Chasing clouds: Tropical cirrus in a high resolution model

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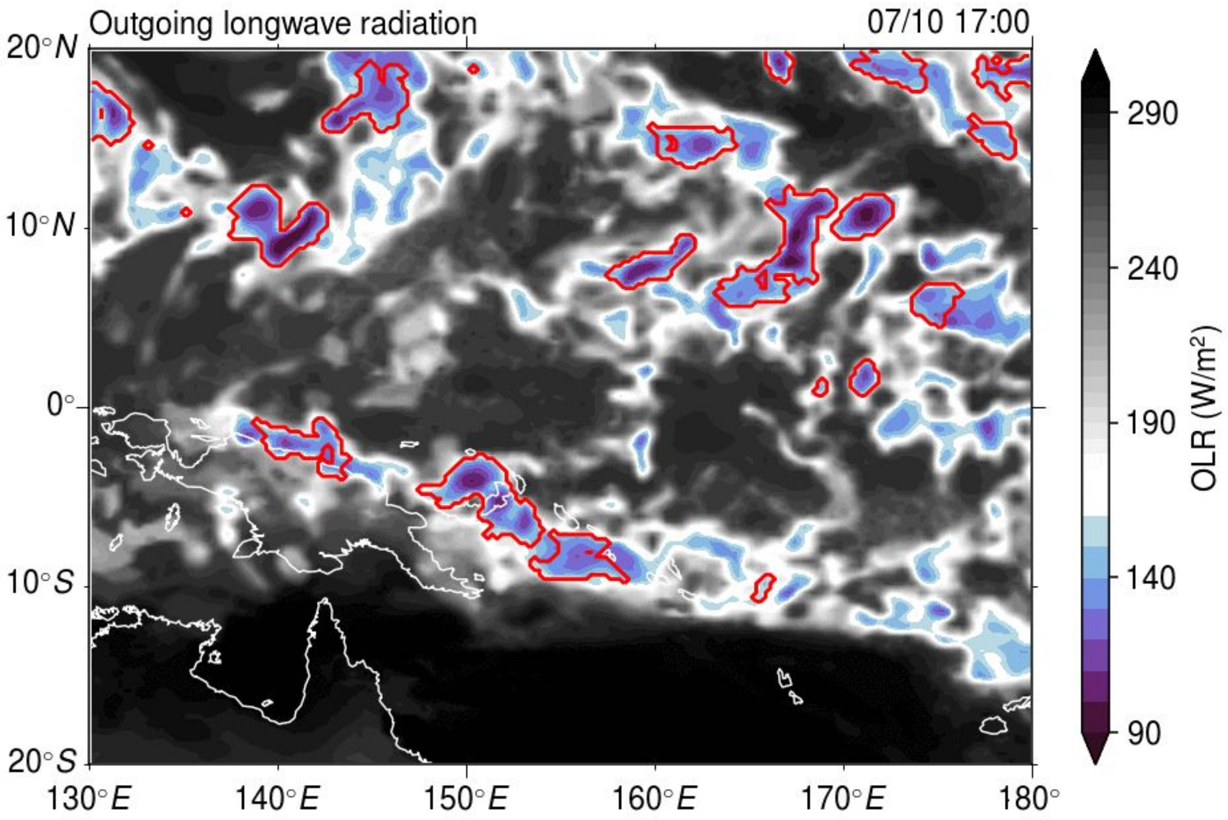
There are many different ways to chase clouds…

1. Storm chasing

Twister, 1996

There are many different ways to chase clouds…

2. Storm tracking: e.g. following active deep convection



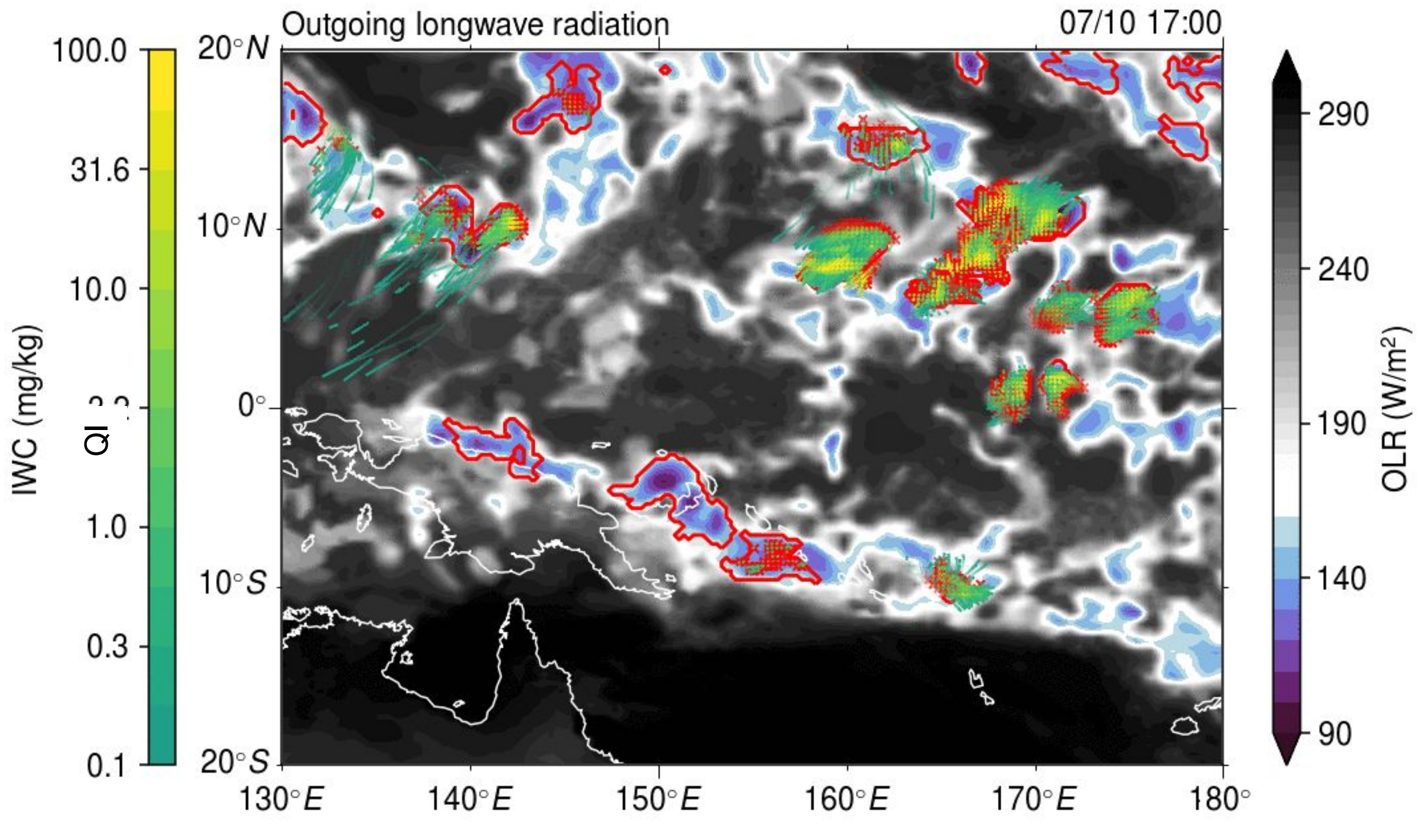
Red contours: tracked storms

2D storms tracking based on selected thresholds, e.g. brightness temperature of clouds (TOOCAN tracking software)

Gasparini et al., 2021

There are many different ways to chase clouds…

3. Flow-following trajectories: e.g. LAGRANTO, embedded in a high res. GCM



Red crosses: trajectory starting locations

Red contours: tracked storms

Offline forward trajectories that follow air parcels detrained from deep convection

Gasparini et al., 2021

There are many different ways to chase clouds…

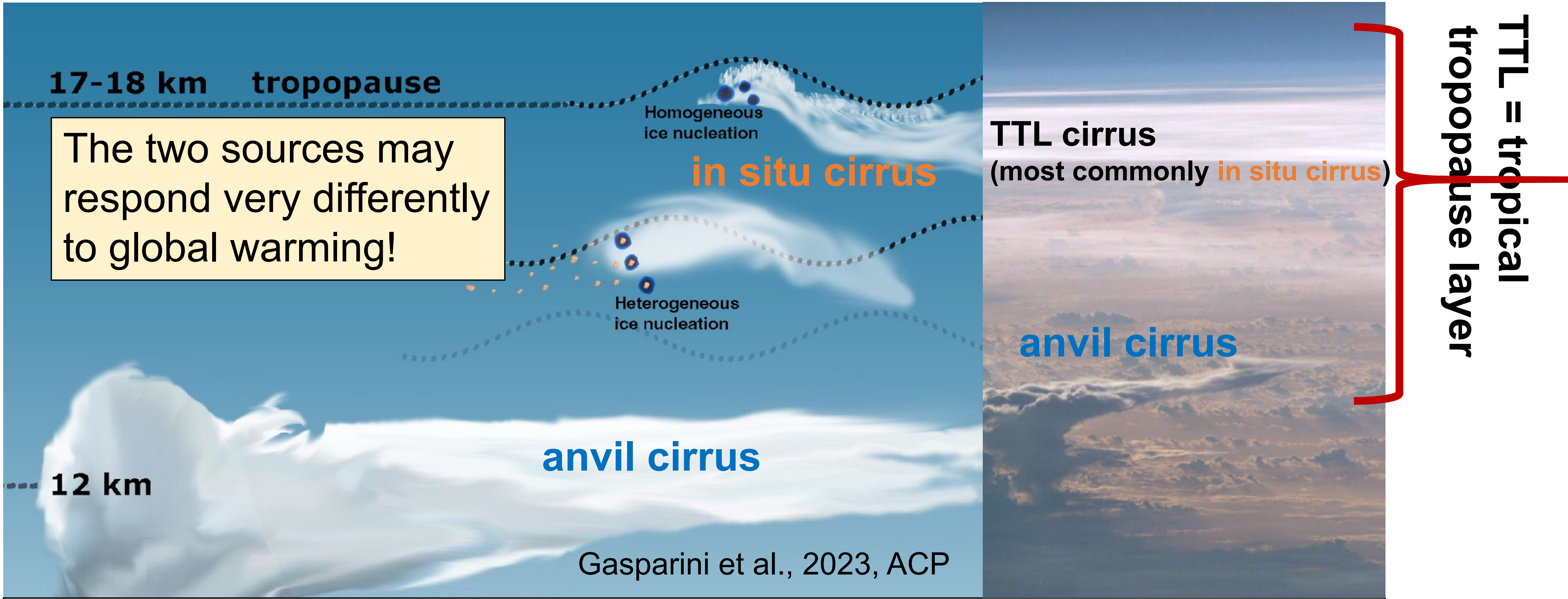
	Positive	Negative
Storm chasing	High adrenalin, teamwork	Time-consuming, expensive, needs a team
2D storm tracking	Easy to implement, works with model and satellite output, can be done in post-processing	Limited to some climatic features (e.g., MCS)
Flow-following 3D trajectories (offline)	Useful for models, can be done in post-processing	Needs high-frequency output, not that easy to set up
Flow-following 3D trajectories (online)	Elegant, insightful analysis, precise	Hard to set up, computationally heavy, need to think in advance what you want

My interests/use cases:

global climate &
cloud processes

high resolution
model data

Tropical cirrus of two sources: convection and ice nucleation



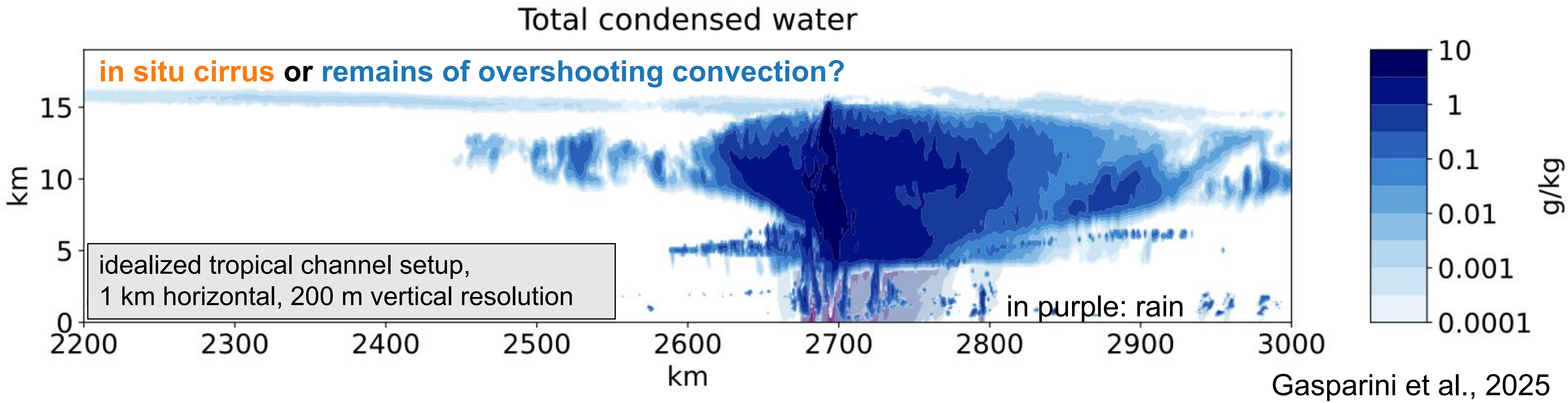
The two sources may respond very differently to global warming!

Gasparini et al., 2023, ACP

anvil cirrus = of **convective origin**

in situ cirrus = cirrus formed by **ice nucleation**

SAM cloud-resolving model with improved ice microphysics has a good skill in simulating tropical cirrus



Gasparini et al., 2025

What is a simple way to tell the origin of cirrus clouds?

Are **in situ cirrus** relevant for the radiative budget at TOA?

TOA = top-of-the-atmosphere

There are many different ways to chase clouds…

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Flow-following 3D trajectories (offline)	Useful for models, can be done in post-processing	Needs high-frequency output, not that easy to set up
Flow-following 3D trajectories (online, <u>during model integration</u>)	Elegant, insightful analysis, precise	Hard to set up, computationally heavy, need to think in advance what you want

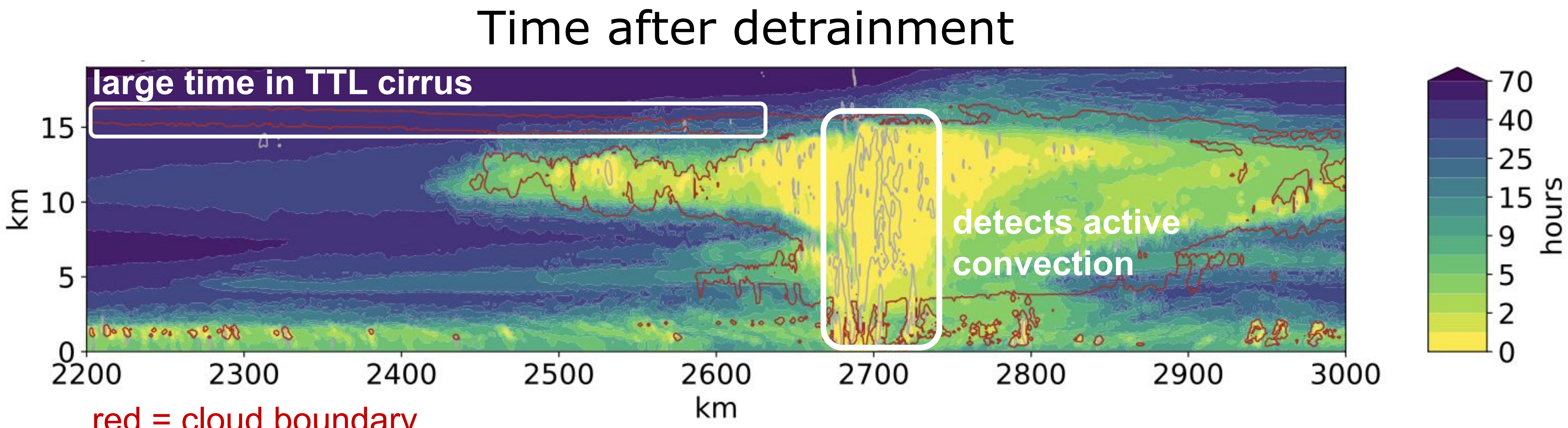
There are many different ways to chase clouds…

	Positive	Negative
~~**Storm chasing**~~	~~High adrenalin, teamwork~~	~~Time-consuming, expensive, needs a team~~
~~**2D storm tracking**~~	~~Easy to implement, works with model and satellite output, can be done in post-processing~~	~~Limited to some climatic features (e.g., MCS)~~
Flow-following 3D trajectories (offline)	Useful for models, can be done in post-processing	**Needs high-frequency output**, not that easy to set up
Flow-following 3D trajectories (online, during model integration)	Elegant, insightful analysis, precise	**Hard to set up**, computationally heavy, **need to think in advance what you want**

not useful for 3D model data

What can we do instead?

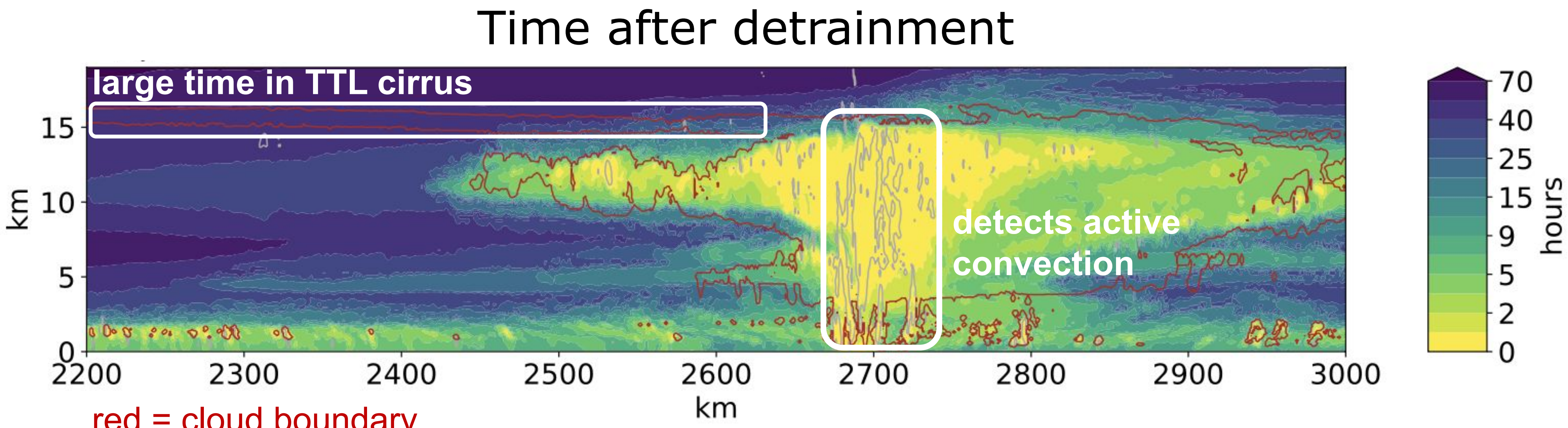
Passive tracers: a simple method to track cloud evolution



red = cloud boundary
grey = updraft of 1 m/s

if cloudy updraft
tracer =1
else:
tracer = decay factor x tracer value

Passive tracers: a simple method to track cloud evolution



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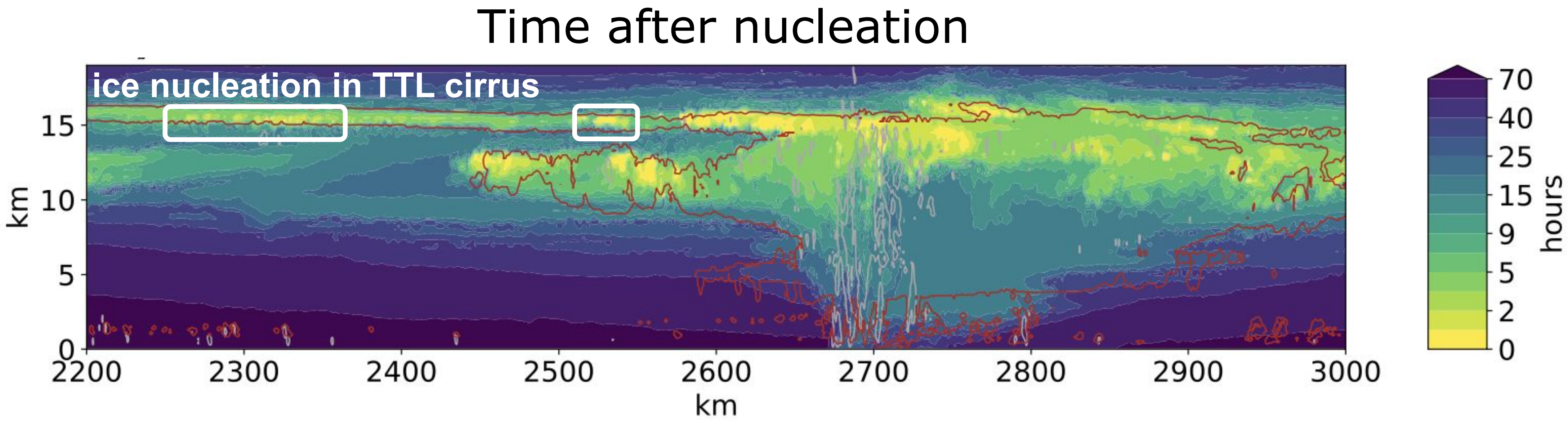
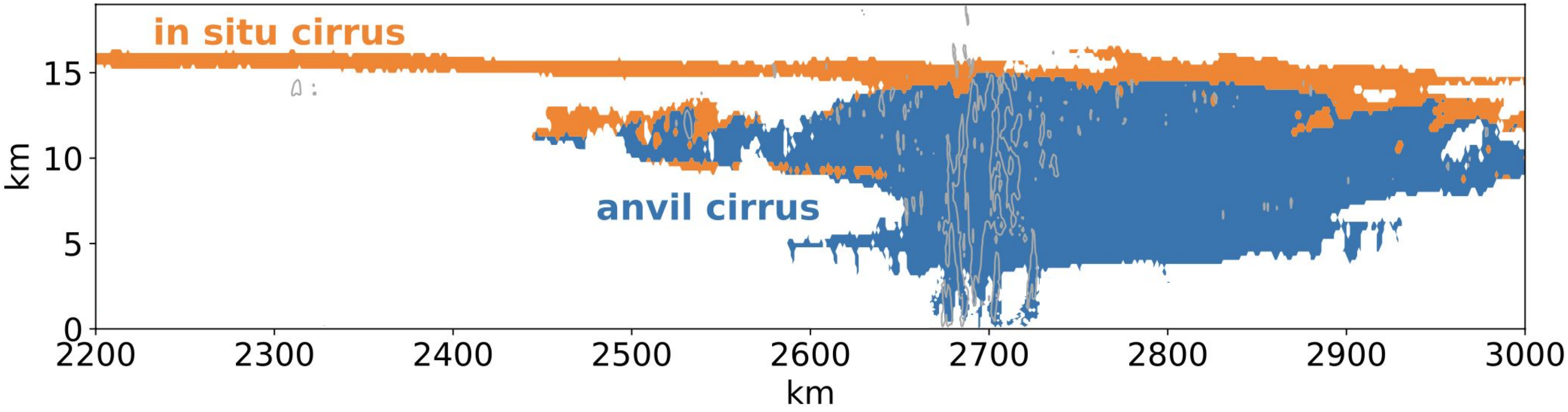


if ice nucleation
tracer =1
else:
tracer = decay factor x tracer value

Classifying cirrus origin with the help of passive tracers

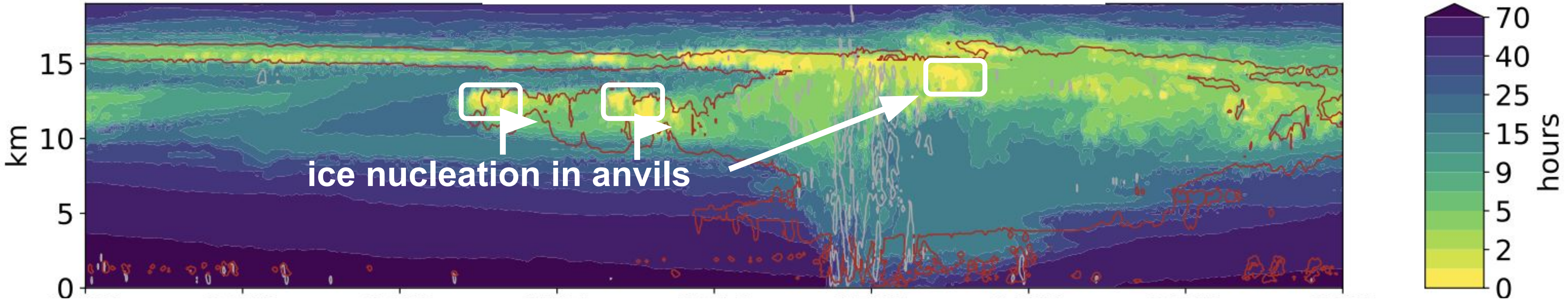


Sometimes ice nucleation occurs within anvils!

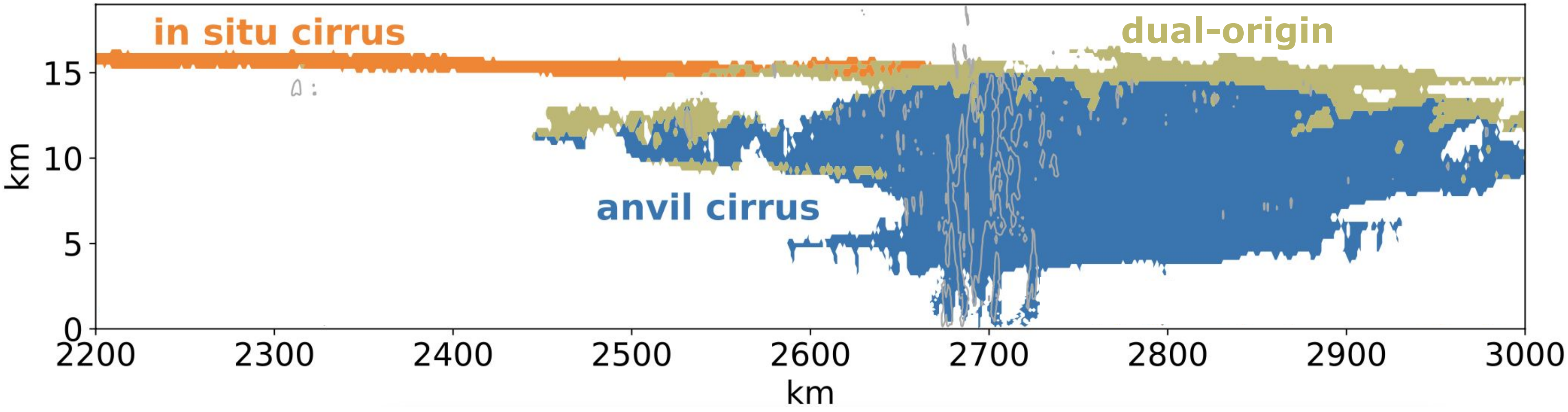
in situ cirrus if time after nucleation < time after detrain.

anvil cirrus: if time after detrainment > time after nucleation

Time after nucleation



Classifying cirrus origin with the help of passive tracers

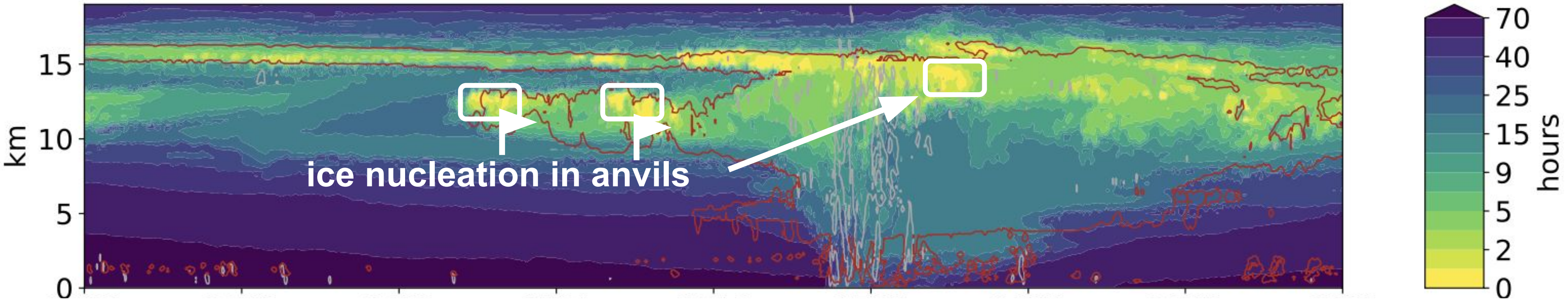


Sometimes ice nucleation occurs within anvils!

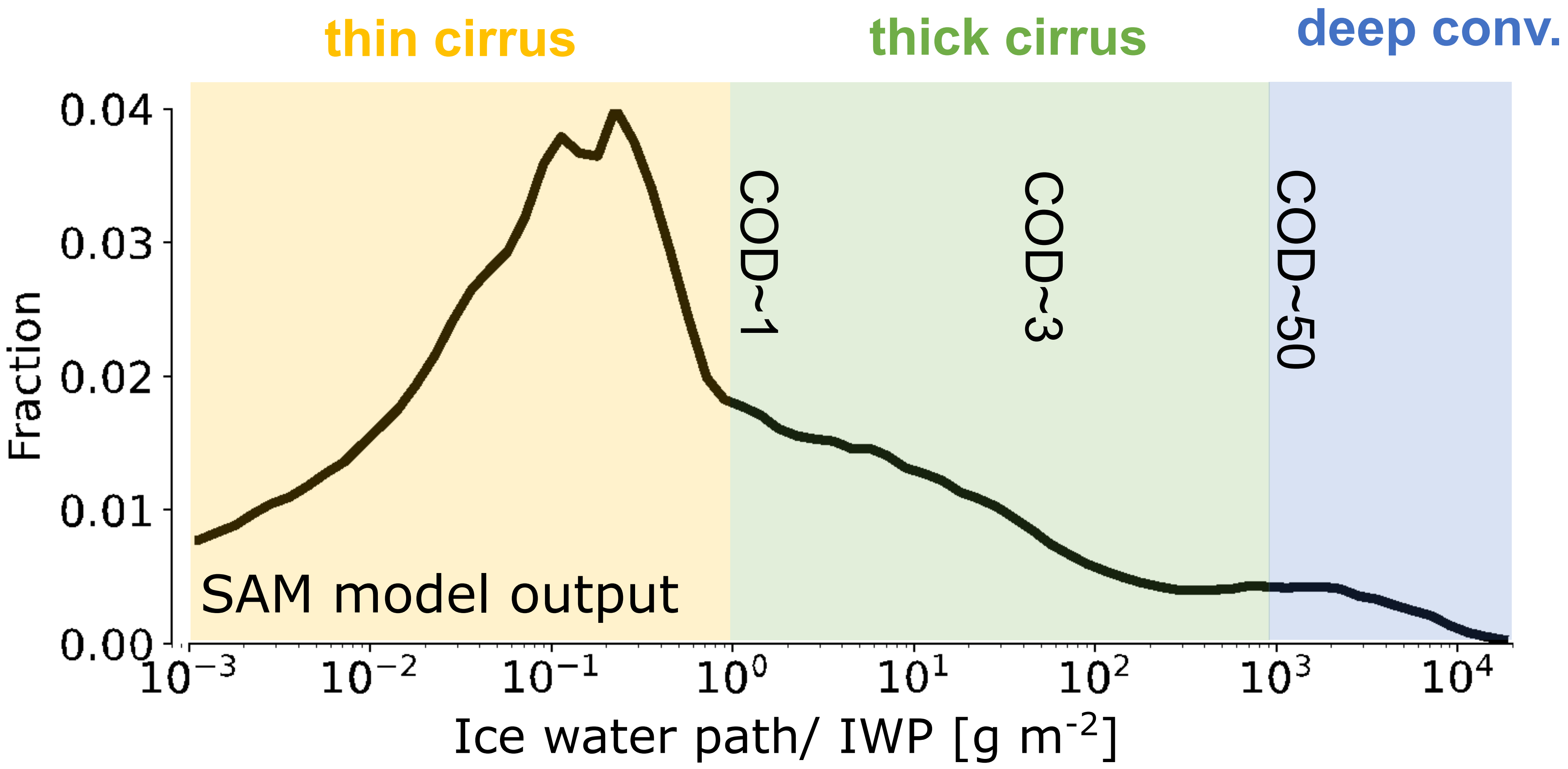
in situ cirrus if t_nucl< t_detr & t_detr>24 h

dual-origin: anvils, where in situ ice nucleation present (but detrained ice mass dominant)

anvil cirrus: all within 24 h of time after detrainment with no new in situ nucleation

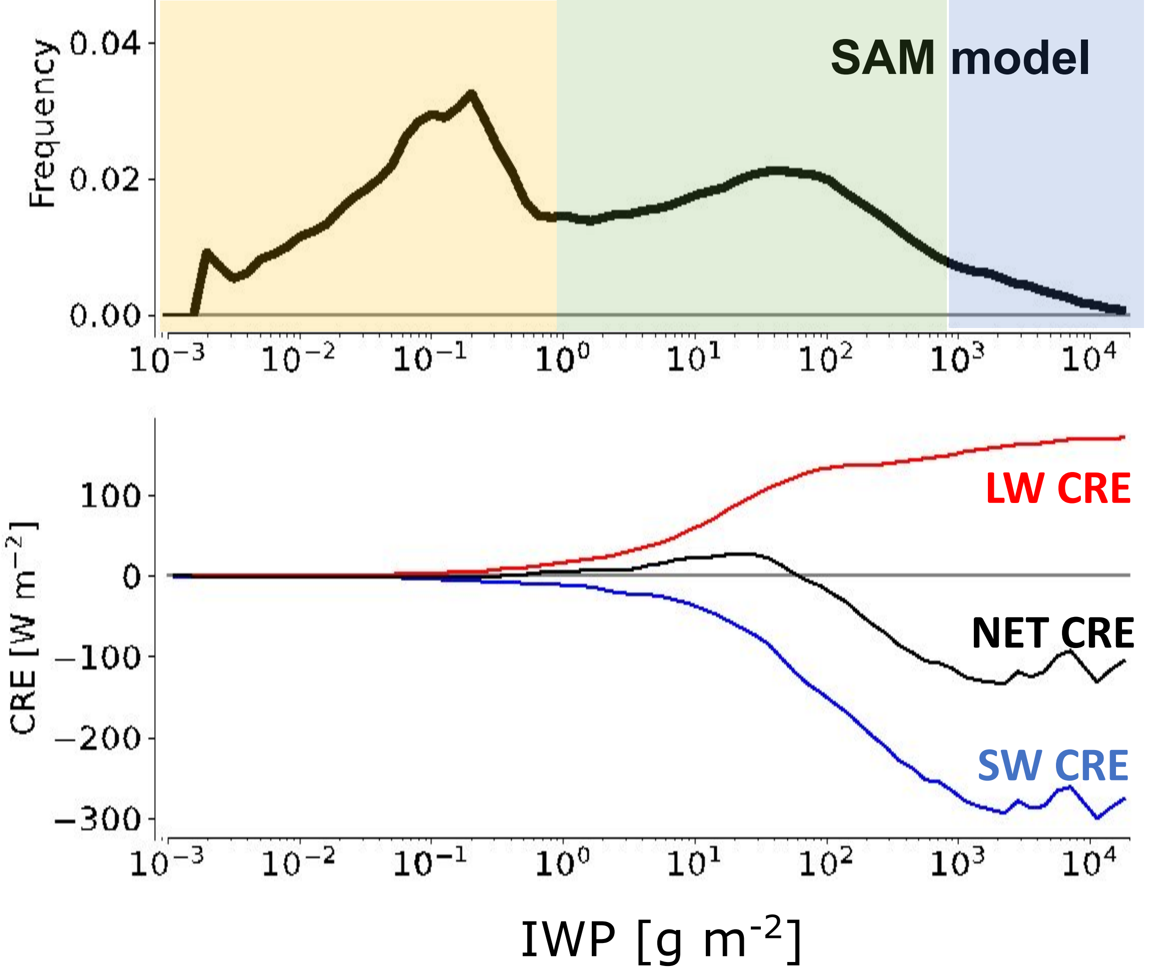


Do we need to consider **in situ cirrus** to represent the tropical TOA energy balance?



We can estimate the IWP-binned cloud radiative effects (CRE)

CRE binned by IWP
(How much a cloud of a certain IWP contributes to CREs?)



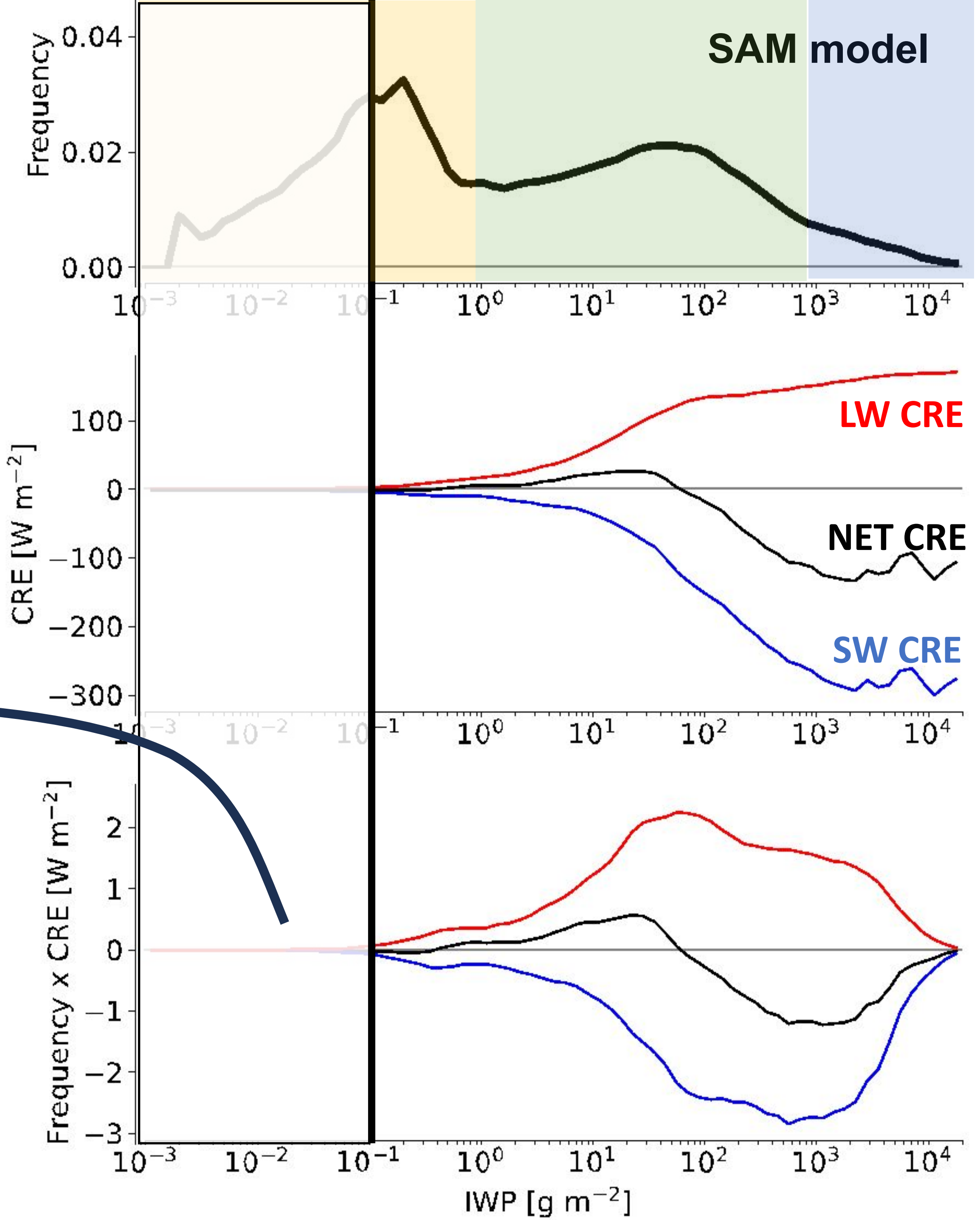
We can estimate the IWP-binned cloud radiative effects (CRE)

CRE binned by IWP

can be neglected!
cloud too thin,
COD<0.03

CRE weighted by frequency:
(upper panel × middle panel)

What is the climatological CRE importance of each IWP bin?



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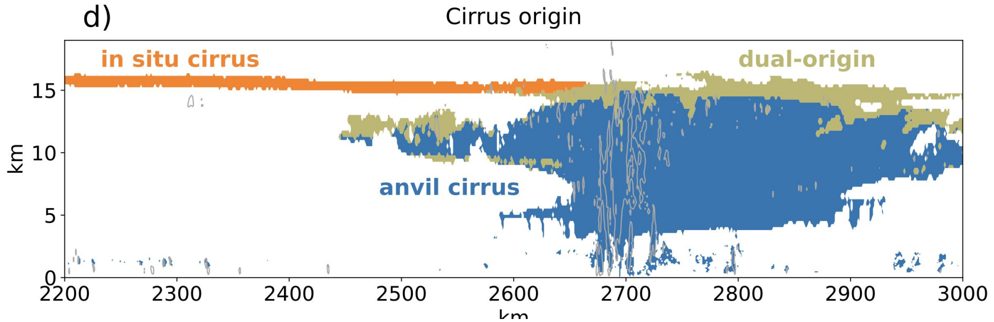
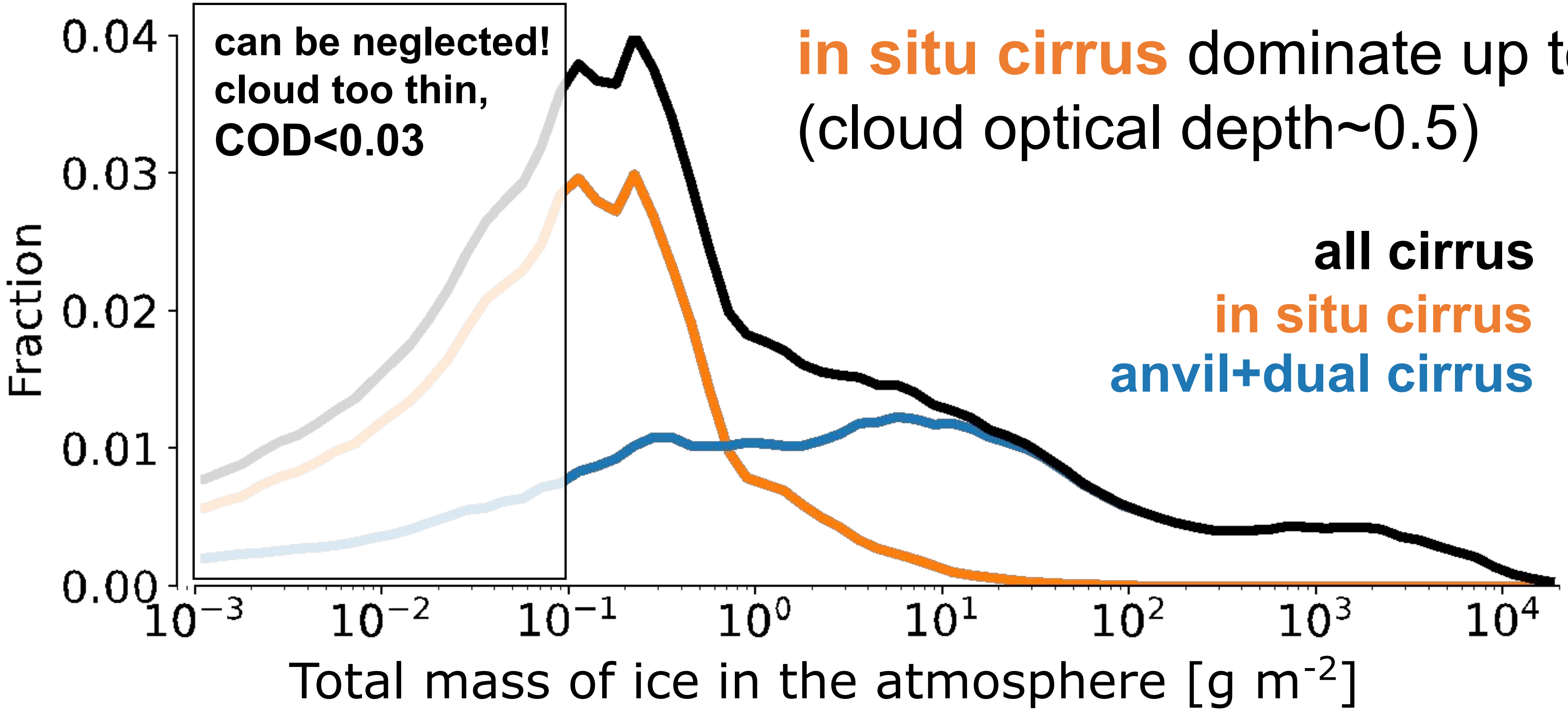
Apply the cirrus origin criterion and divide the PDF

Remember our classification

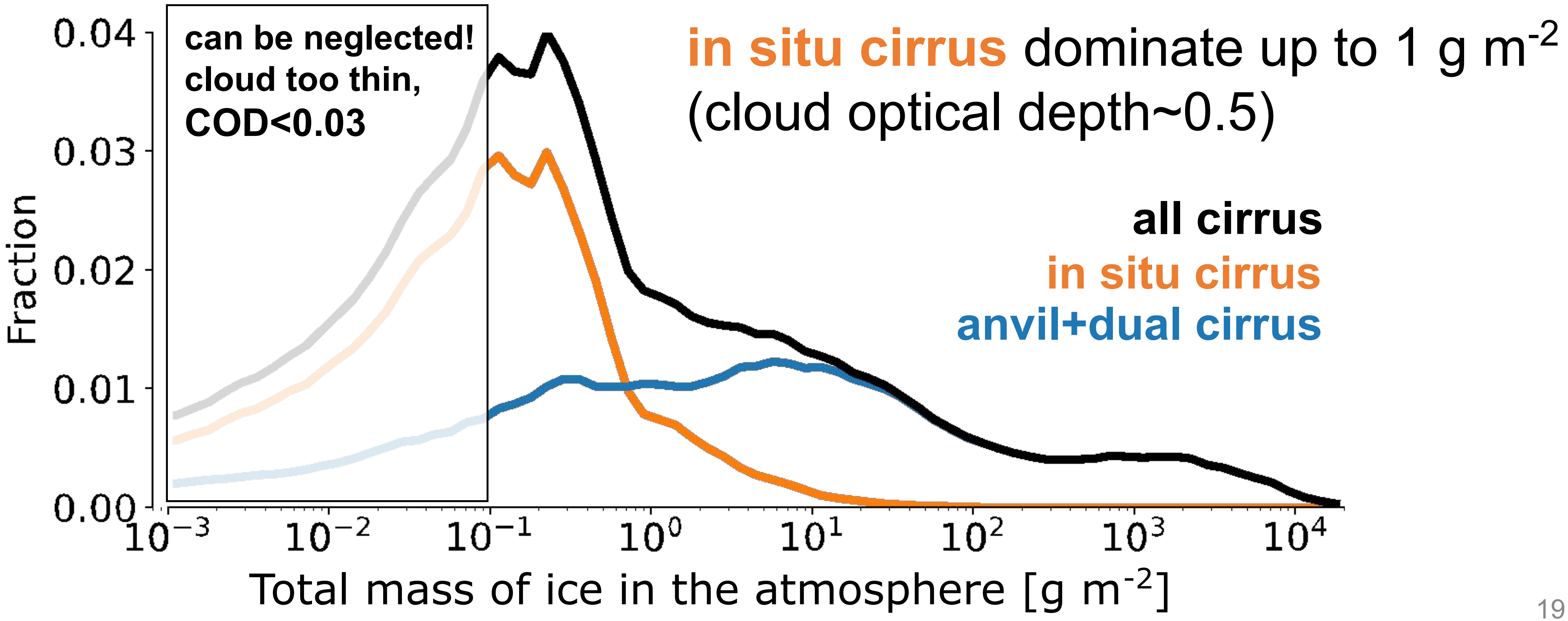




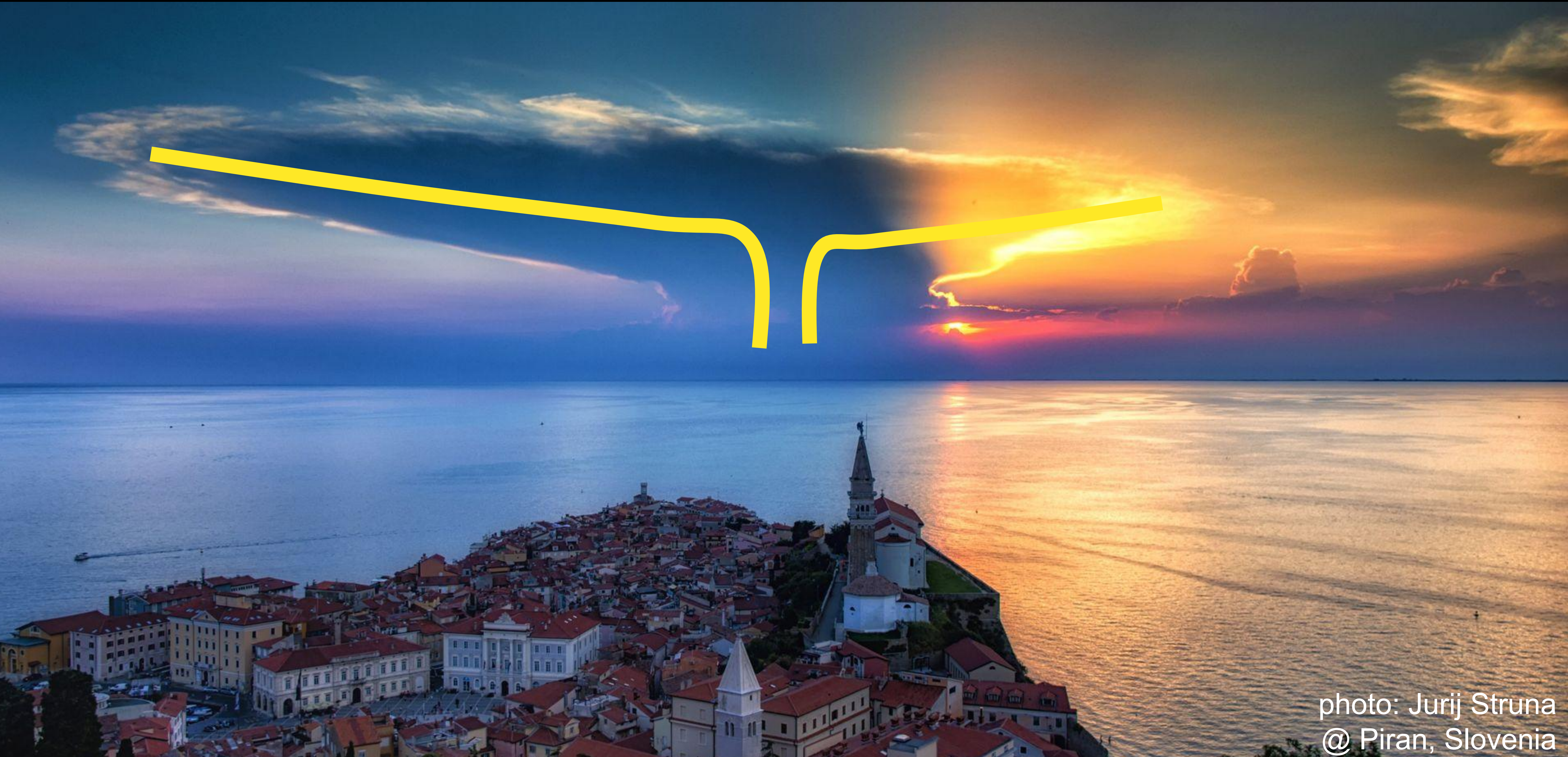
in situ cirrus dominate up to 1 g m^{-2}
(cloud optical depth~0.5)

In situ cirrus contribute ~7% of the tropical cirrus CRE

(~3 W m^{-2} for both LW and SW CRE at the TOA)



The journey of ice crystals from deep convection to thin cirrus



Summary

1. Tracers are an easy way to track evolution of cloud properties in a climatological sense

2. **In situ cirrus** contribute 5-10% to the total radiative effect of cirrus clouds at the TOA

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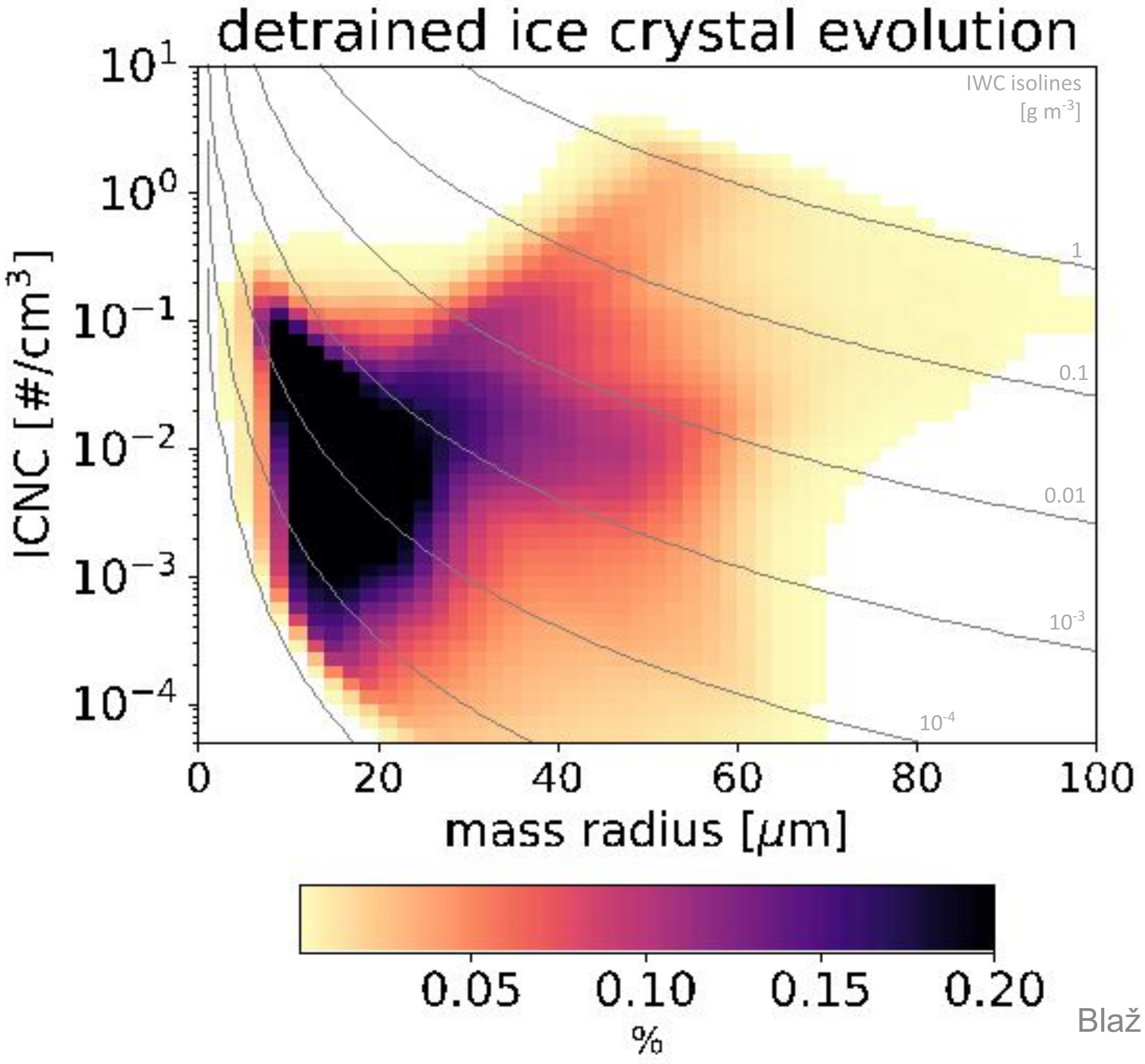
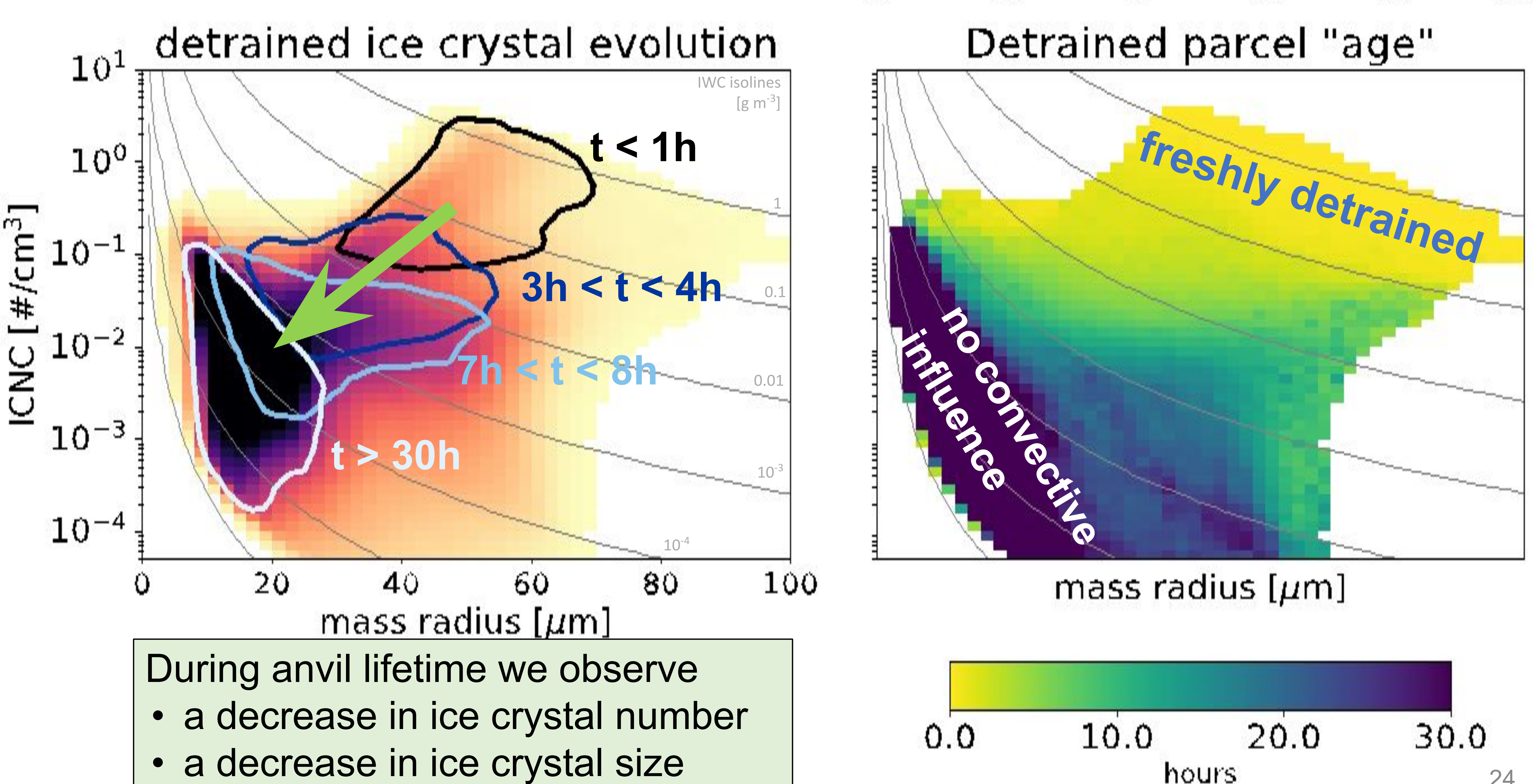
Gasparini et al., 2025
in revision for ACP

The journey of ice crystal from deep convection to thin cirrus



occurrence frequency for all tropical cirrus at T<-40°C

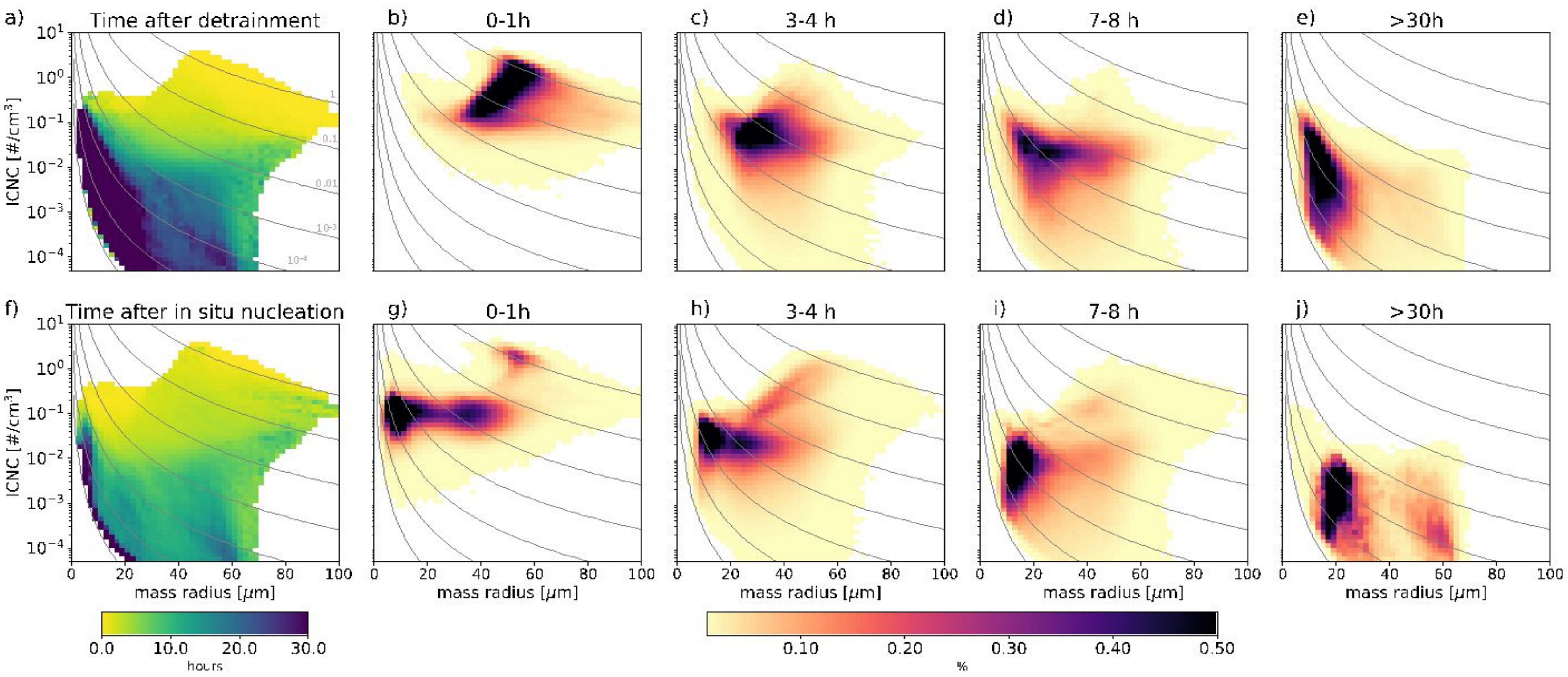
The journey of ice crystal from deep convection to thin cirrus

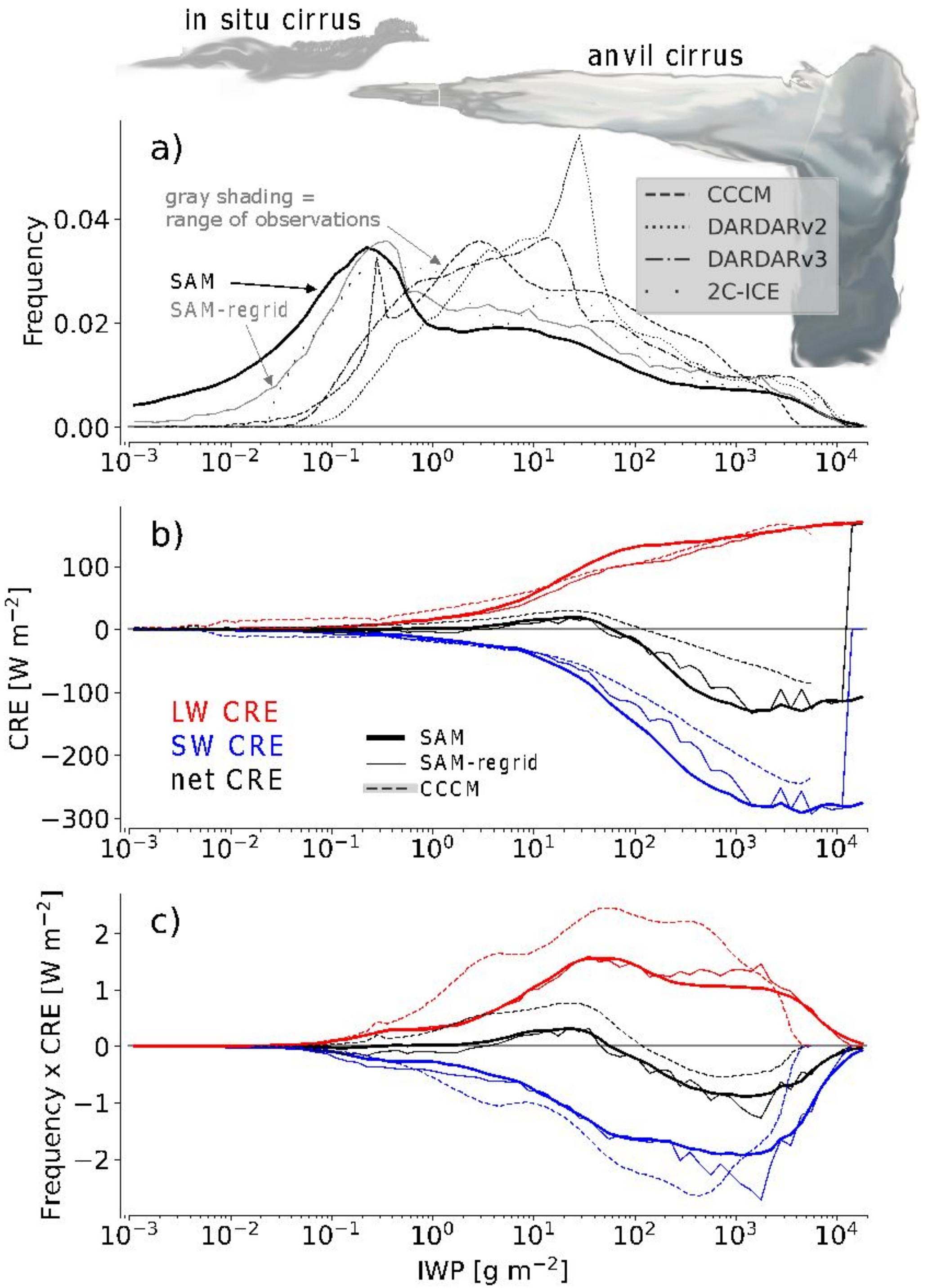


During anvil lifetime we observe

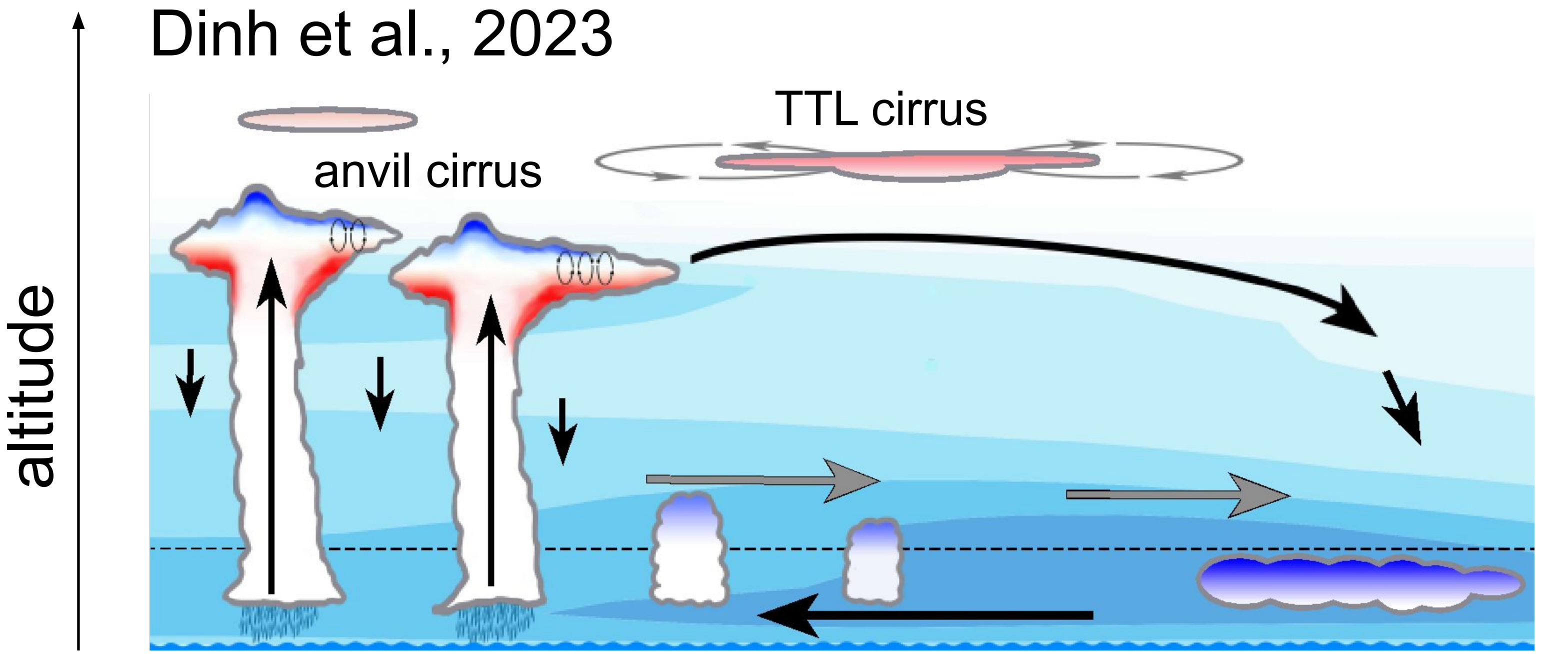
- a decrease in ice crystal number
- a decrease in ice crystal size

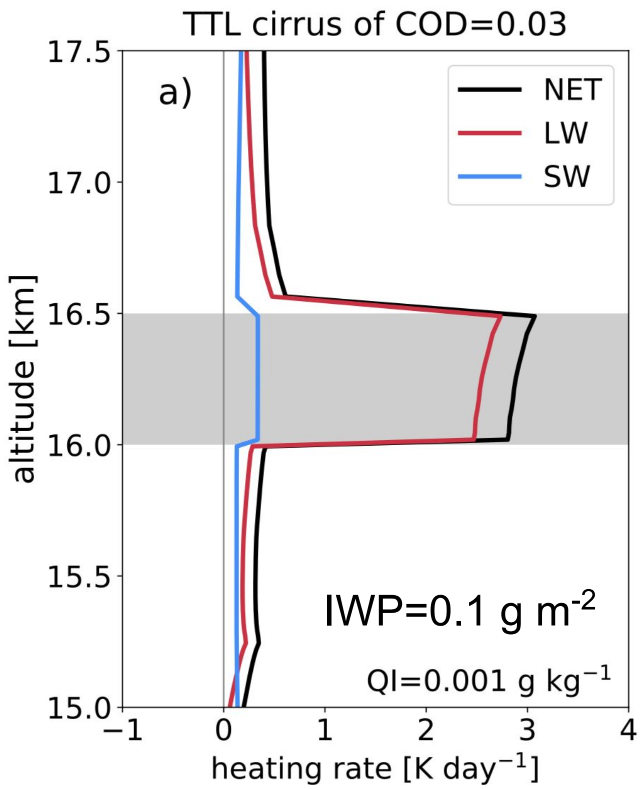
The journey of ice crystal from deep convection to thin cirrus




in situ cirrus
anvil cirrus
a)
gray shading =
range of observations
CCCM
DARDARv2
DARDARv3
2C-ICE
SAM
SAM-regrid
Frequency
b)
LW CRE
SW CRE
net CRE
SAM
SAM-regrid
CCCM
CRE [W m^{-2}]
c)
Frequency x CRE [W m^{-2}]
IWP [g m^{-2}]

Even thin TTL cirrus can substantially change CRH





Cloud radiative heating drives large-scale dynamics and its response to global warming (e.g. Voigt et al., 2021, Dinh et al., 2023) and mesoscale circulations (e.g. Gasparini et al., 2022)