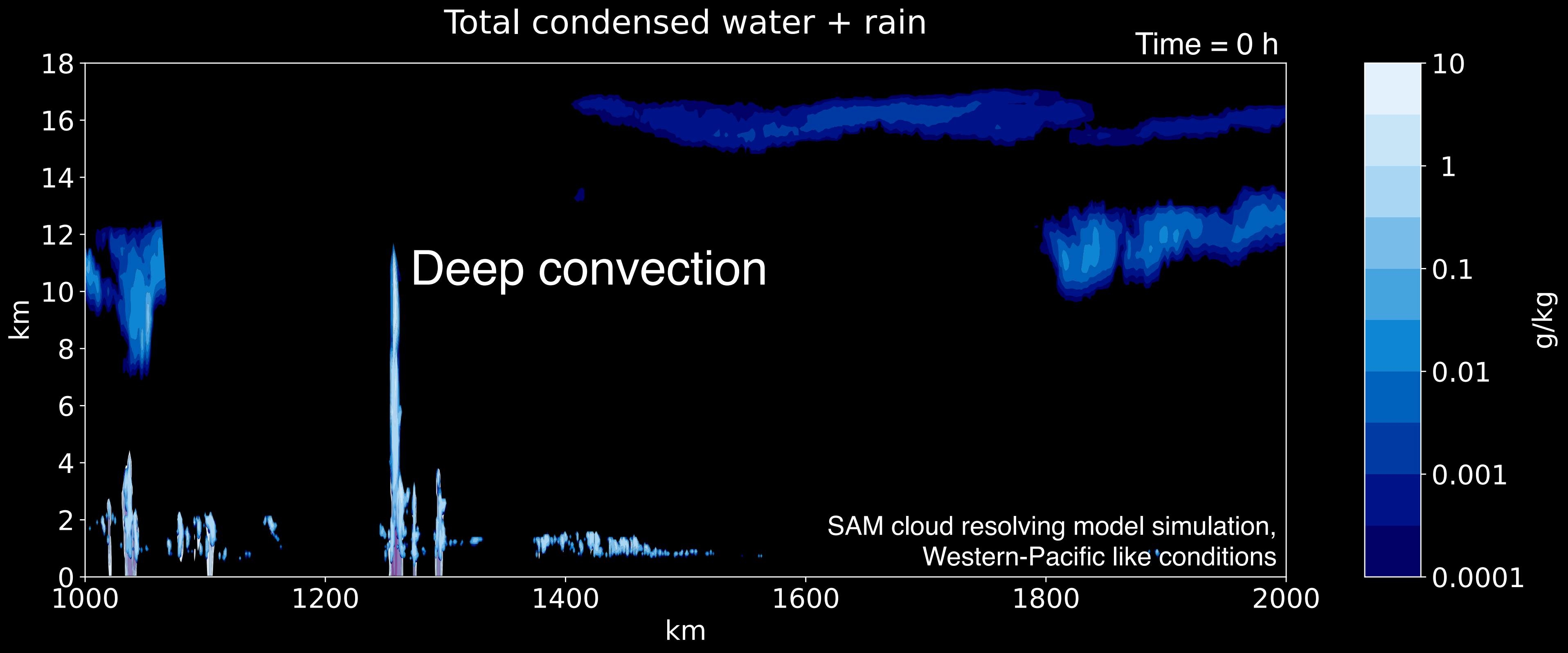
Blaž Gasparini[1], Peter Blossey[2], Dennis Hartmann[2], Aiko Voigt[1]

[1]University of Vienna, [2]University of Washington

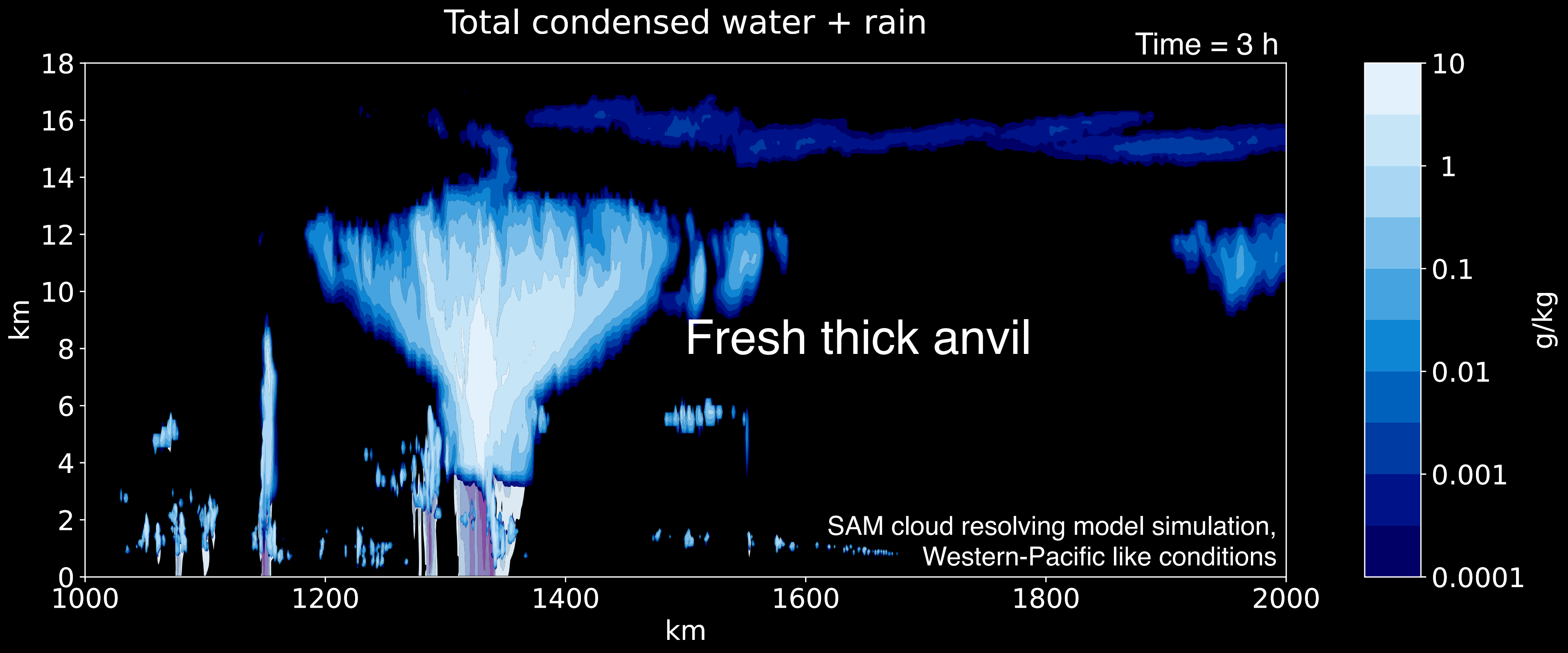
Funded by the European Union

Swiss National Science Foundation

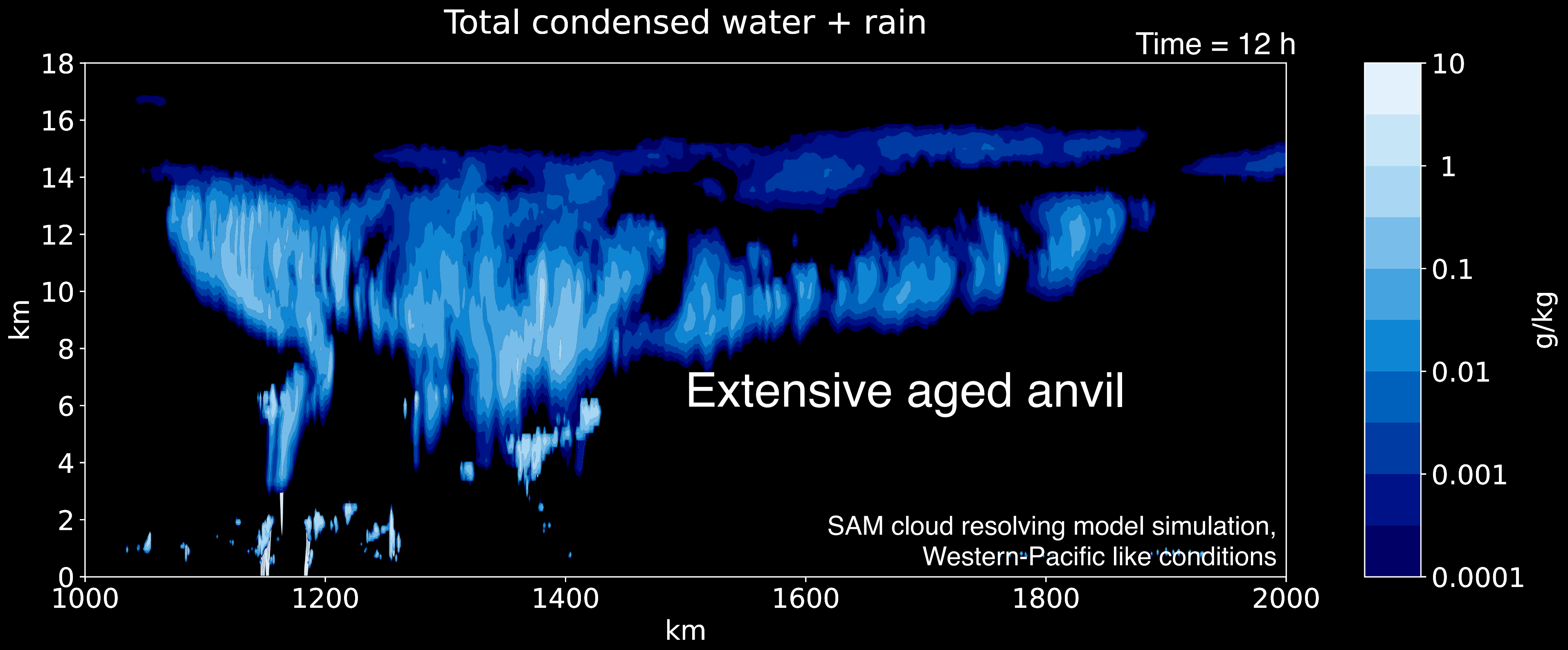
Anvil lifecycle: from reflective, rainy convective cores to long-lived semi-transparent thin cirrus



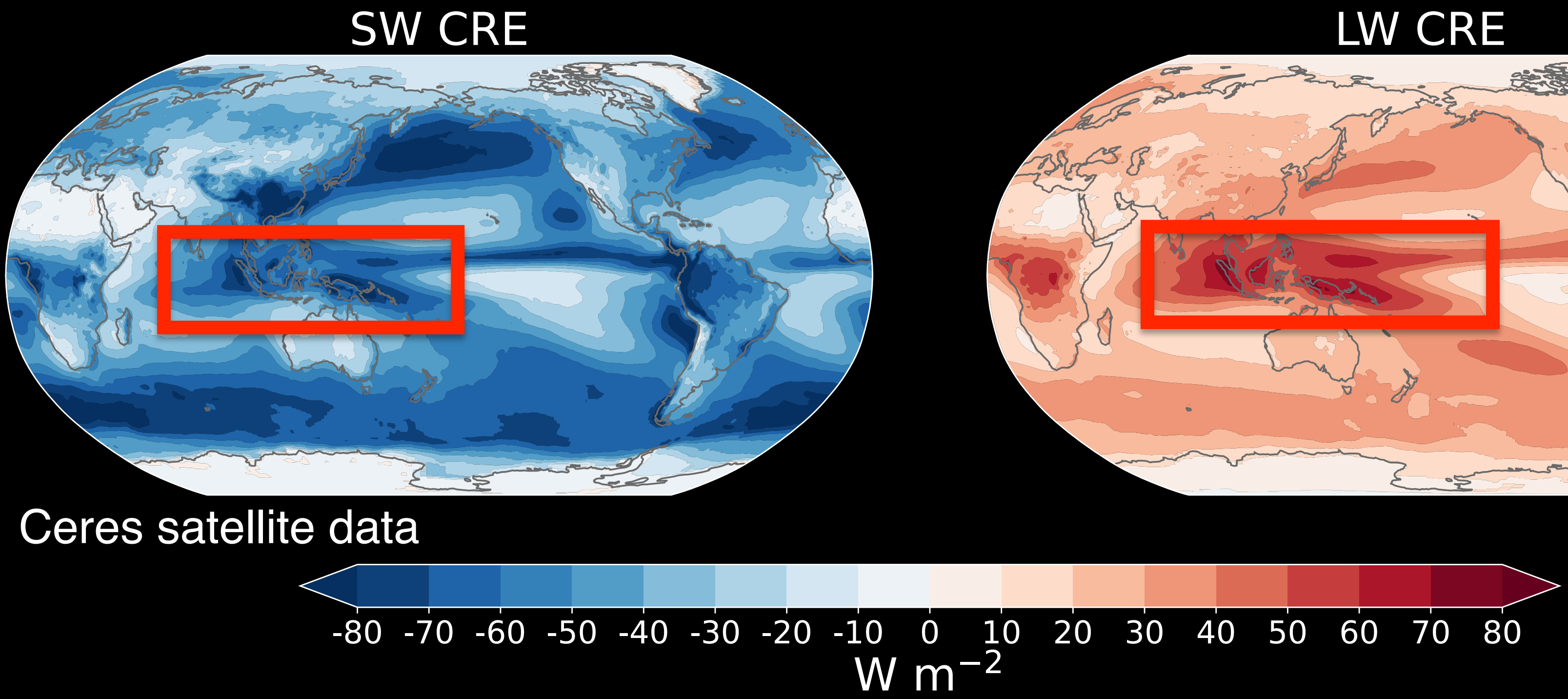
Anvil lifecycle: from reflective, rainy convective cores to long-lived semi-transparent thin cirrus



Anvil lifecycle: from reflective, rainy convective cores to long-lived semi-transparent thin cirrus

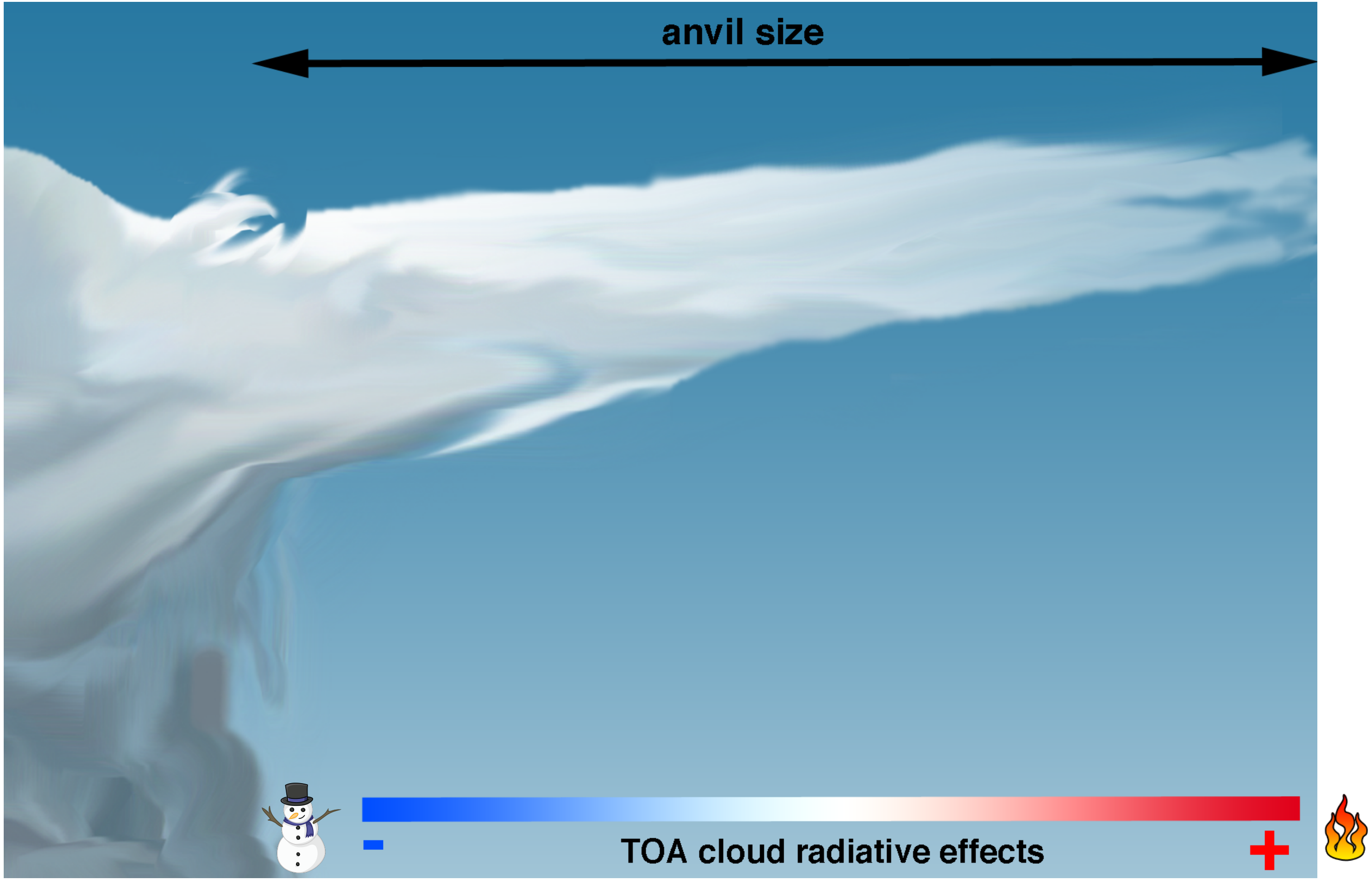


Anvil clouds are the dominant cloud type in the tropics both in terms of frequency and cloud radiative effects



Ceres satellite data

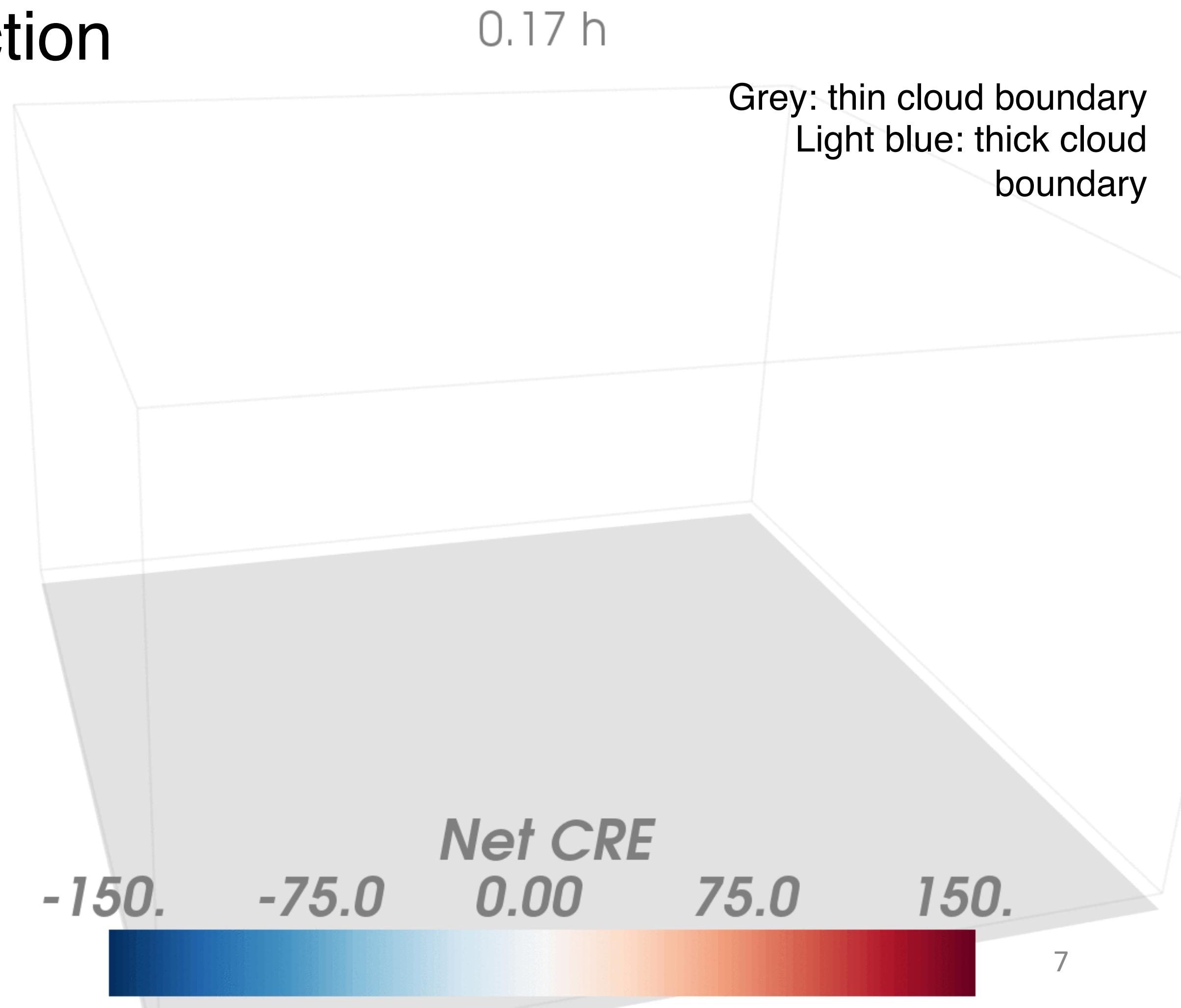
What drives the evolution from thick fresh anvils to thin cirrus?



Isolated deep convection

Grey: thin cloud boundary
Light blue: thick cloud boundary

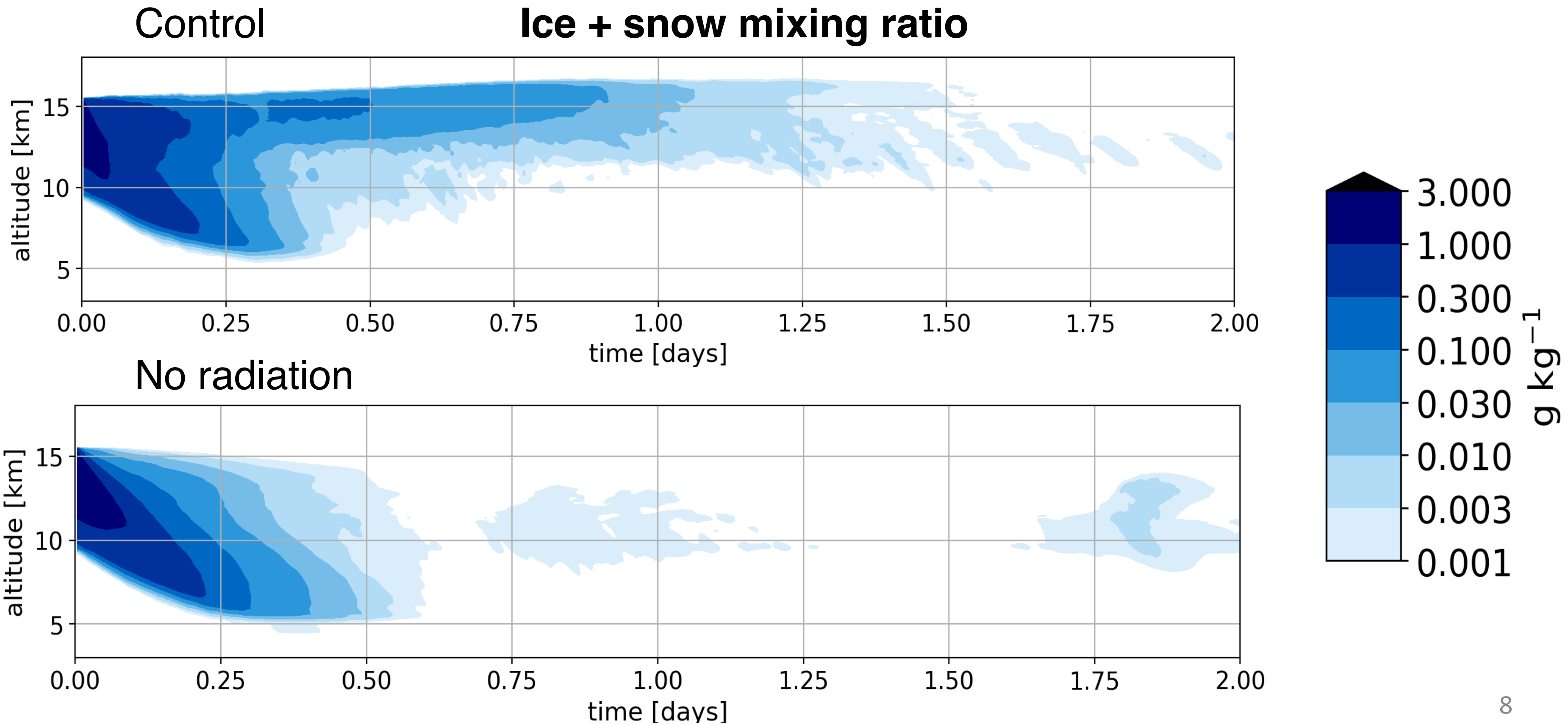
- SAM cloud resolving model
- 1x1 km horizontal and
- 250m vertical grid spacing (in the upper troposphere)



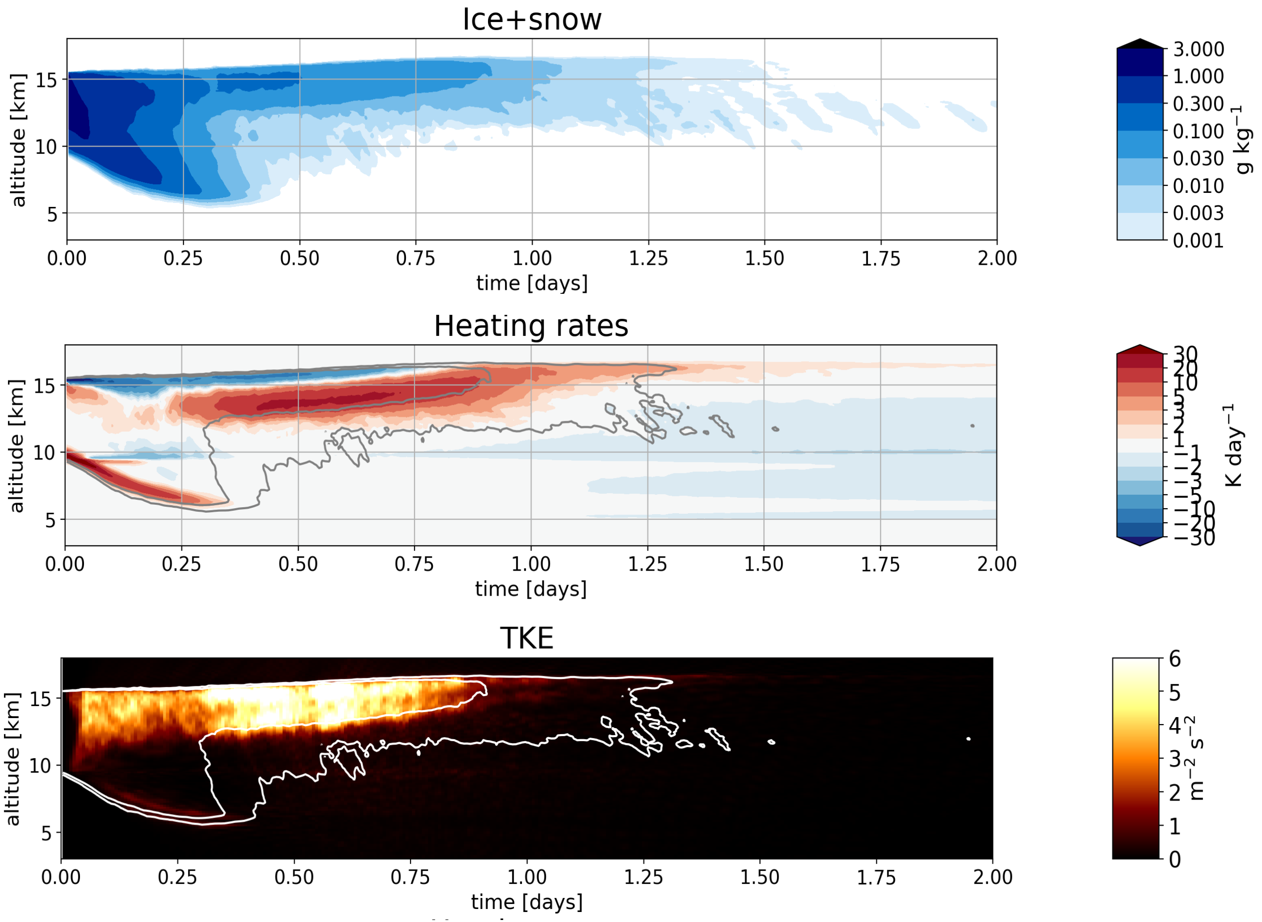
Simulations:
- **Control**: full physics
- **No radiation**: no cloud radiative heating/cooling
- **No nucleation**: no in-situ ice nucleation

Gasparini et al., 2019, JAMES
Hartmann et al., 2018, JAMES

Cloud radiative heating prolongs the anvil lifetime

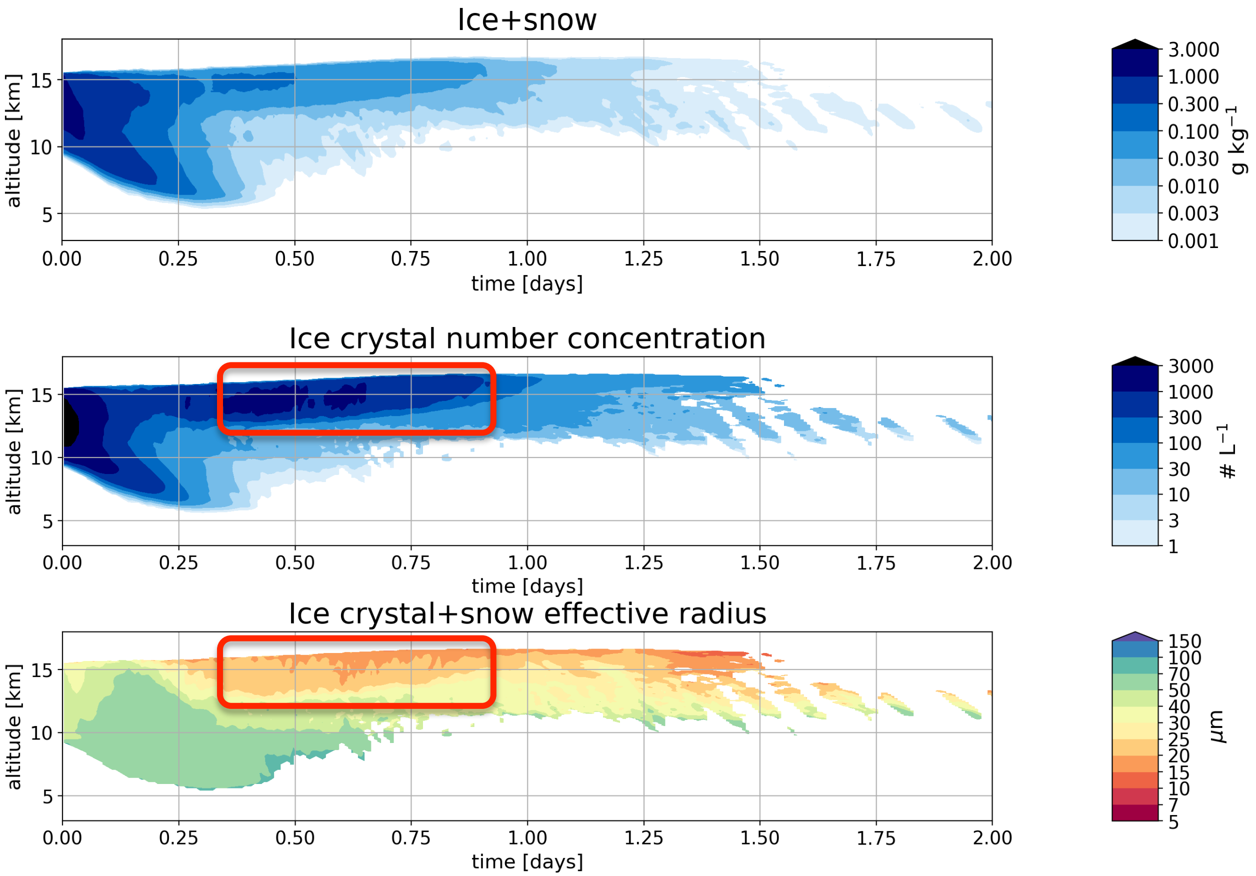


Effect of radiation on the anvil lifecycle



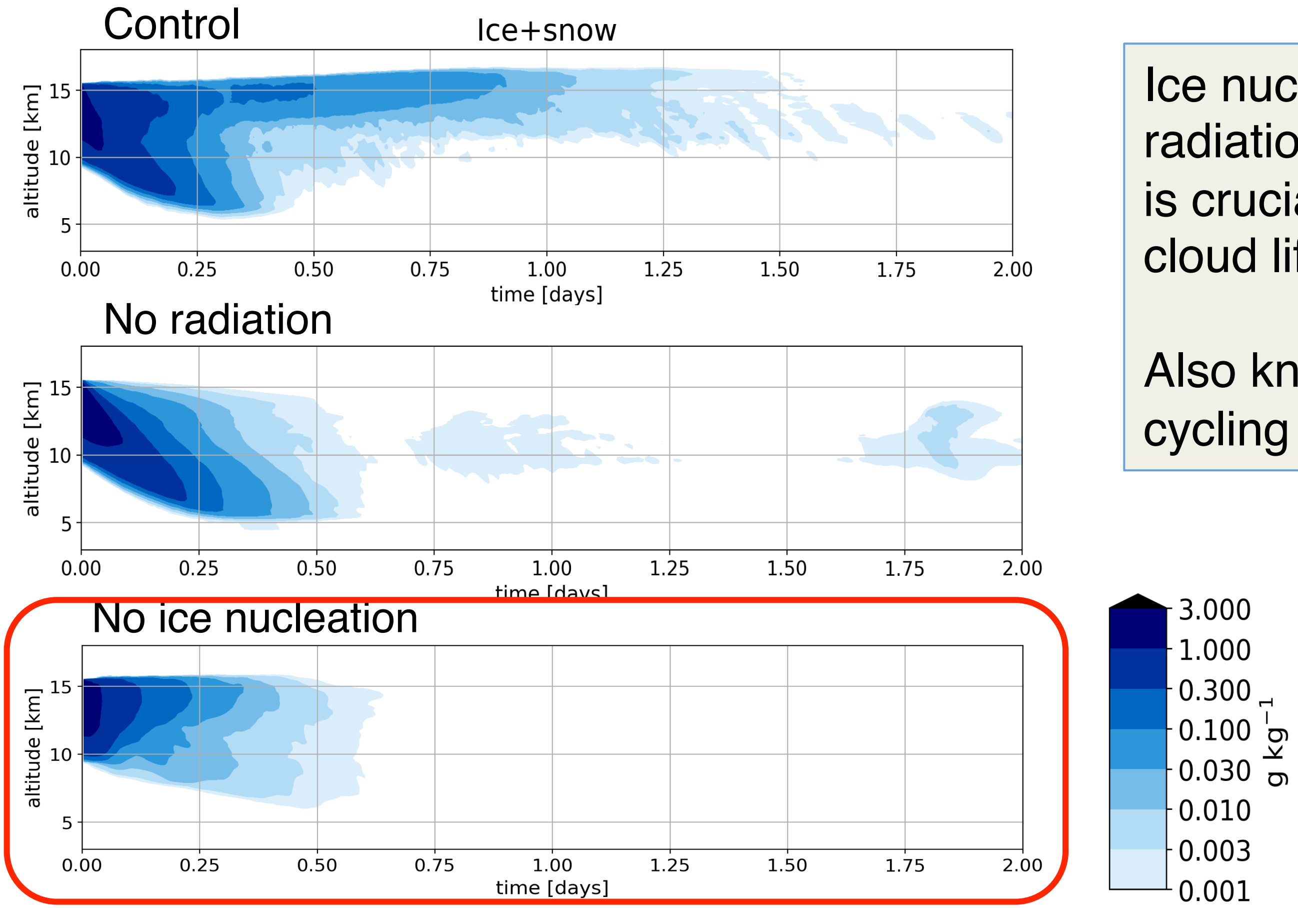
1. Cloud top cooling and cloud base warming dipole
2. Driving turbulent kinetic energy (TKE) and in-cloud convective motions
3. In-cloud convection leads to the formation of numerous small ice crystals

Radiation-driven turbulence nucleates new ice crystals



1. Cloud top cooling and cloud base warming dipole
2. Driving turbulent kinetic energy (TKE) and in-cloud convective motions
3. In-cloud convection leads to the formation of numerous small ice crystals

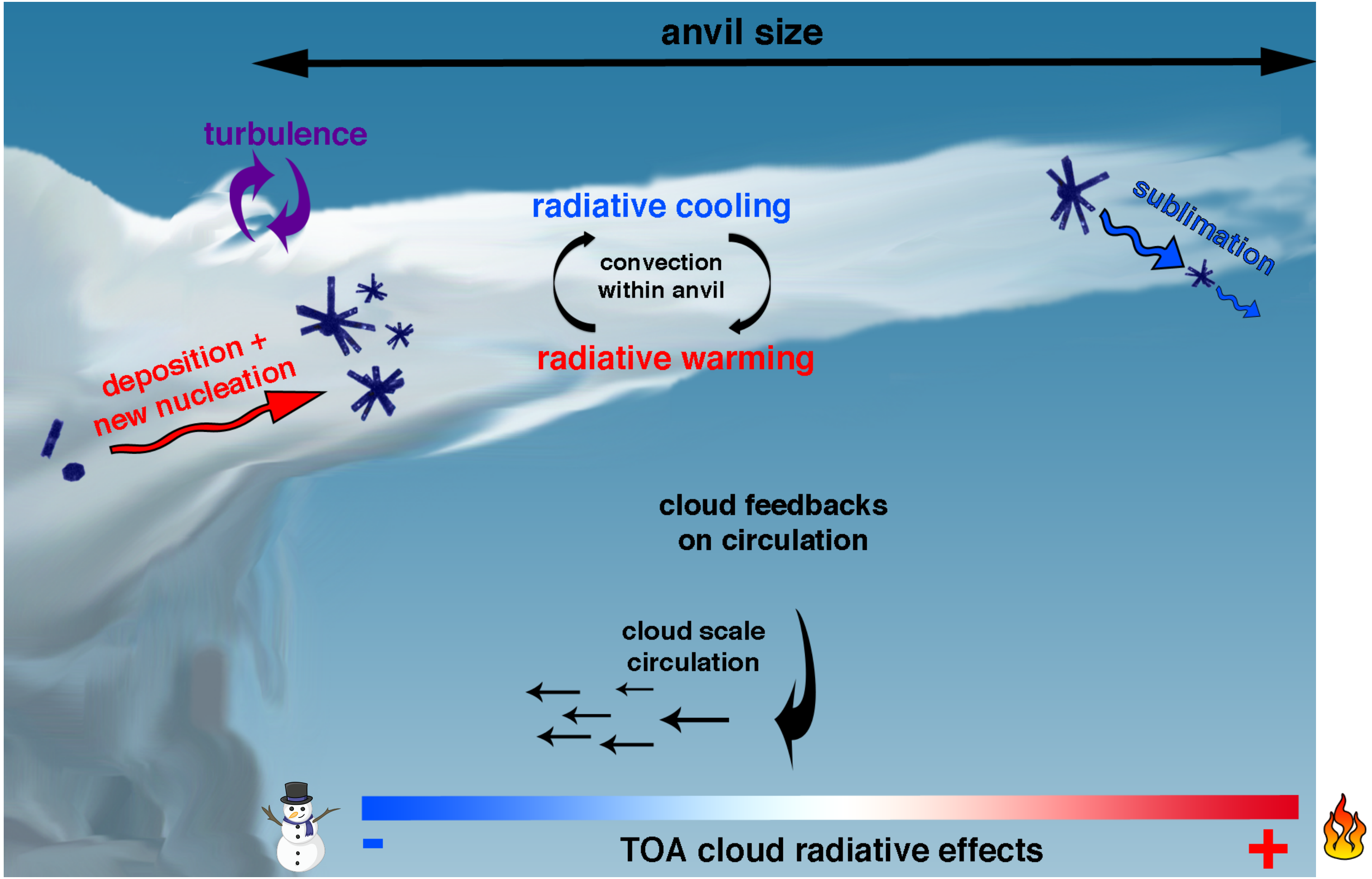
Radiation and ice nucleation play important roles in anvil lifecycle



Ice nucleation (driven by radiation-generated turbulence) is crucial in prolonging the anvil cloud lifetime.

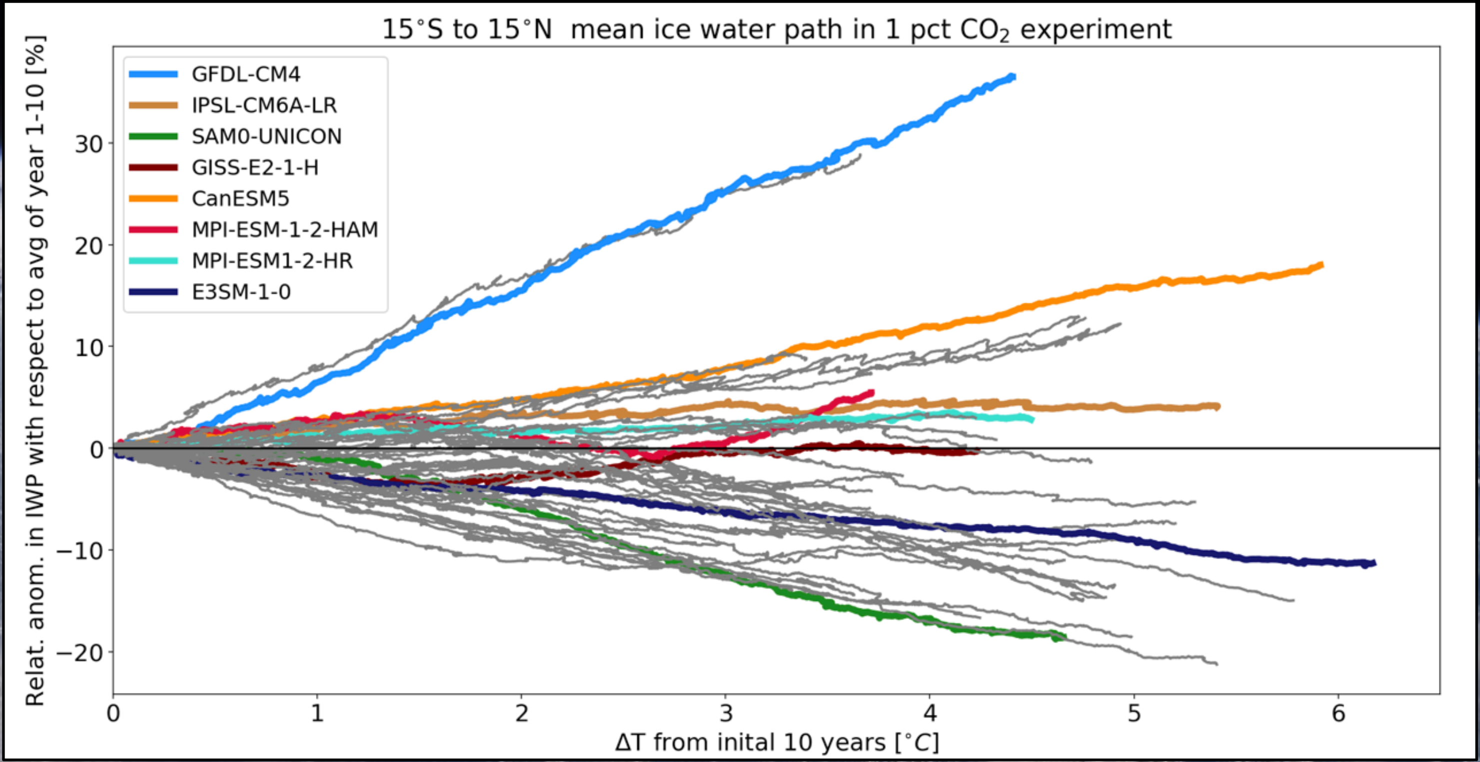
Also known as “microphysical cycling hypothesis”

Anvil clouds are driven by complex interactions of several processes



The future of atmospheric ice

The future of atmospheric ice is **very uncertain**



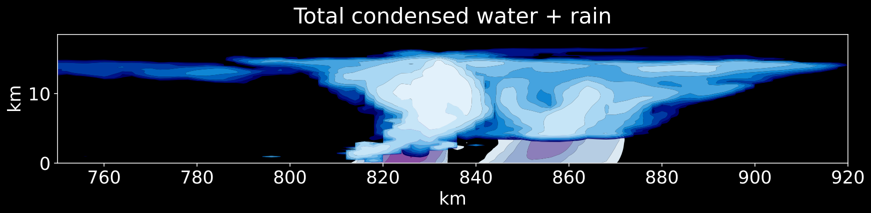
"As for GCMs, they are not deemed trustworthy for the simulation of anvil cloud area because they lack sufficient cloud microphysics and convective organization processes, among other reasons.

….

This leaves observed variability as the primary guide to tropical high-cloud feedbacks."

From Sherwood et al., 2020: An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence

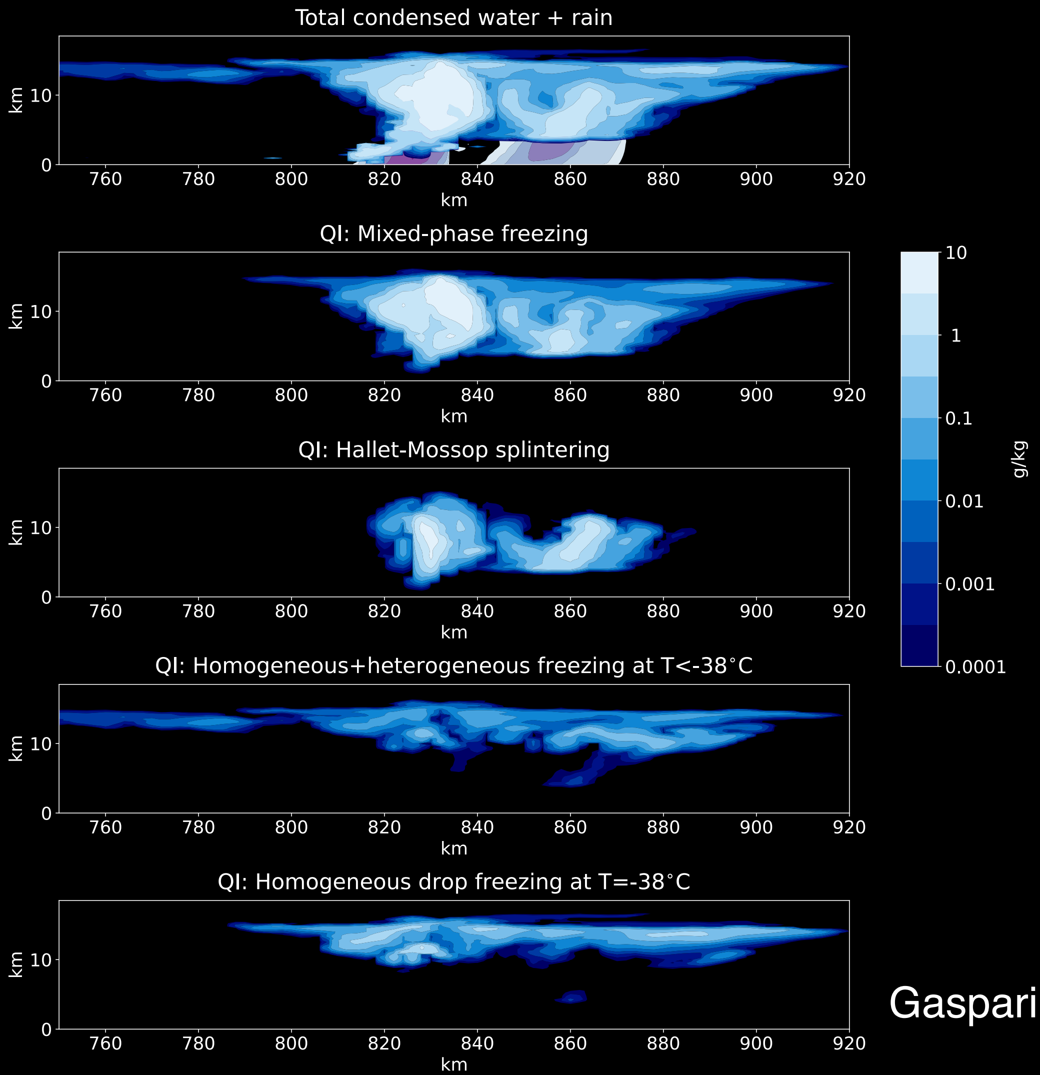
Can we do better?

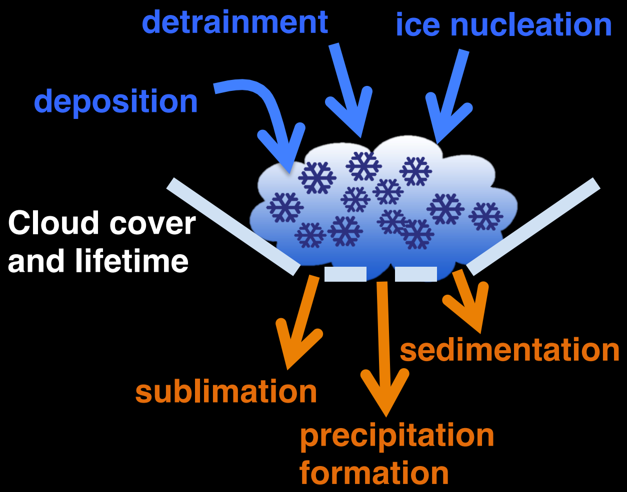


A typical tropical convective storm with detrained anvil cloud
[SAM cloud resolving model simulation]

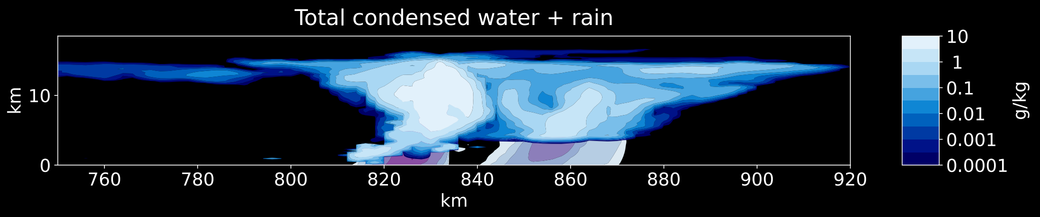
Where to go next?
A source and sink perspective

Where to go next? A source and sink perspective

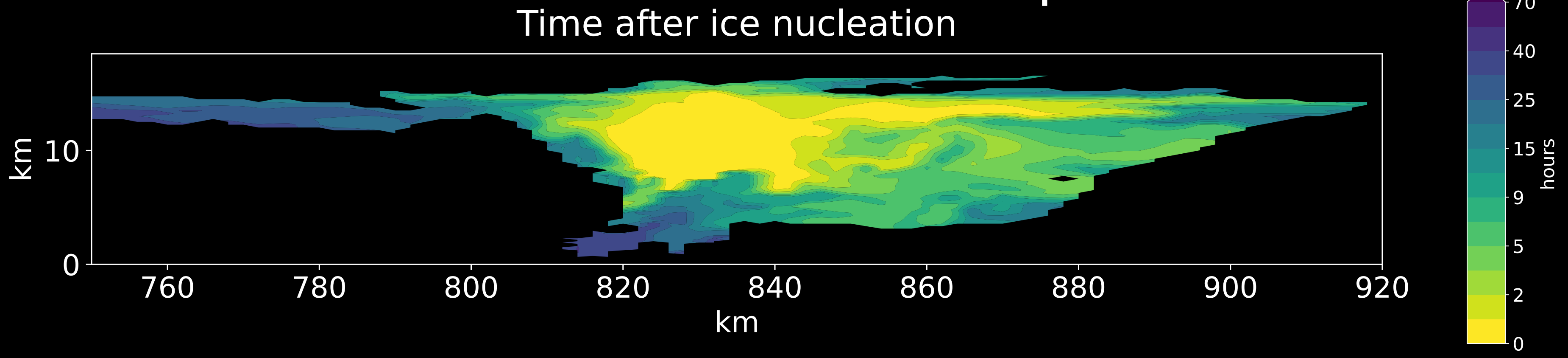




Gasparini et al., in prep.



Where to go next?
A source and sink perspective…
…with a strong evolution component



Gasparini et al., in prep.

See also: Trajectories following detrained clouds,
Gasparini et al., JGR-A 2021

Summary

Anvil clouds are sensitive to both details of microphysics (ice nucleation) and radiation + their interaction (turbulence)

The climate projections of high clouds and their properties remains largely unconstrained by models and observations

Huge gap in the understanding of ice clouds; better use of existing models (analyze process rates!, creative evolutional perspective), will help addressing it

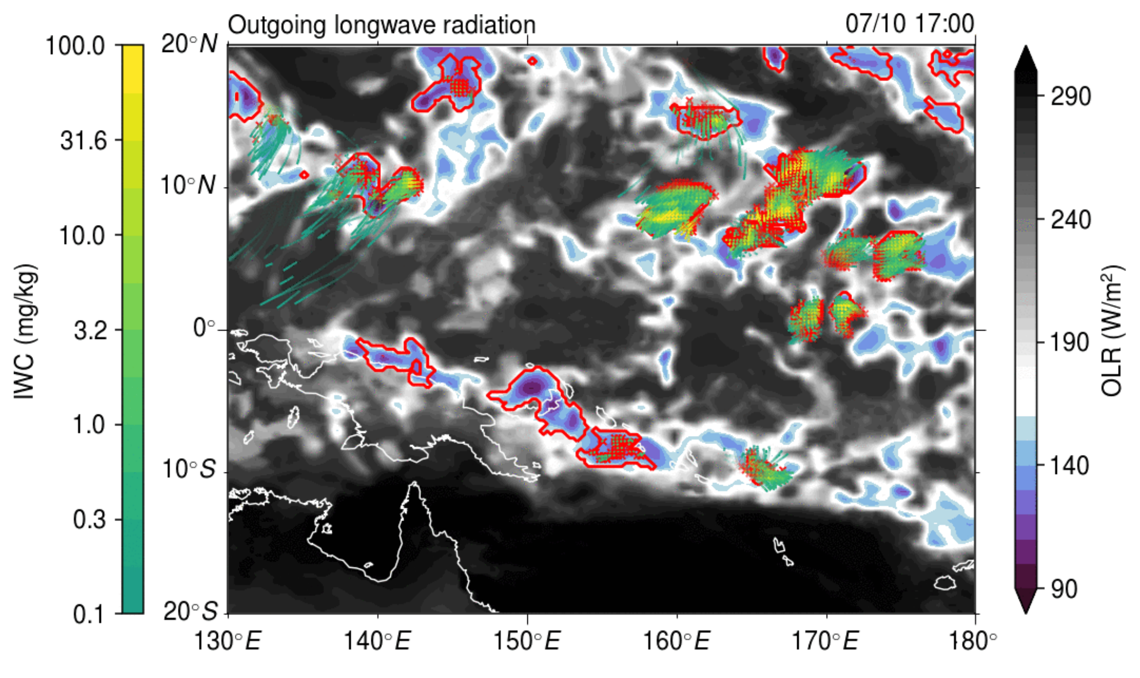
[together with the new generation of high resolution models and new approaches to microphysics]

blaz.gasparini@univie.at.ac

Lagrangian methods used:

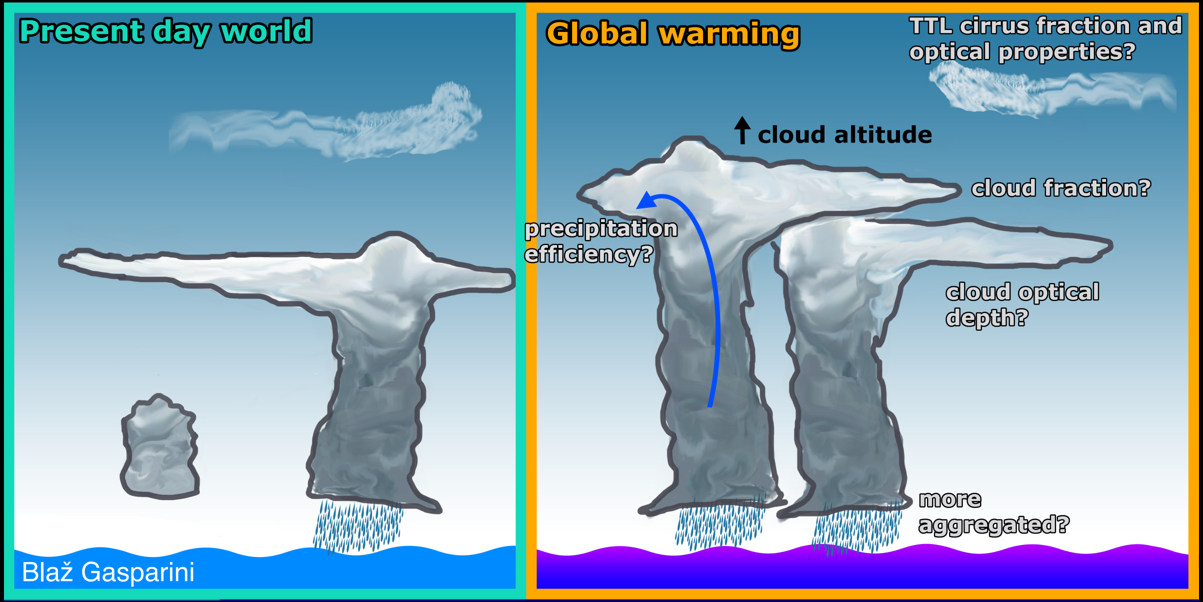
1. Mesoscale convective system tracking (in red)

2. 3D trajectories following detrained air parcels/evolving anvil clouds
(evolving spaghetti)



Detrained clouds following trajectories, Gasparini et al., JGR-A 2021

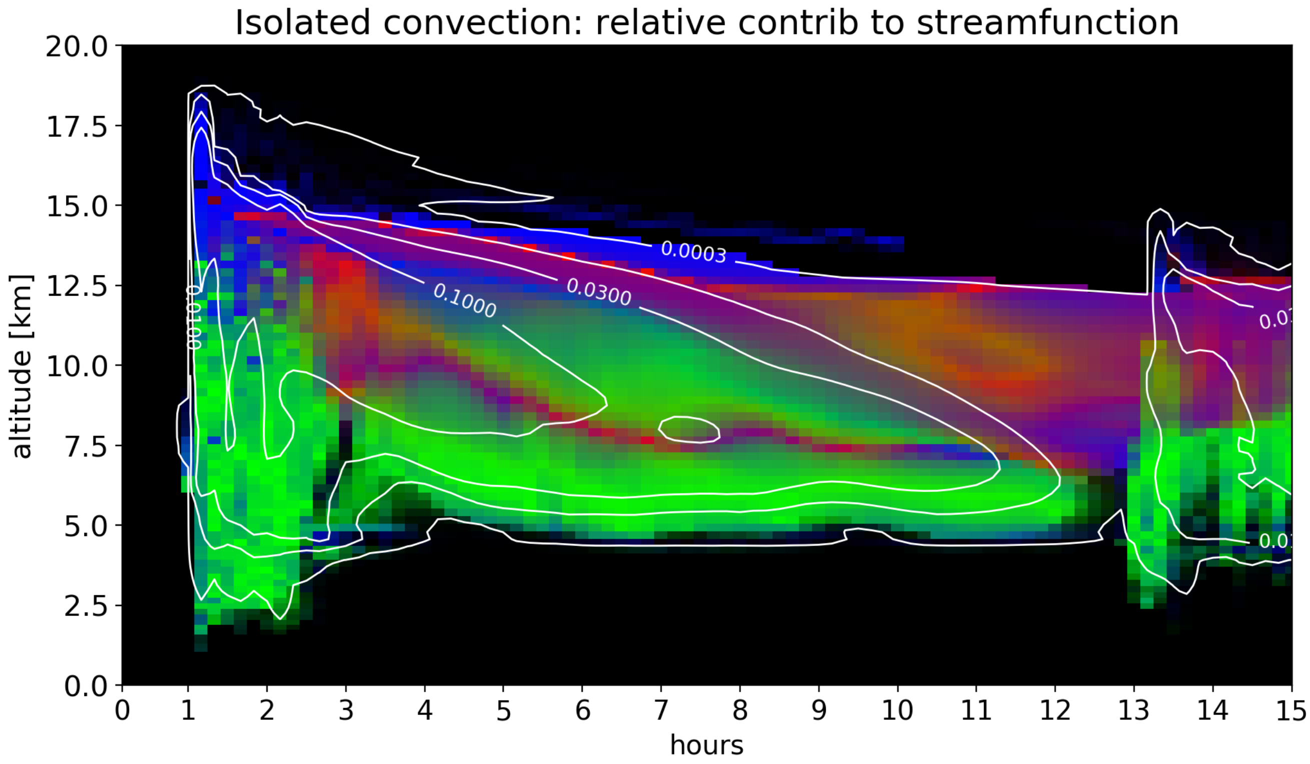
The future of atmospheric ice is **very uncertain**

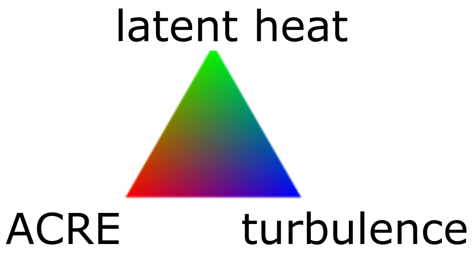


Known:
Anvil shift at in altitude while keeping at approximately constant temperature (FAT hypothesis)

Unknown:
Pretty much all the rest

Latent heating drives circulations in the initial phase and near cloud base
ACRE always important at cloud top and when the cloud is thin





Gasparini et al., 2019, JAMES
Hartmann et al., 2018, JAMES

but, because nature is not so simple additional mechanisms in:
Wall et al., 2020, JClim
Gasparini et al., 2022, JClim