SCREAMing about cirrus: Ice microphysical changes in RCE

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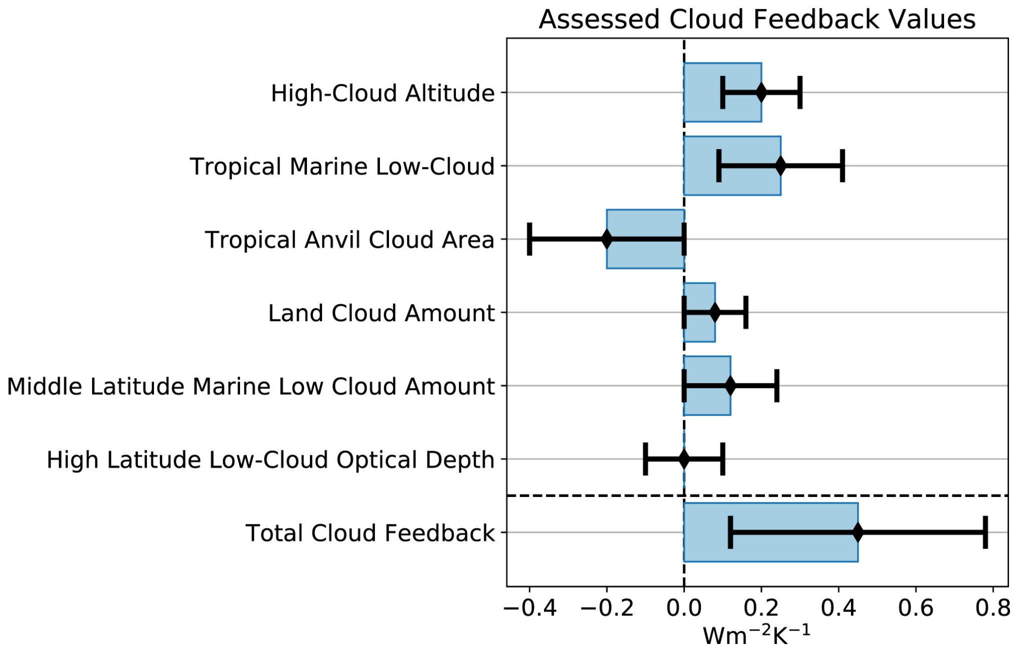
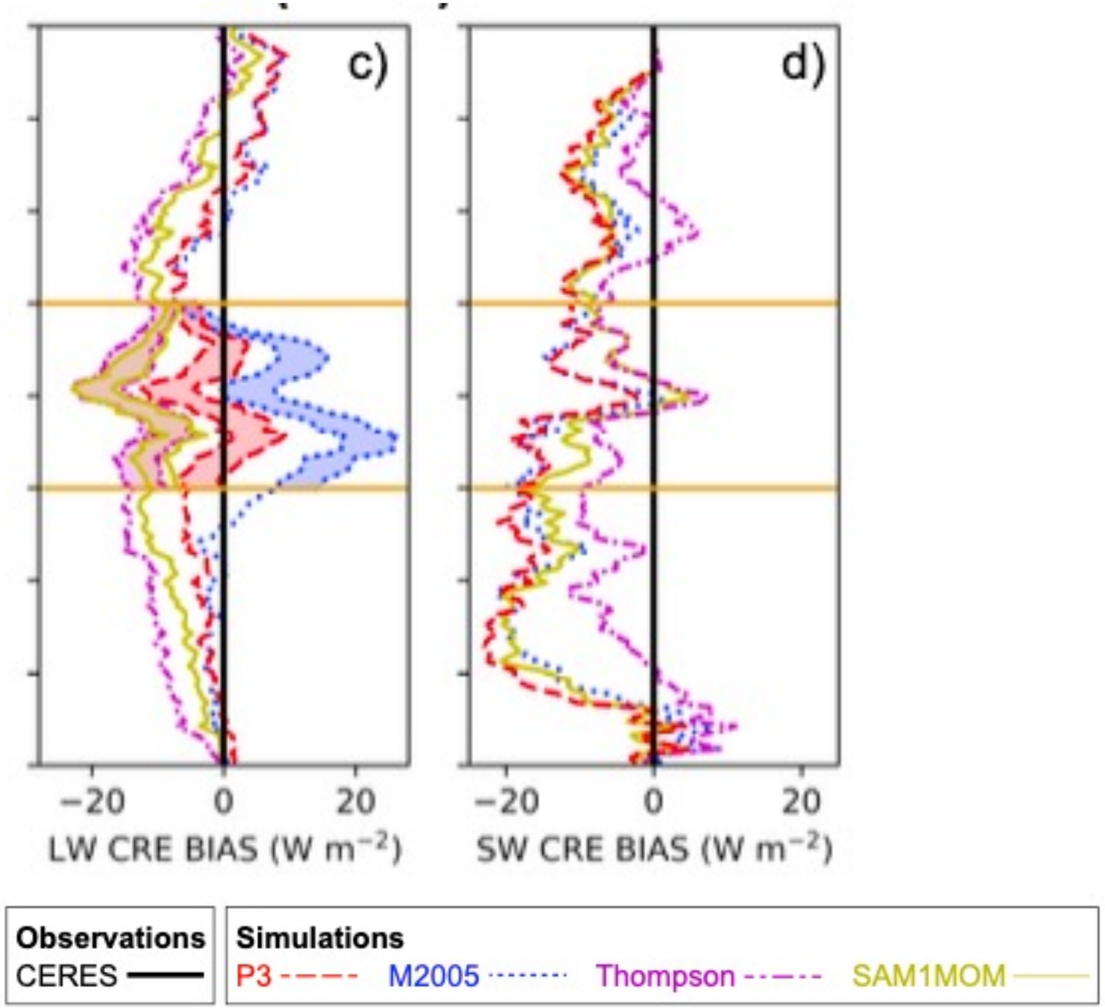
Why does microphysics matter?

Largest uncertainty in cloud feedback

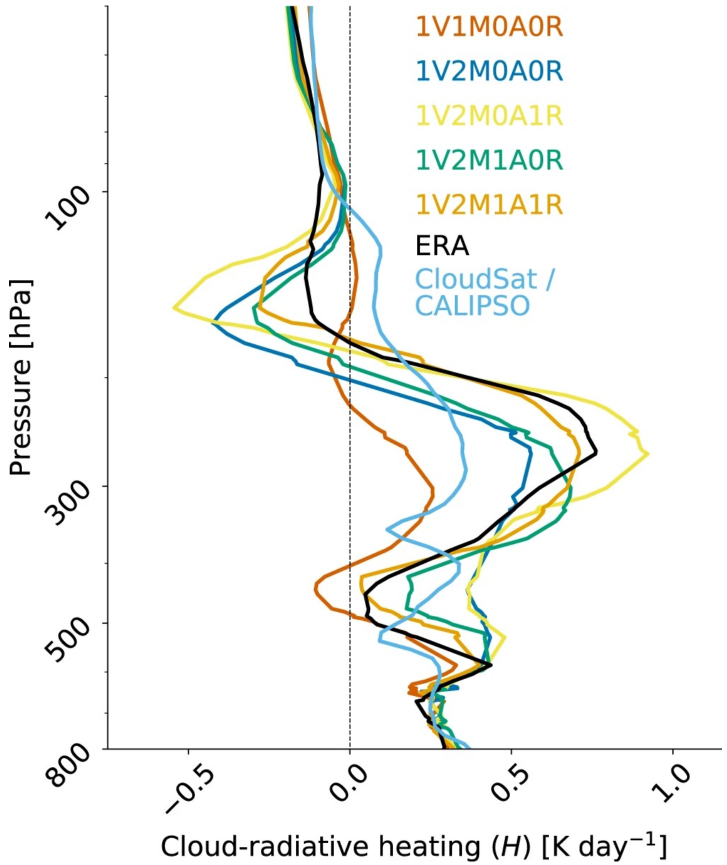


Sherwood et al., 2020

Past microphysics studies – different schemes



Atlas et al., submitted; Fig. 1: SAM microphysics schemes



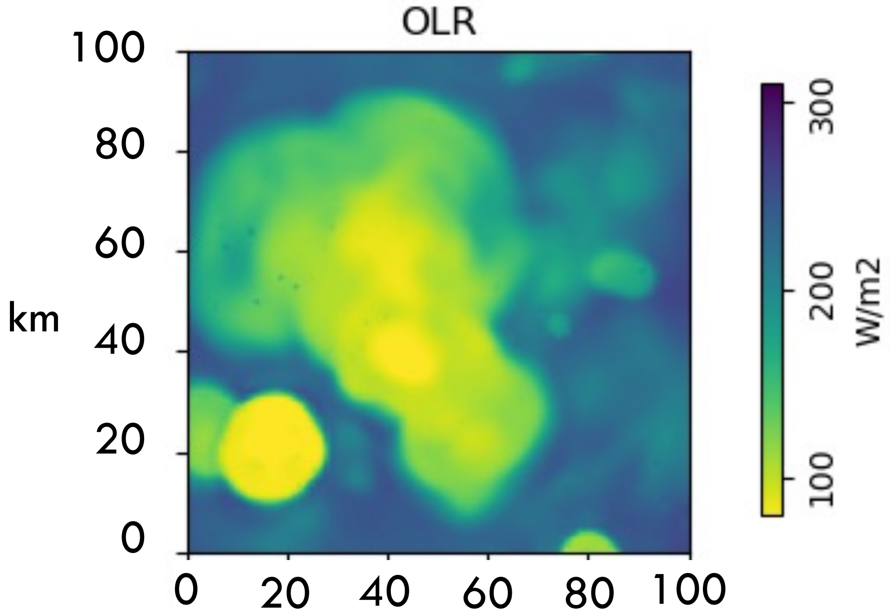
Sullivan & Voigt, 2021; Fig. 2: Even in convection-resolving simulations, we can generate a wide range of □ profiles by adjusting ice microphysical parameters.

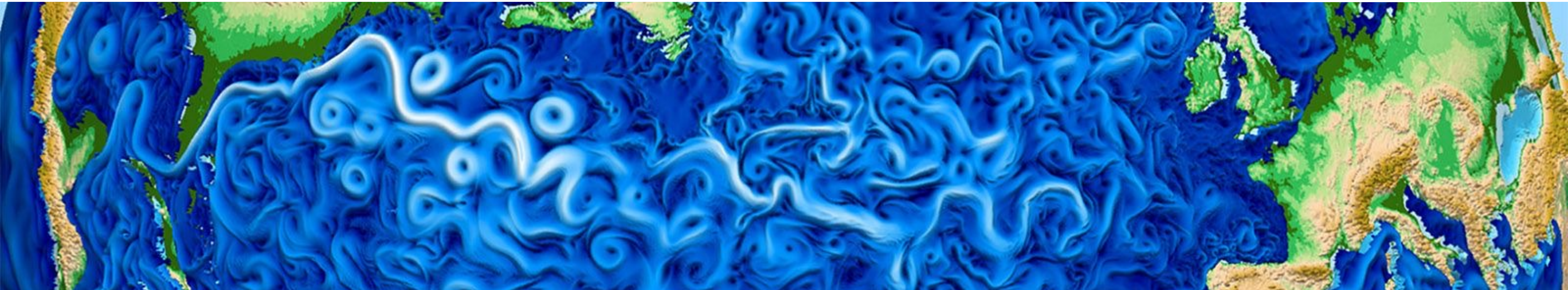
Microphysics sensitivity study using RCE-SCREAM

3.3 km horizontal resolution

128 vertical levels (17 in the TTL; ~200m)

P3 microphysics (Morrison & Milbrandt, 2014)





Research questions

How do microphysics parameterizations affect cirrus clouds?

1. Comparing two ice nucleation schemes

2. Sensitivity study: turning up and down certain processes

P3 microphysics: old vs new

Standard ice_nucleation scheme

1. Default freezing mechanism (Cooper 1986)
2. Options for using predicted or prescribed CCN and number concentration

New ice nucleation scheme is more complex

Standard ice_nucleation scheme

1. Default freezing mechanism
   (Cooper 1986)
2. Options for using predicted or prescribed CCN and number concentration

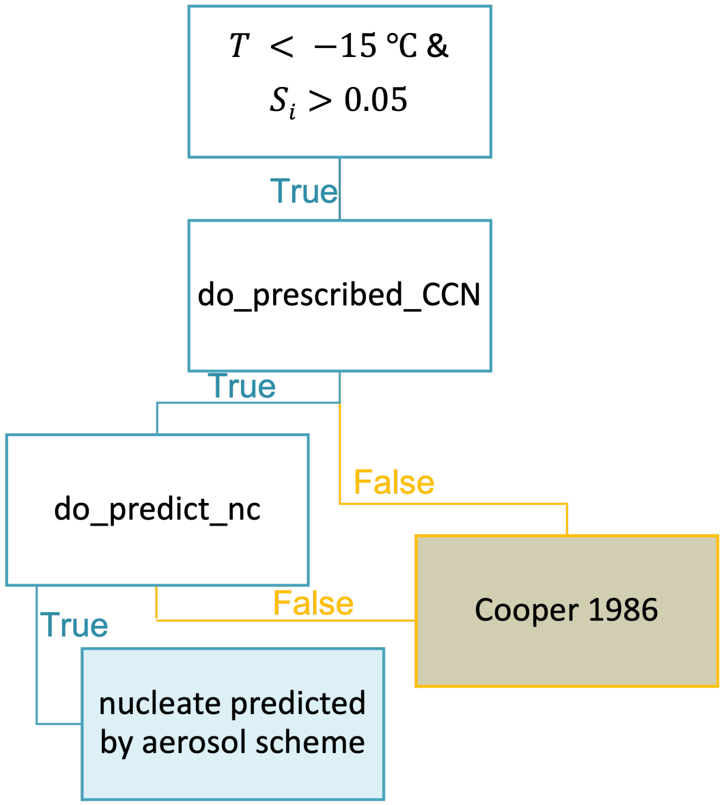
New ice_nucleation scheme

1. Freezing for mixed phase
   (Cooper 1986)
2. Allows for deposition freezing in cirrus
   (Mohler et al., 2006)
3. Allows for heterogeneous vs homogeneous competition
   (Liu & Penner, 2005)

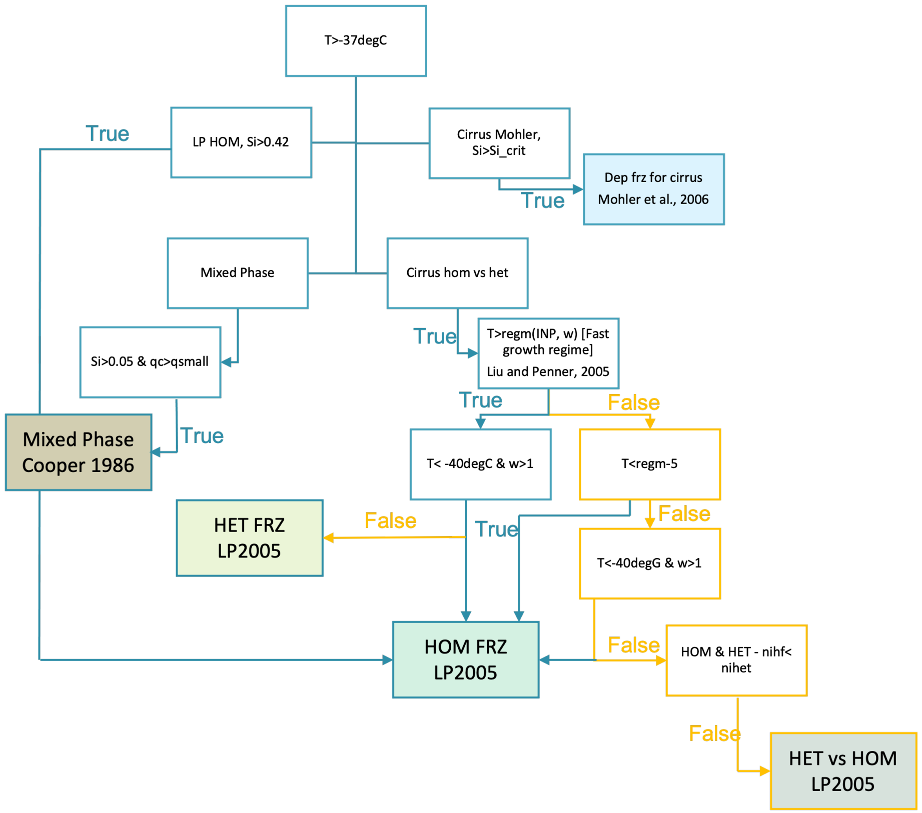
New ice nucleation scheme is more complex

(and hopefully more physical)

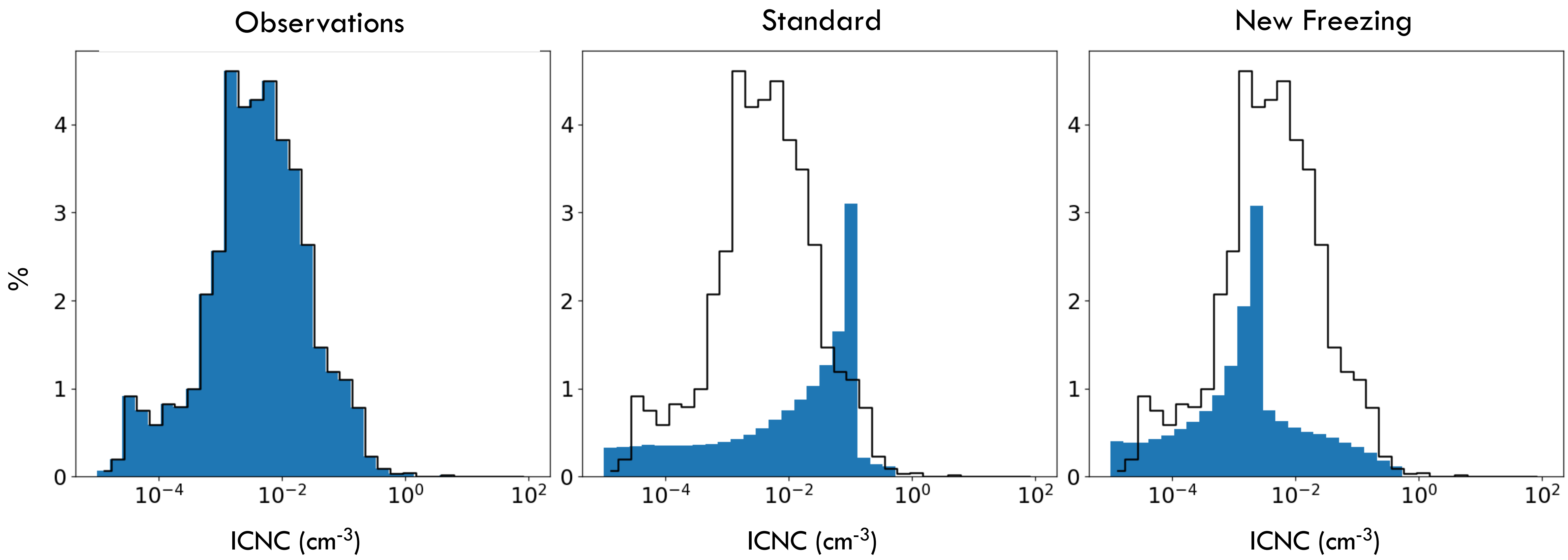
Standard ice_nucleation scheme



New ice_nucleation scheme

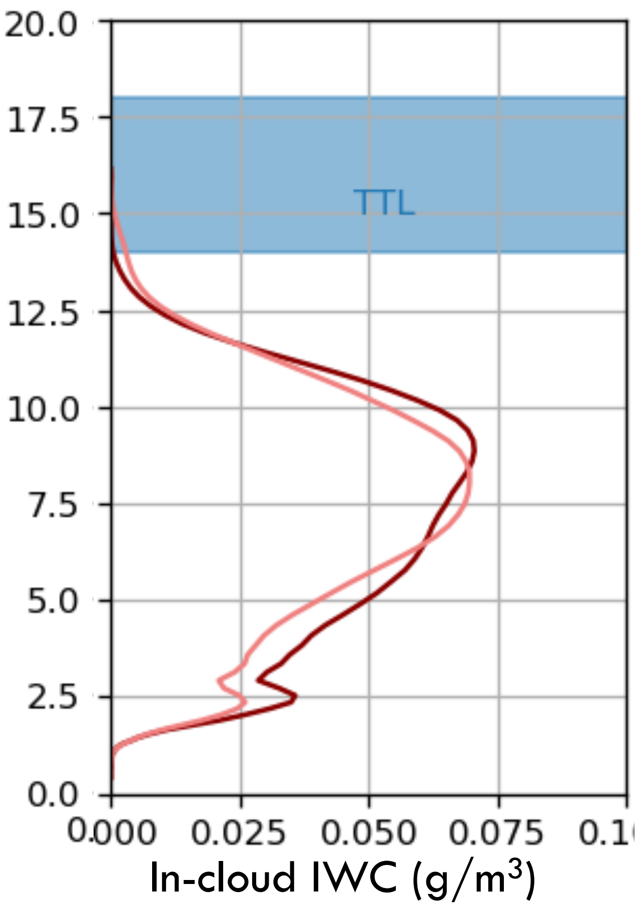


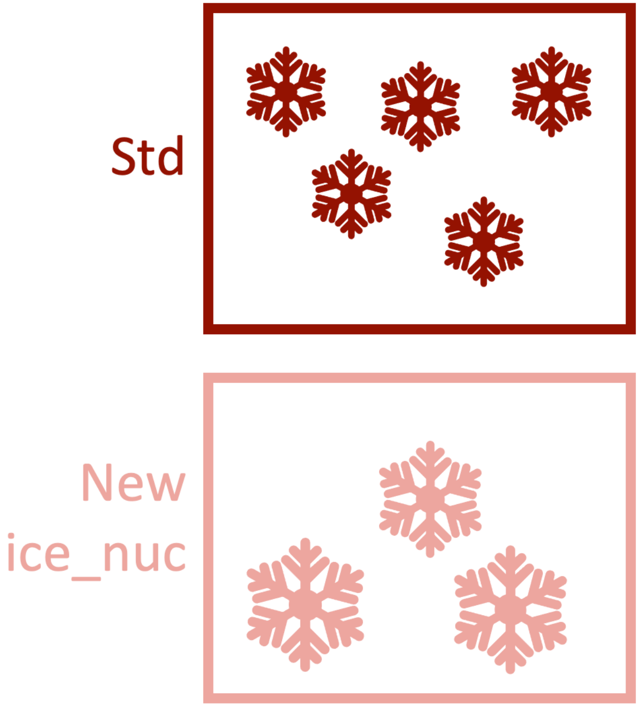
Microphysical changes in new freezing scheme



ICNC = Ice crystal number concentration

Changing ice nucleation impacts the vertical structure and cloud (micro)physics

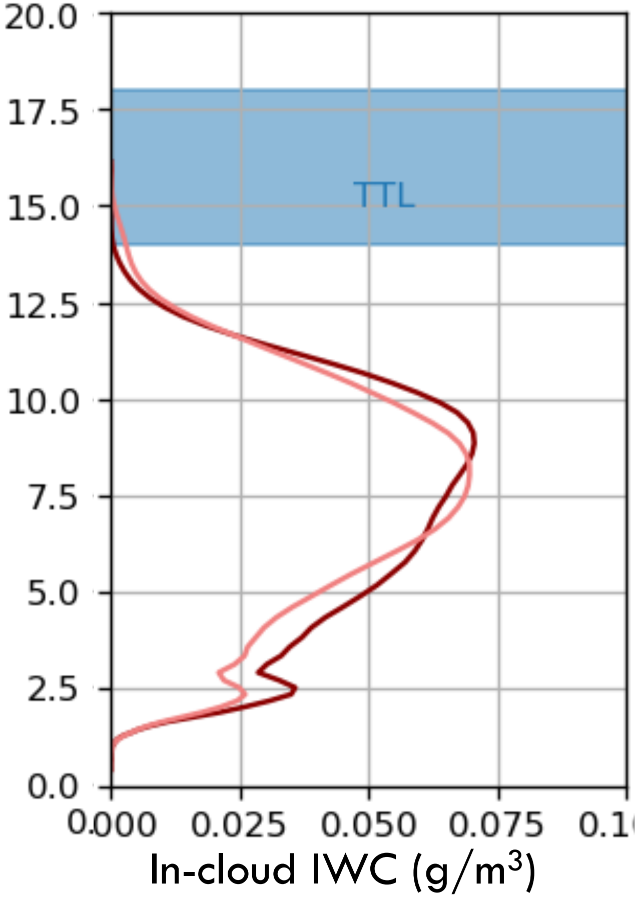


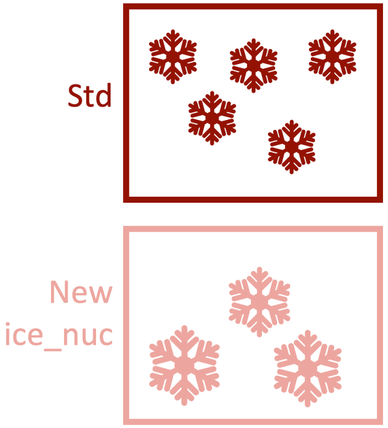


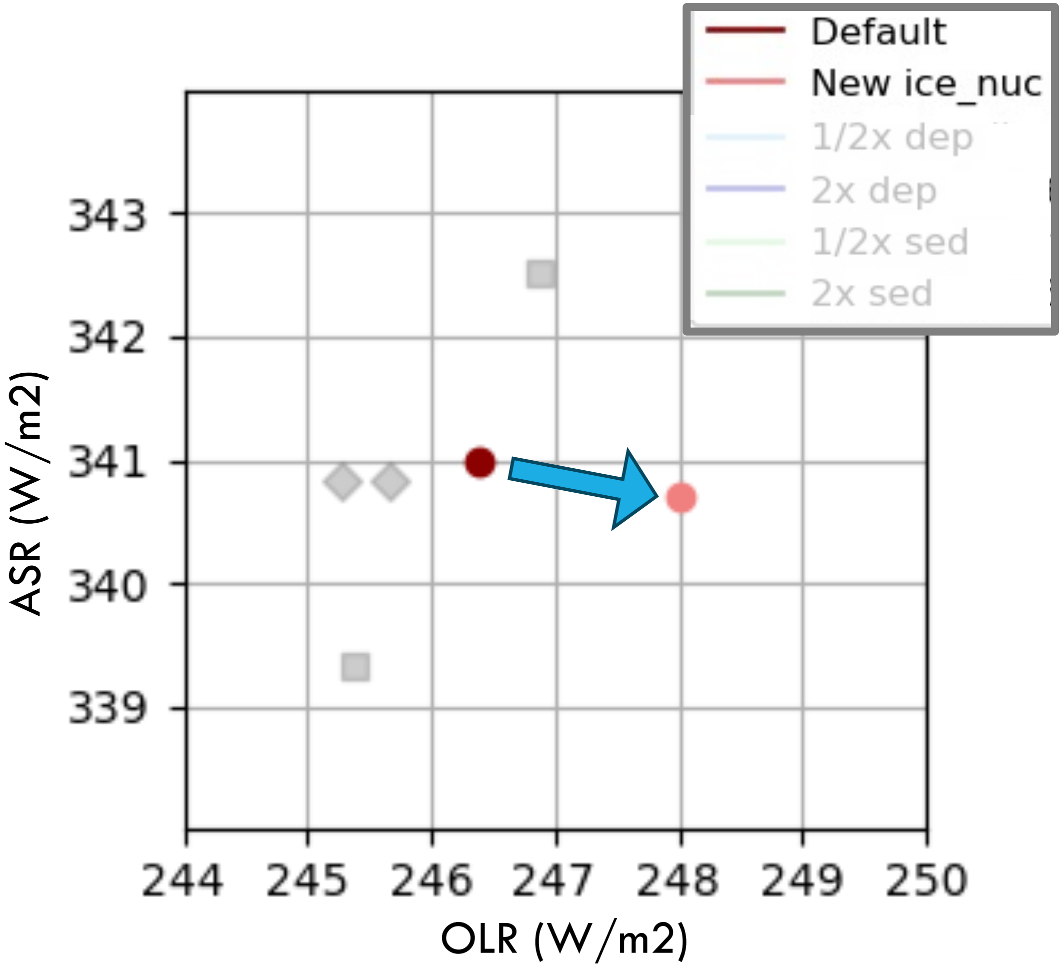
Fewer ice crystals but they are larger in size

This larger ice mass is shifted downwards

The peak cloud ice mass is shifted to a lower altitude (higher OLR)







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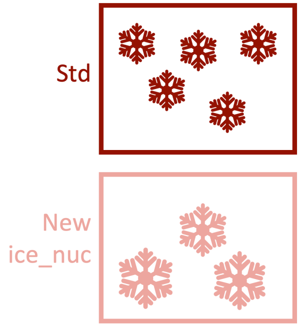


1. Comparing two ice nucleation schemes

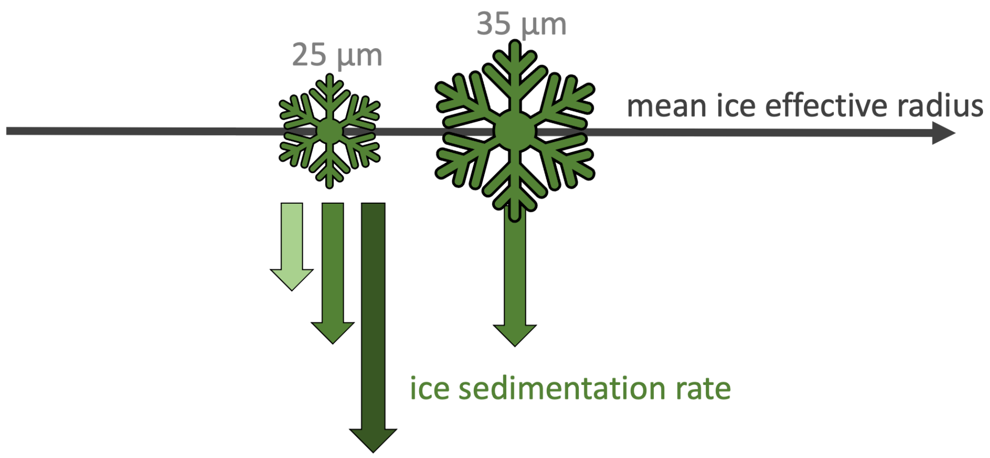
2. Sensitivity study: turning up and down certain processes

Changes to processes of ice nucleation can impact the microphysics of cirrus clouds in ice crystal number concentration (ICNC), mean ice mass radius, and more

Sensitivity Study

Ice sedimentation ice_sedimentation

Scaling by ½ - 2 x for
average grid box ice mass
with $R_{eff} < 25$ μm



Credit: *PNAS*

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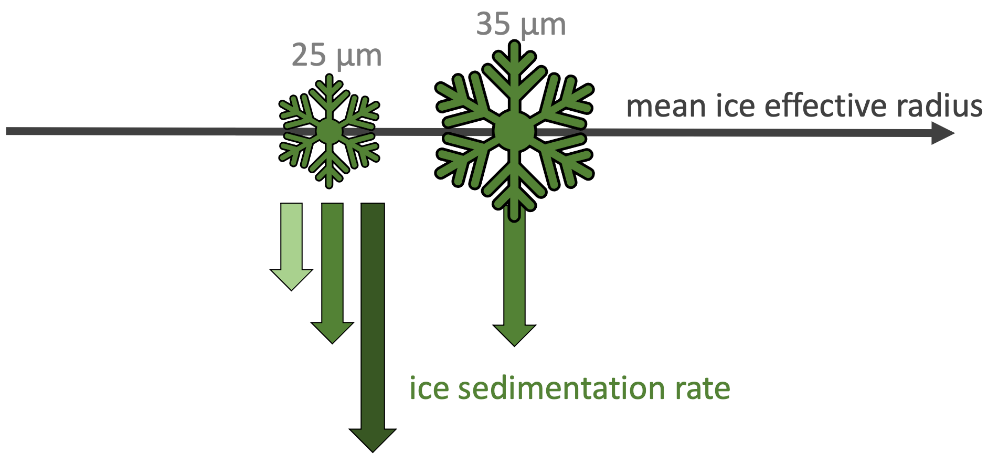
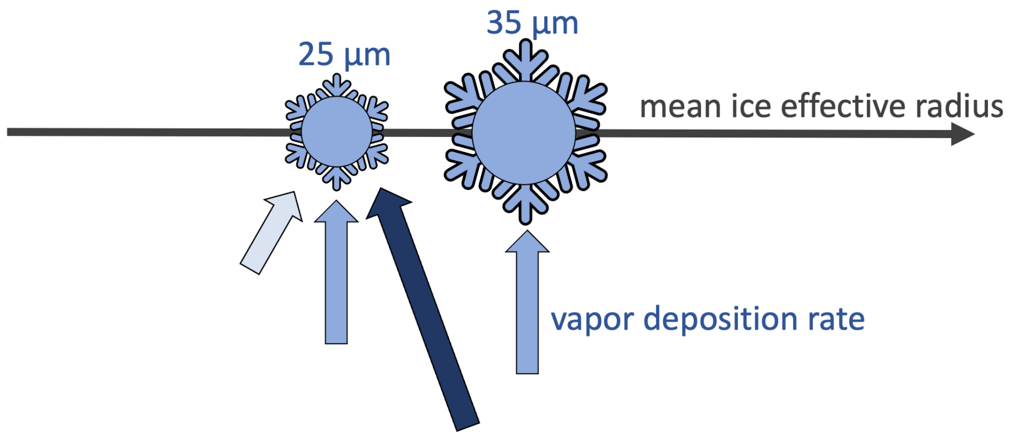


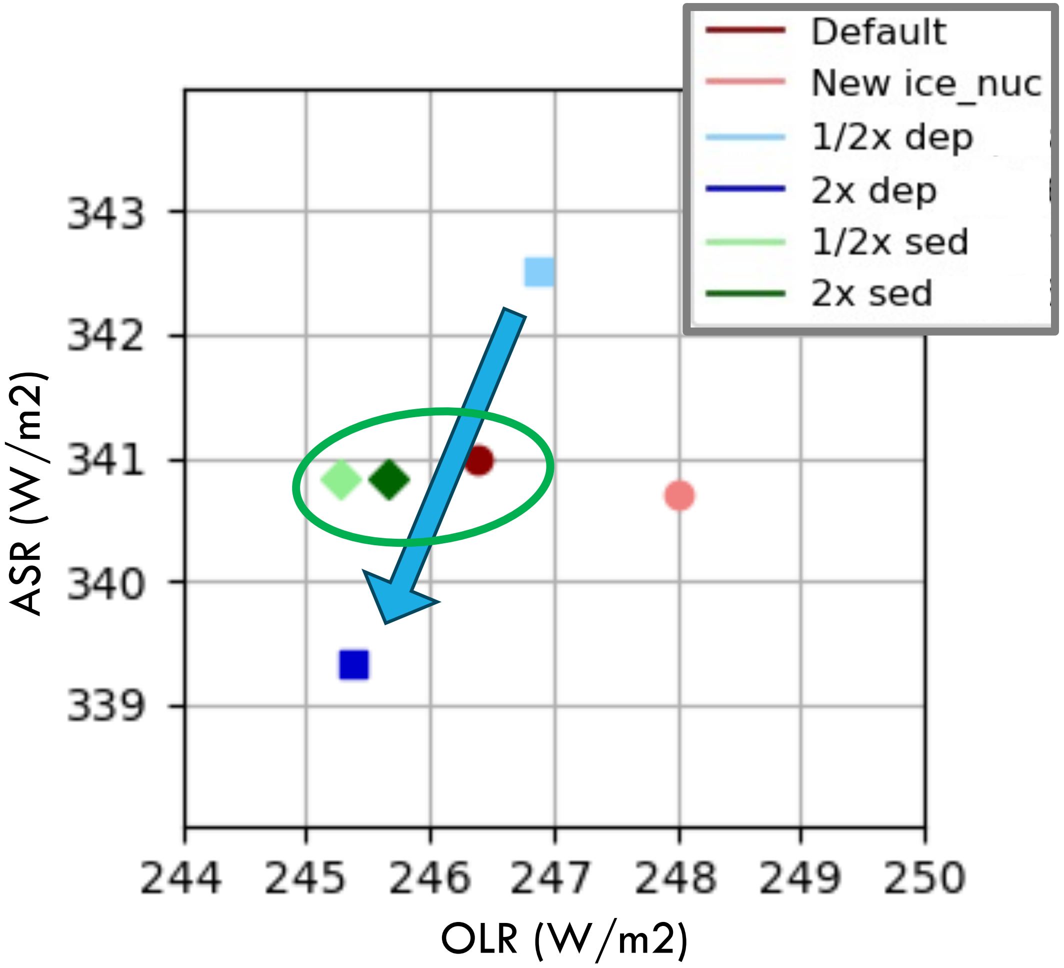
Vapor deposition ice_deposition_sublimation



Microphysical changes affect top-of-atmosphere radiation

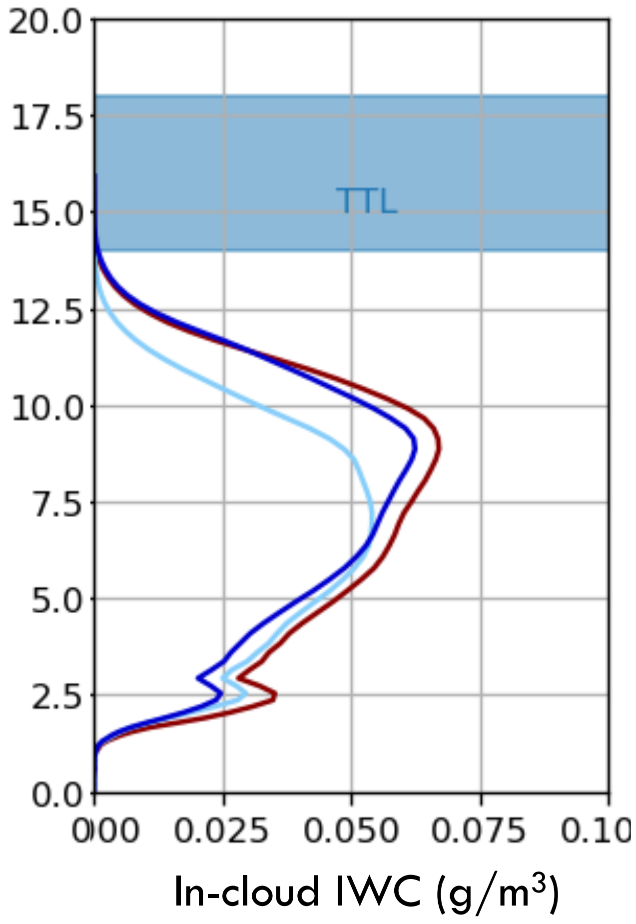
DYAMOND models had a standard deviation of 10 W/m2 in OLR (spread of 60 W/m2)

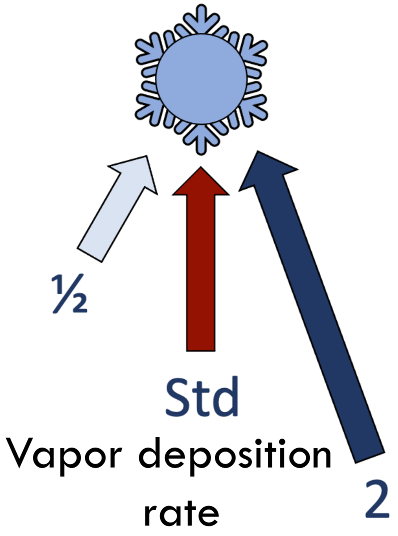
- Vapor deposition impacts SW more than LW
- Sedimentation rate has a small impact on TOA radiation

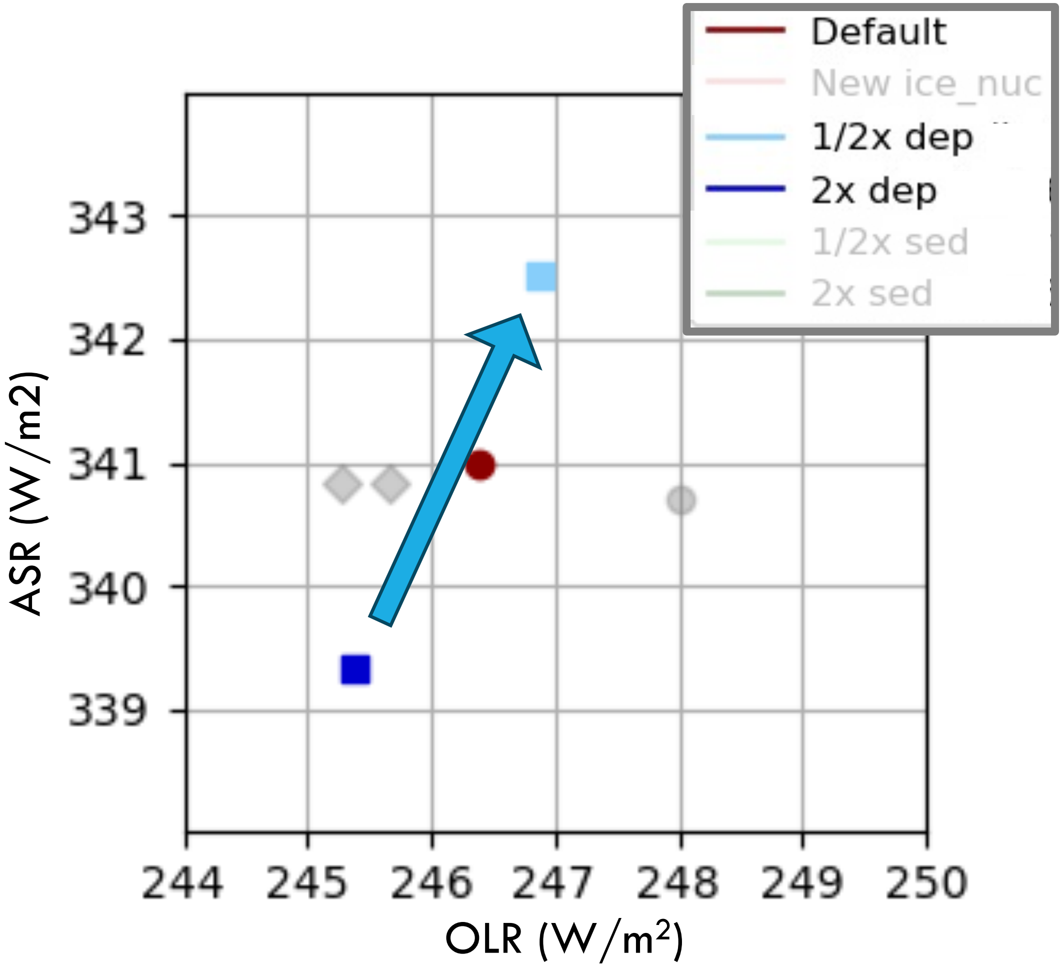


OLR = Outgoing longwave radiation
ASR = Absorbed shortwave radiation

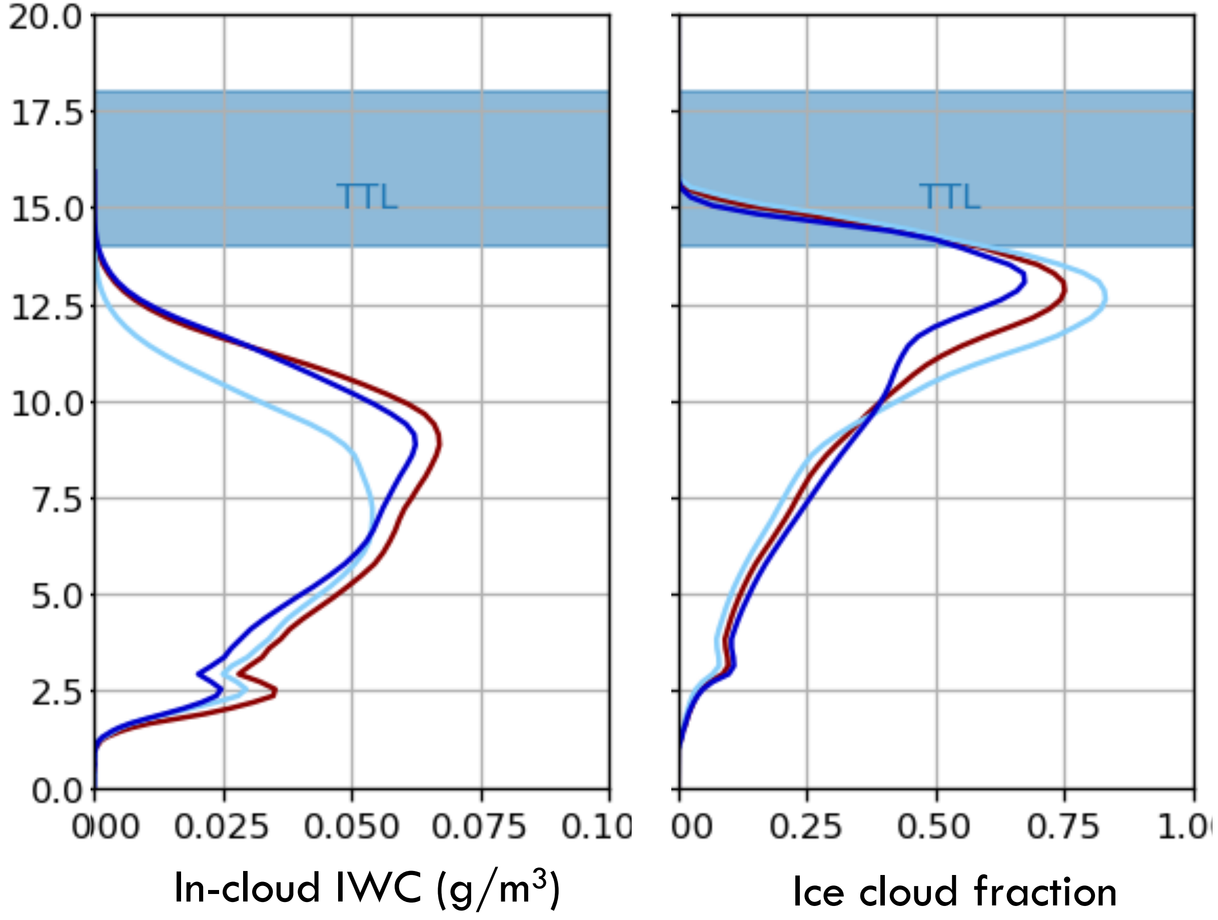
Decreasing vapor deposition decreases cloud ice

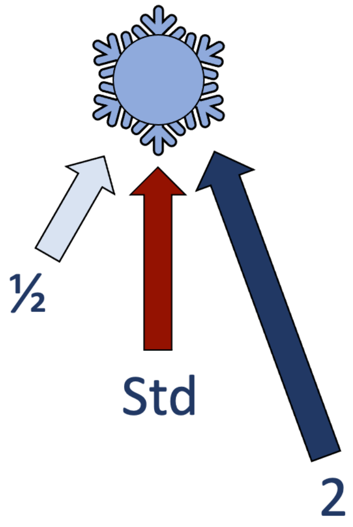




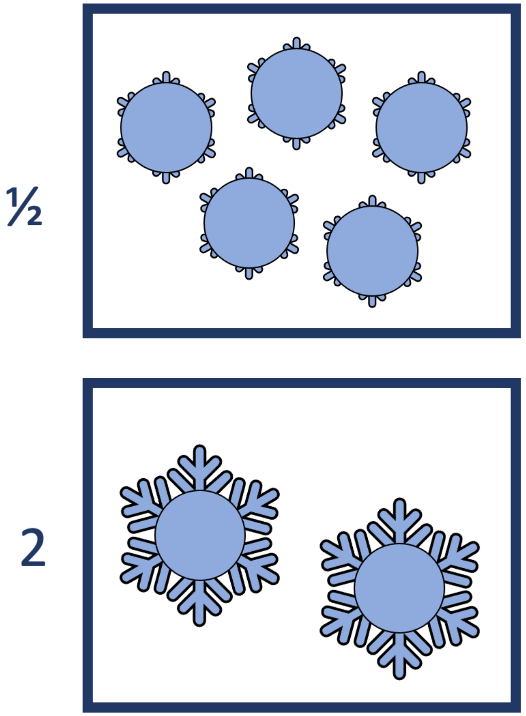


Increasing vapor deposition decreases cloud fraction



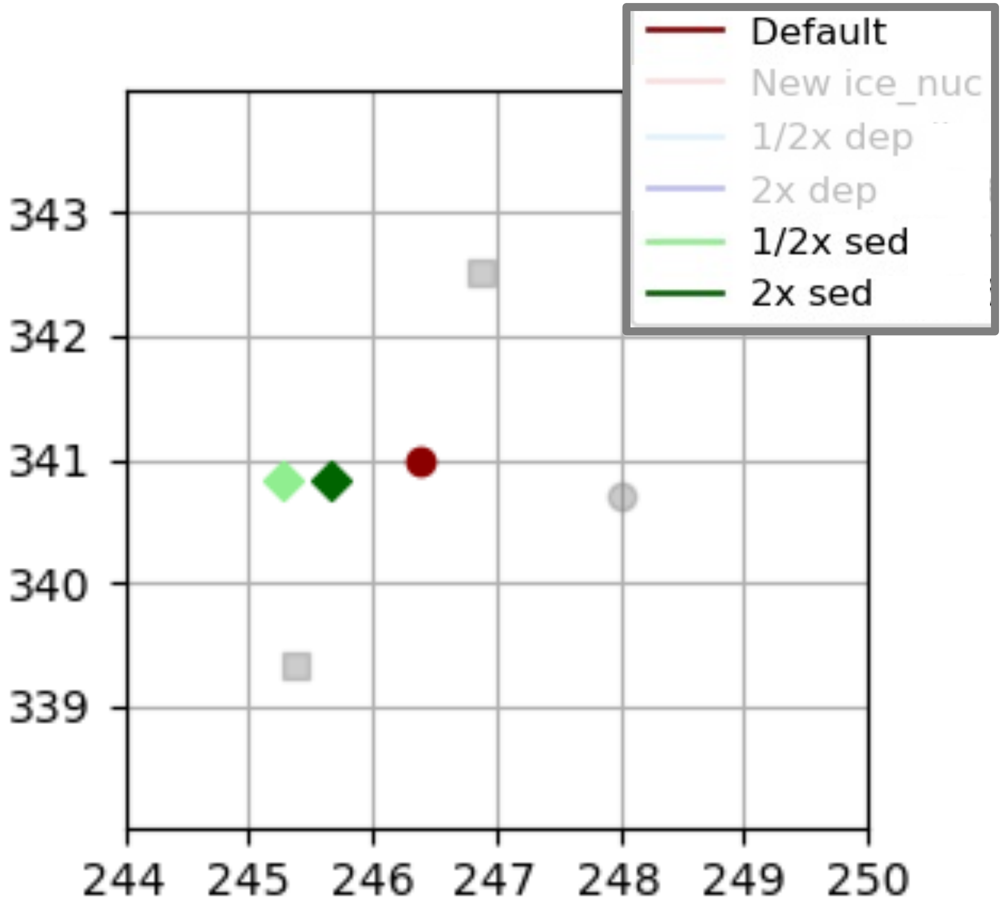


ice crystals grow slower but are larger in number and stick around longer

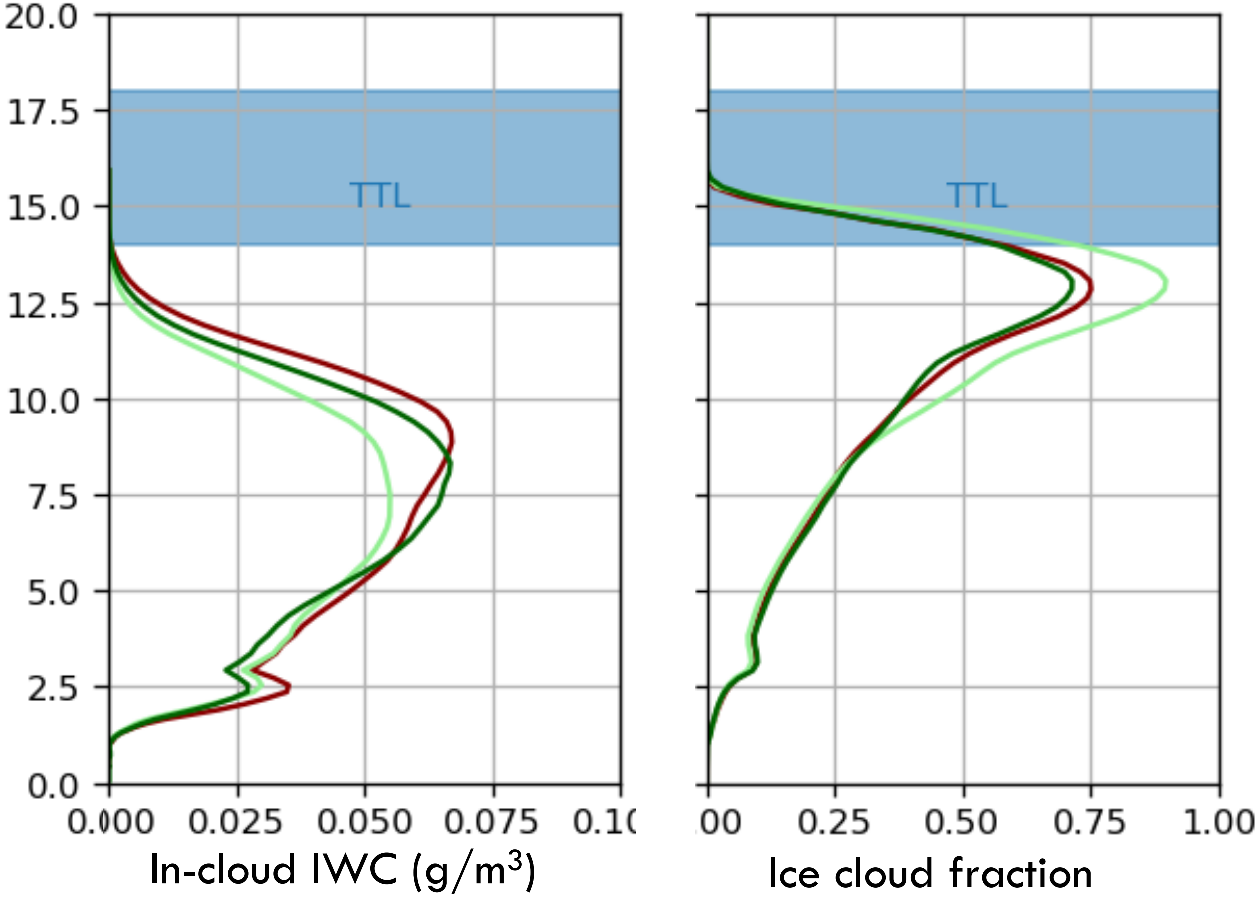


ice grows quickly which means less ice crystals overall and they fall out more quickly

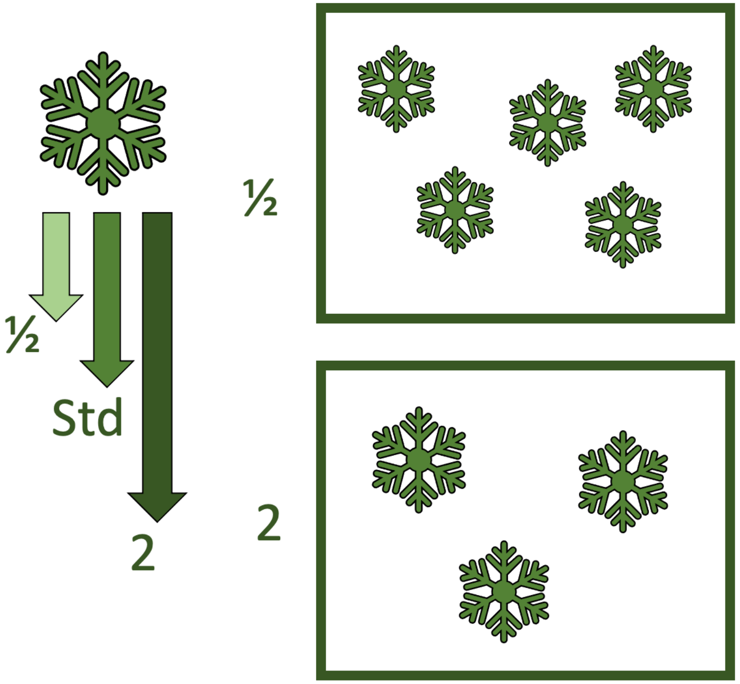
Changing sedimentation rate has no impact on TOA radiation



Decreasing sedimentation rate decreases cloud ice mass but increases cloud fraction, nearly balancing out



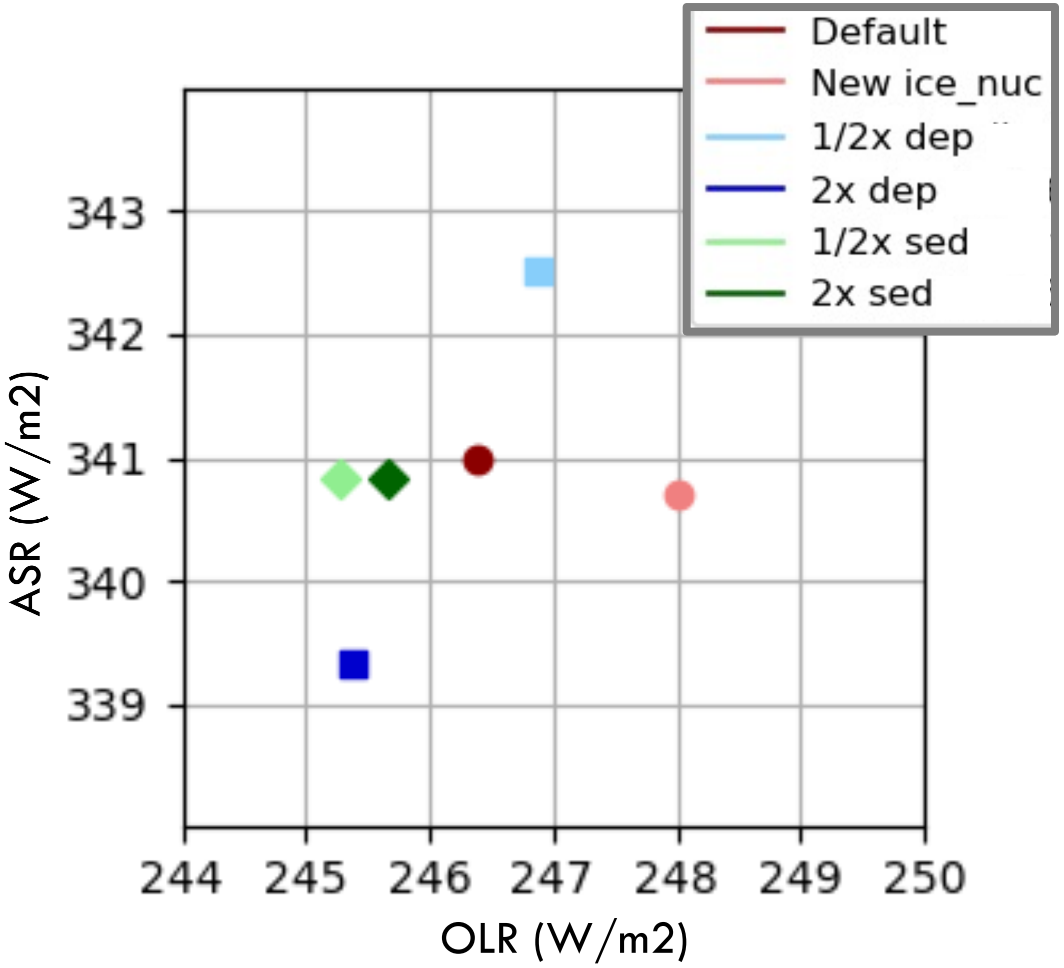
less ice falls out, larger ice number concentration



more ice sediments but leftover ice crystals grow larger (higher mass & maybe larger than 35 μm threshold)

Microphysical changes affect top-of-atmosphere radiation

- Vapor deposition impacts SW more than LW at TOA
- Vapor deposition has a stronger influence on thin cirrus and TOA radiation than sedimentation



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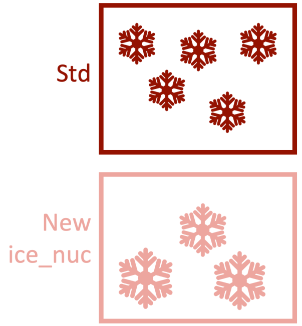

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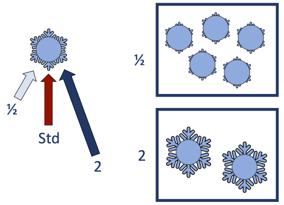
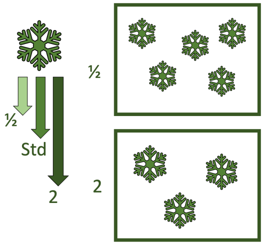




Small changes in microphysics have important implications for TOA radiation and cloud physics – sedimentation doesn't play as large a role for small ice crystals

Research questions & preliminary results

How do microphysics parameterizations affect cirrus clouds?

Small changes in microphysics have important implications for TOA radiation and cloud physics – sedimentation doesn't play as large a role for small ice crystals

How can changes in microphysics contribute to the model spread and interact with the model dynamics?

Model spread in TOA radiation for small changes in microphysics for is up to 6 W/m^2 (maybe up to 10% of variability of DYAMOND models)

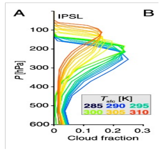
Research questions & preliminary results

How do microphysics parameterizations affect cirrus clouds?

Small changes in microphysics have important implications for TOA radiation and cloud physics – sedimentation doesn't play a large role for small ice crystals

How can changes in microphysics contribute to the model spread and interact with the model dynamics?

Model spread in TOA radiation for small changes in microphysics for is up to 3 W/m^2 (maybe up to 30% of variability of DYAMOND models)

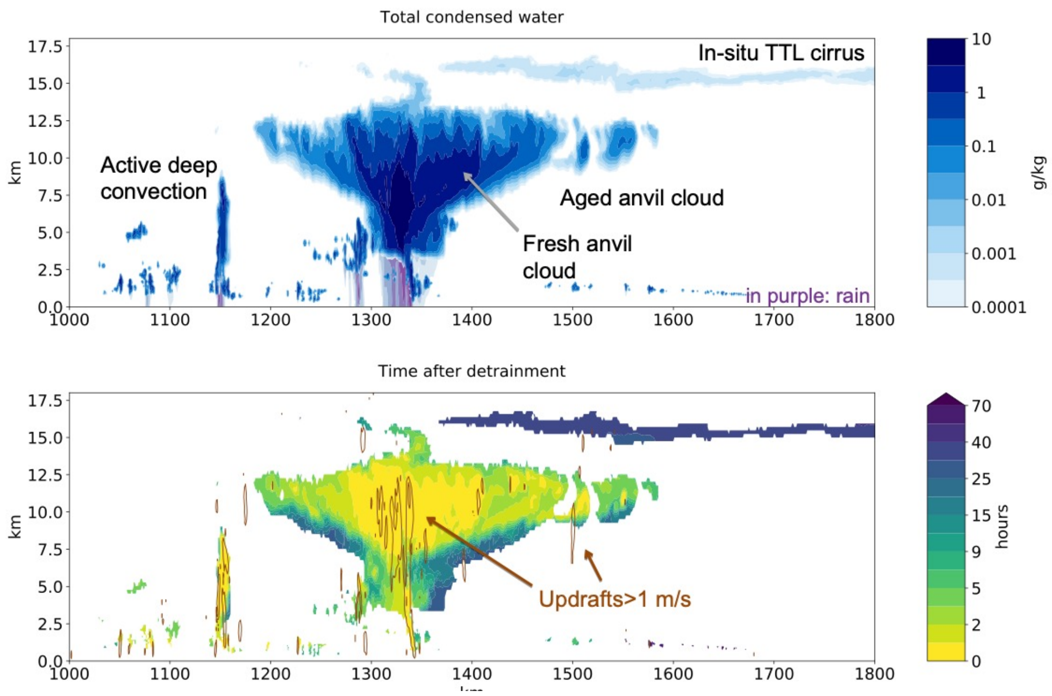


As SSTs increase how do anvil and TTL cirrus change?

Future work: run RCE set-up with +4K SSTs and continue microphysics sensitivity study

Future work

- Add tracers for time since convection & nucleation
- Include L.S. ascent for more realistic TTL
- Run in large domain (bowling alley/variable resolution global configuration) to allow for self-aggregation
- Horizontal grid spacing (1 km)
- Update microphysics to include…
  1. New results from Kärcher, 2022 (JGR)
  2. Pre-existing ice option



Gasparini

Acknowledgements:

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Model:

The SCREAM Project

Computing resources:

DKRZ DEUTSCHES KLIMARECHENZENTRUM

UCAR UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH

Thank you!

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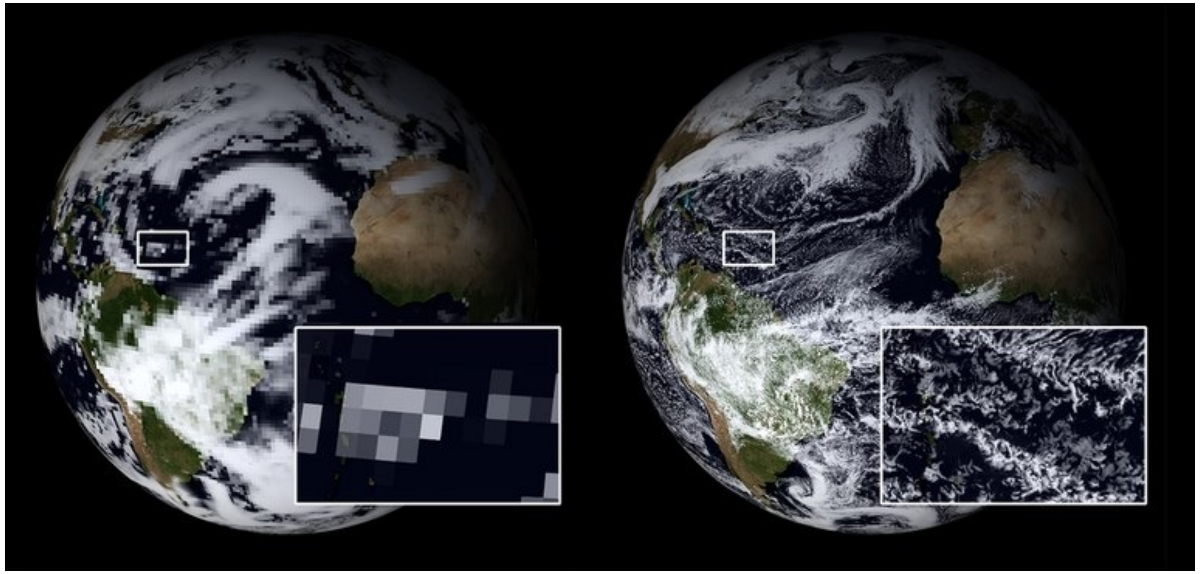
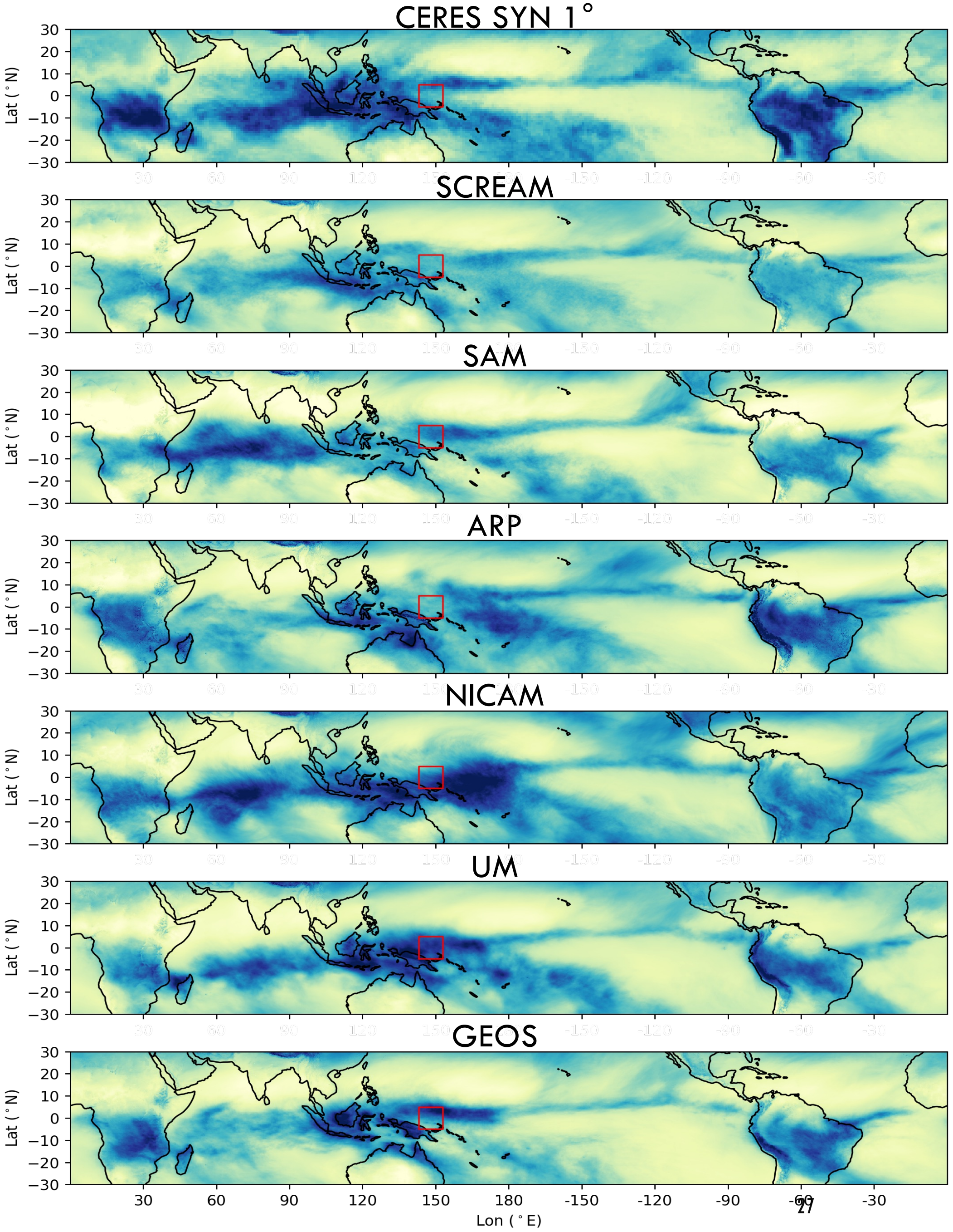
Supplementary slides

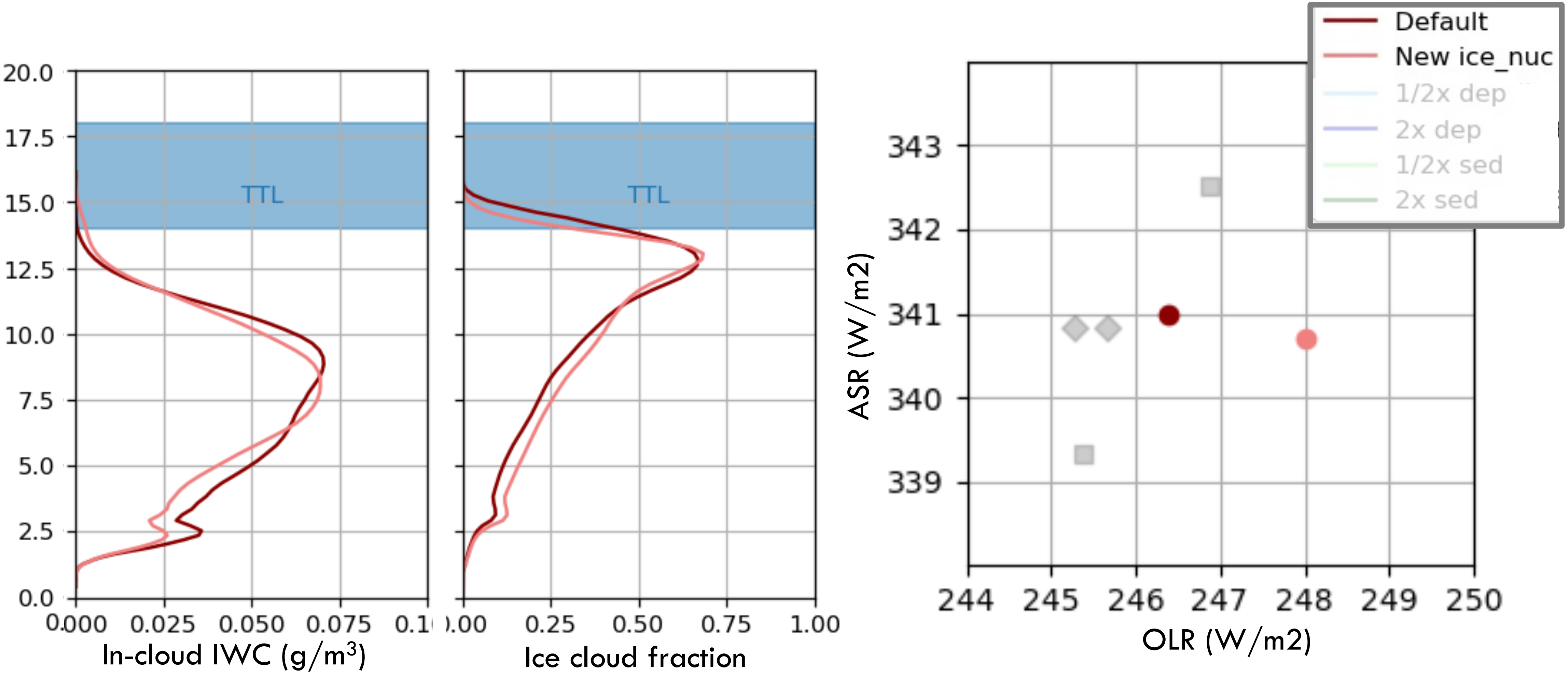
Motivation

Global storm-resolving models from DYAMOND intercomparison project show the **diversity of model behaviors** in top-of-atmosphere radiation

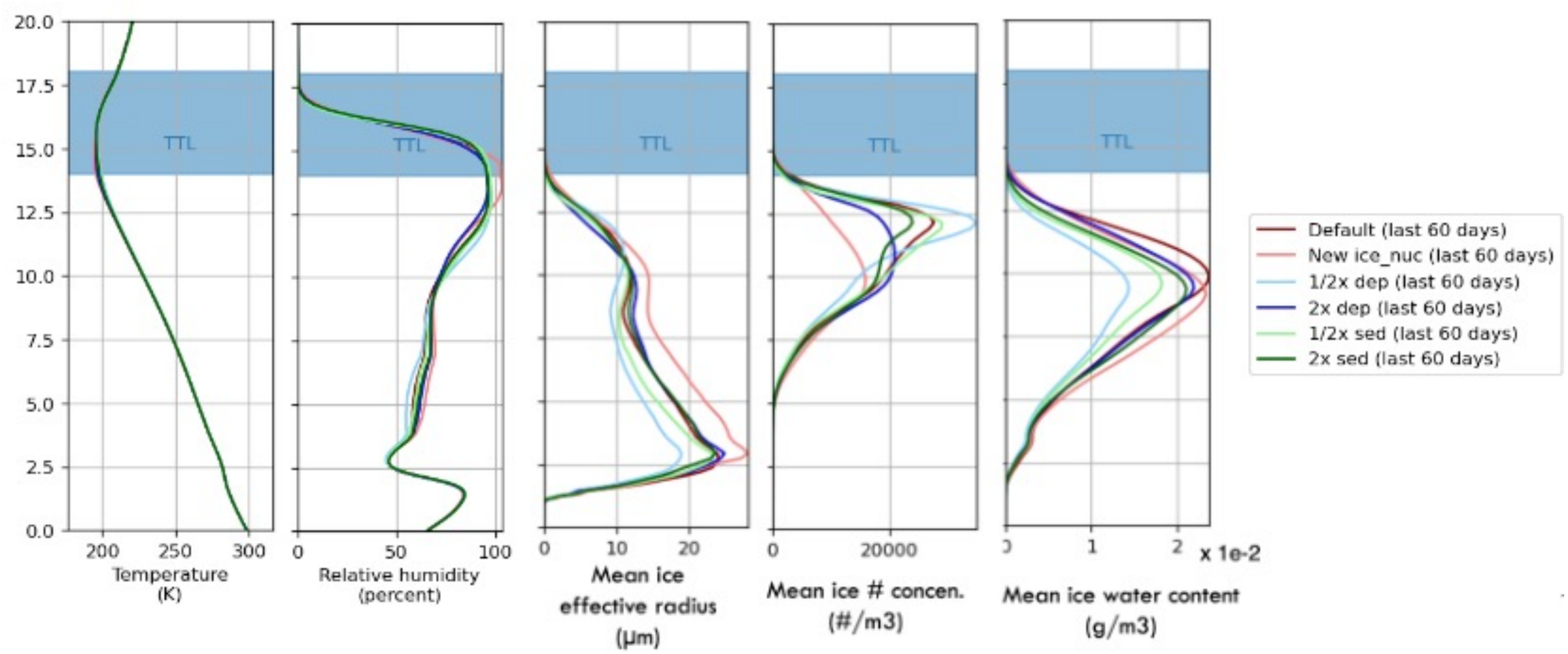




Changing ice nucleation



Vertical mean profiles



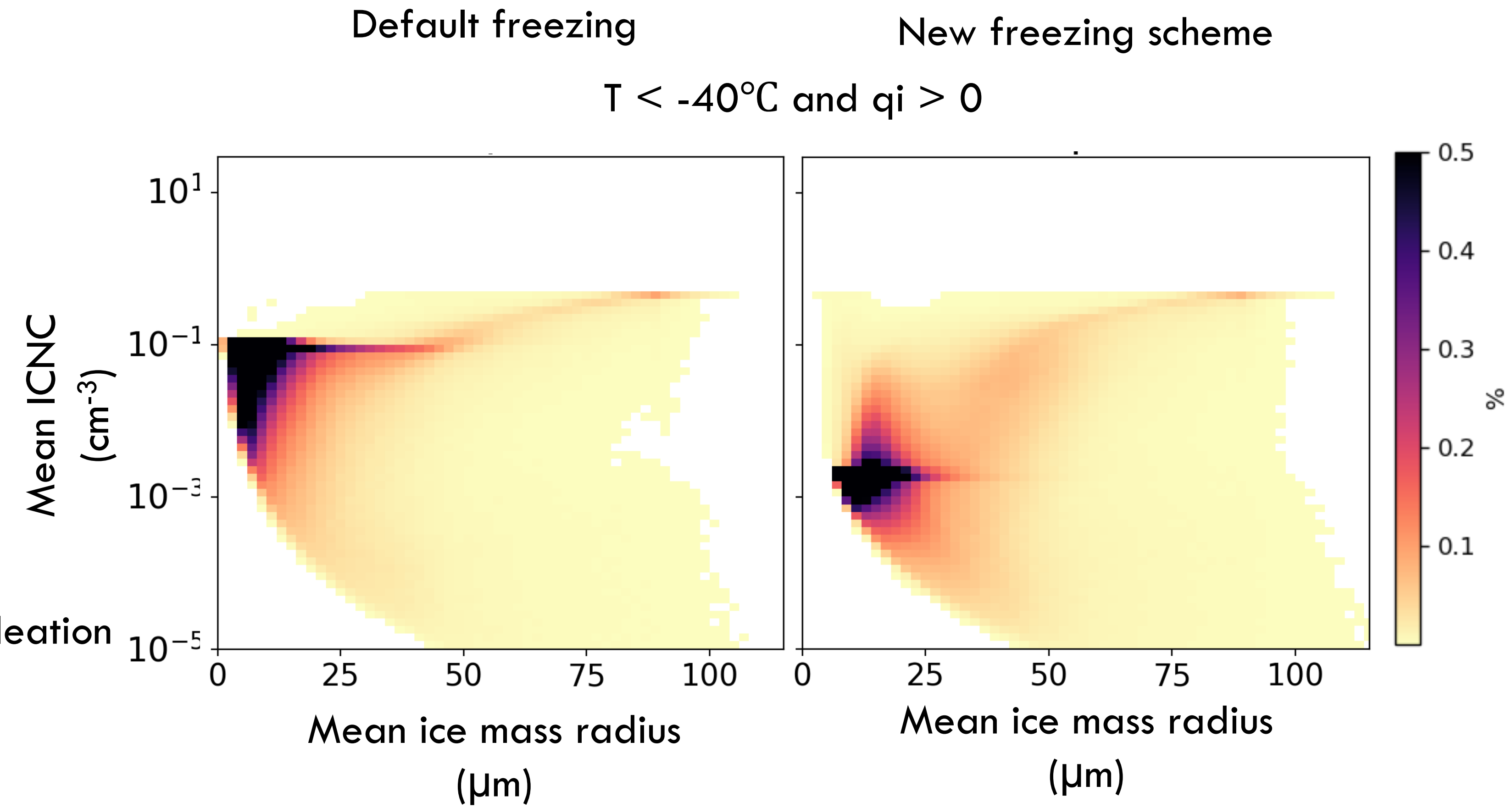
Microphysical changes in new freezing scheme

Default:

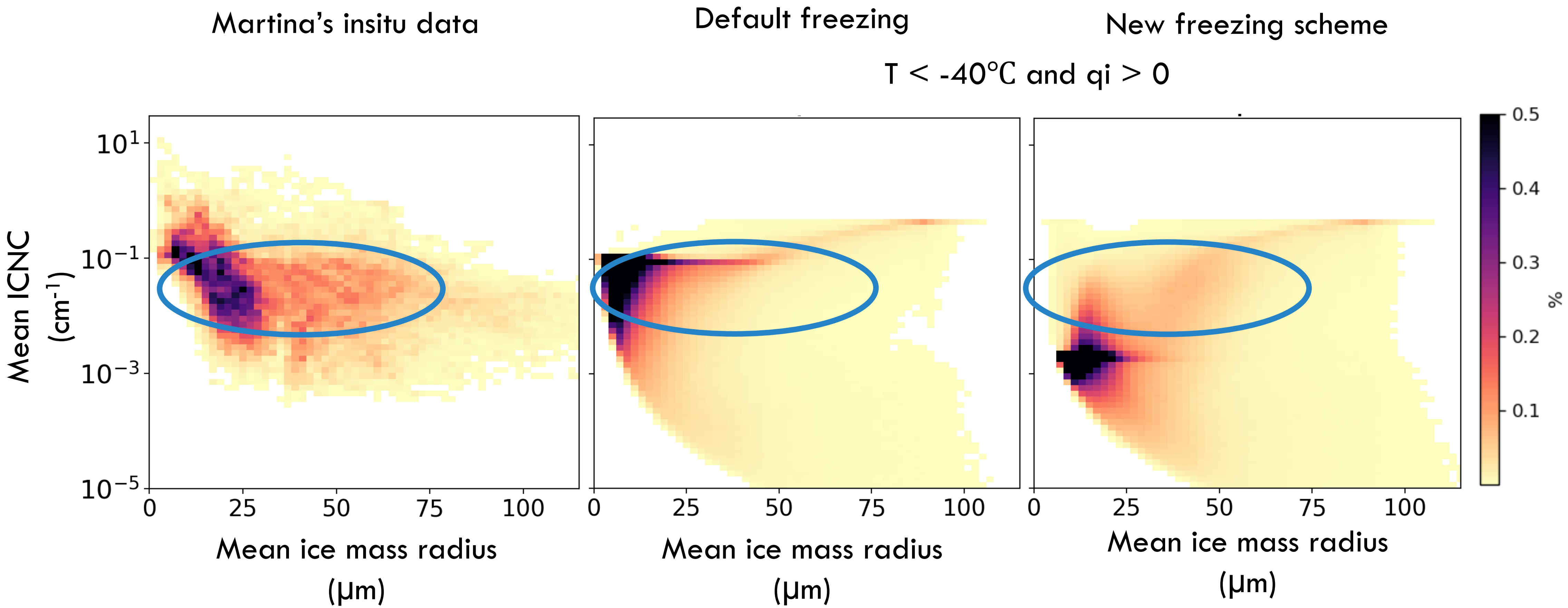
- limit at 10^{-1} cm^{-3}

New freezing

- Mixed phase:
  - limit to 1.5×10^{-1} cm^{-3}
- Cirrus deposition freezing:
  - From INP concentration
  - Limit at 2×10^{-3} cm^{-3}
- Homogeneous/heterogeneous nucleation
  - limit at 80 cm^{-3}



ICNC = Ice crystal number concentration

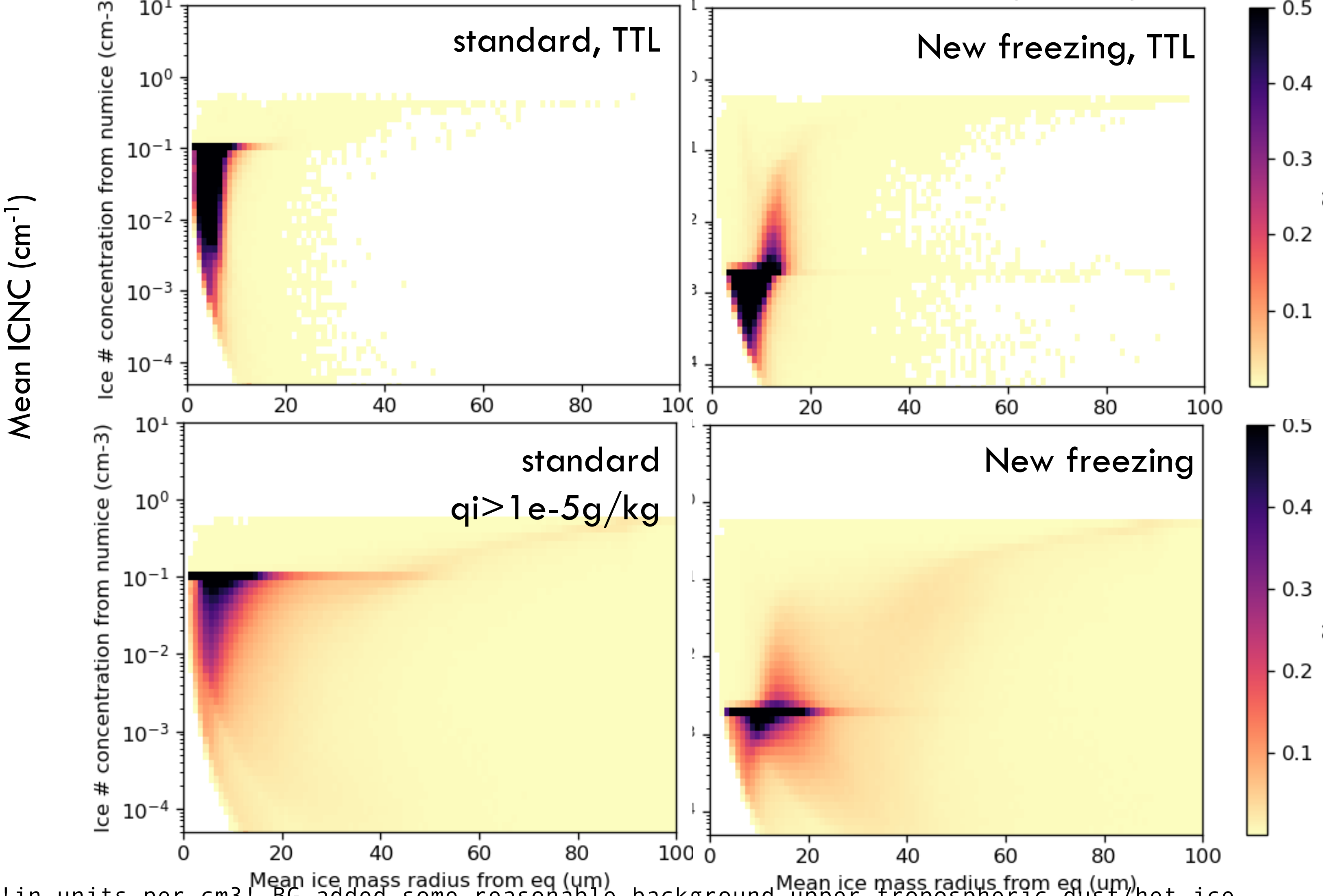


ICNC = Ice crystal number concentration

Results:

Compared to observations and SAM P3 standard

Larger ice radius may be due to small domain




```
real,parameter,public ::  NumCirrusINP = 2.e-3 !in units per cm3! BG added some reasonable background upper tropospheric dust/het ice
  nuclei value for cirrus conditions
!BG: based on simulated upper tropospheric (200 hPa) values of dust in Tropical Western Pacific for ECHAM-HAM GCM simulations
real,public :: NumCirrusSulf = 20. !20 will effectively limit the ice nucleation for one event to 20 k /L: better limit, as no way to
  deplete air mass of nsulf in this code
!100. !100/cm3
!BG max number of sulphate aerosol used for homog freezing -> taken some reasonable value for upper troposphere
!used this number as Liu and Penner, 2005
```