How much does ice microphysics matter for simulating tropical cirrus clouds?

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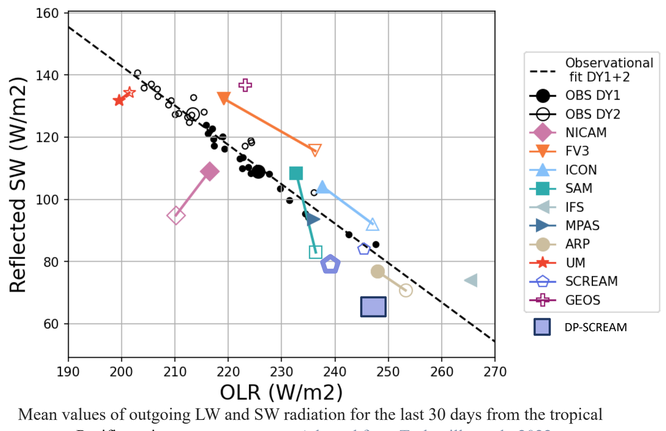
Motivation

How well do Global Storm-Resolving Models (GSRMs) simulate clouds containing ice?



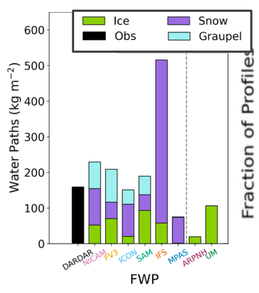
Mean values of outgoing LW and SW radiation for the last 30 days from the tropical western Pacific region Adapted from Turbeville et al., 2022

DYAMOND

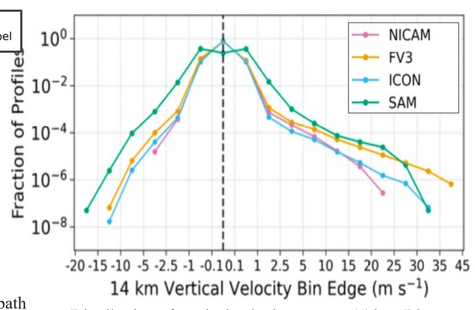
Dynamics of the Atmosphere Modeled on Non-Hydrostatic Domains

- Sub-5km horizontal resolution
- Explicit convection
- Summer & winter phases (40 days)

Large **differences in top-of-atmosphere radiation** (both longwave and shortwave) are driven by **differences in microphysics and dynamics**



Mean values of frozen water path (FWP) as the sum of ice, graupel, and snow for the last 30 days from the tropical western Pacific region

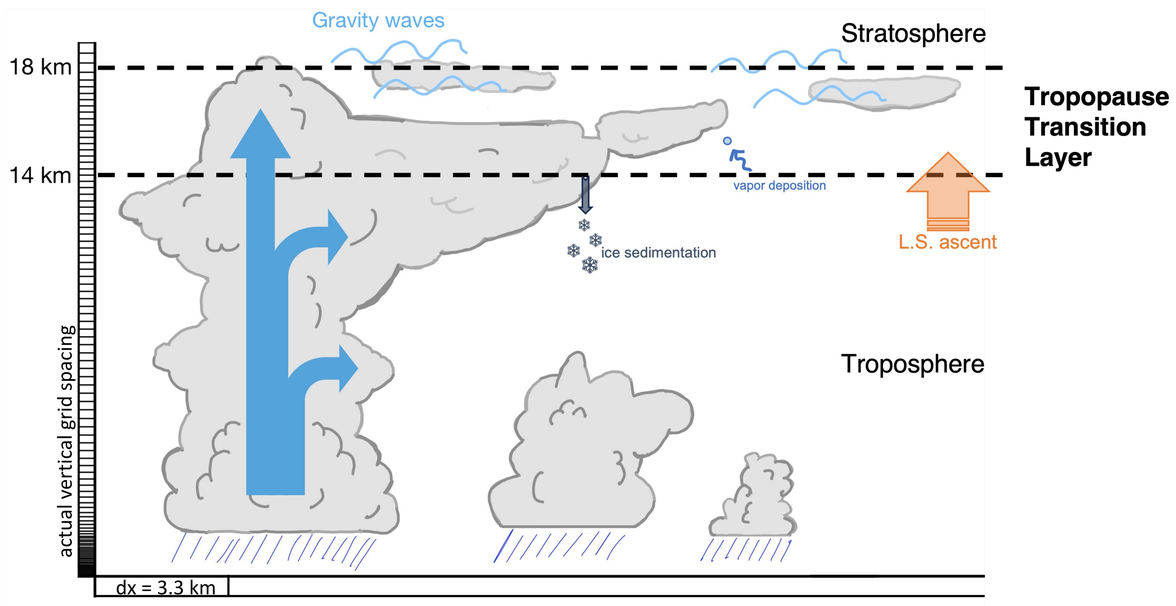


Distribution of vertical velocity, w, at z=14 km. Bins are unevenly spaced in m/s. Nugent et al., 2022

1. Microphysics
   - Frozen hydrometeors impact TOA radiation by their optical properties and vertical distribution
2. Dynamics
   - Vertical velocity extremes are important for bringing ice into the upper troposphere via deep convection

What drives the large range in TOA radiation? How much does microphysics impact cirrus cloud properties?

Ice Microphysics Changes (model set up)

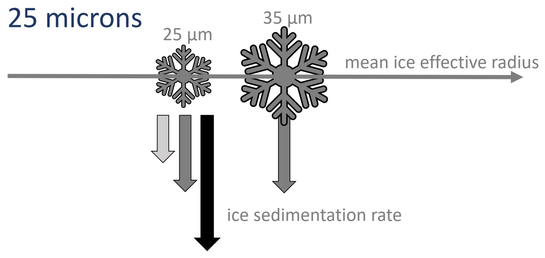


Schematic of cloud processes, especially those related to cirrus clouds in the tropical tropopause transition layer (TTL) such as ice sedimentation and vapor deposition.

Ice processes sensitivity study:

- ice sedimentation
- ice vapor deposition

Simulations whose processes are scaled by ½ or 2 times for ice with effective radius less than 25 microns



Ice nucleation study:

Standard P3	New freezing
All - Cooper 1986	Mixed phase – Cooper 1986
Options for prescribed or predicted CCN or NC	Cirrus deposition – Möhler et al 2006
	Heterogeneous or homogeneous freezing – Liu & Penner 2005

DP-SCREAM Results

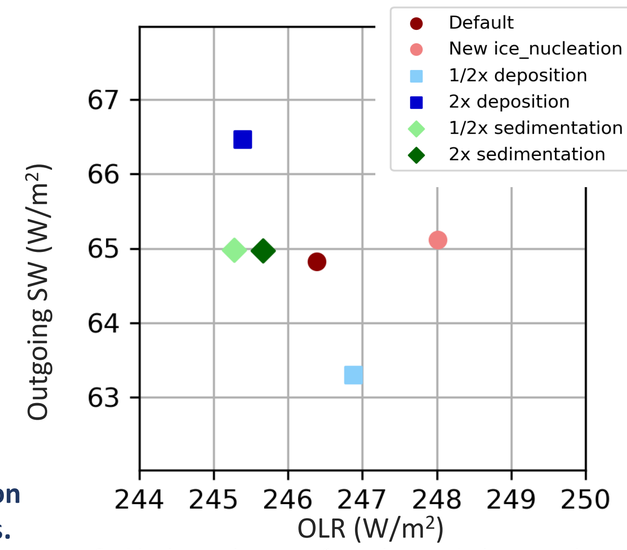
How much does ice microphysics matter for cirrus?

DP-SCREAM

Doubly Periodic version of the Simple Cloud Resolving E3SM Atmosphere Model

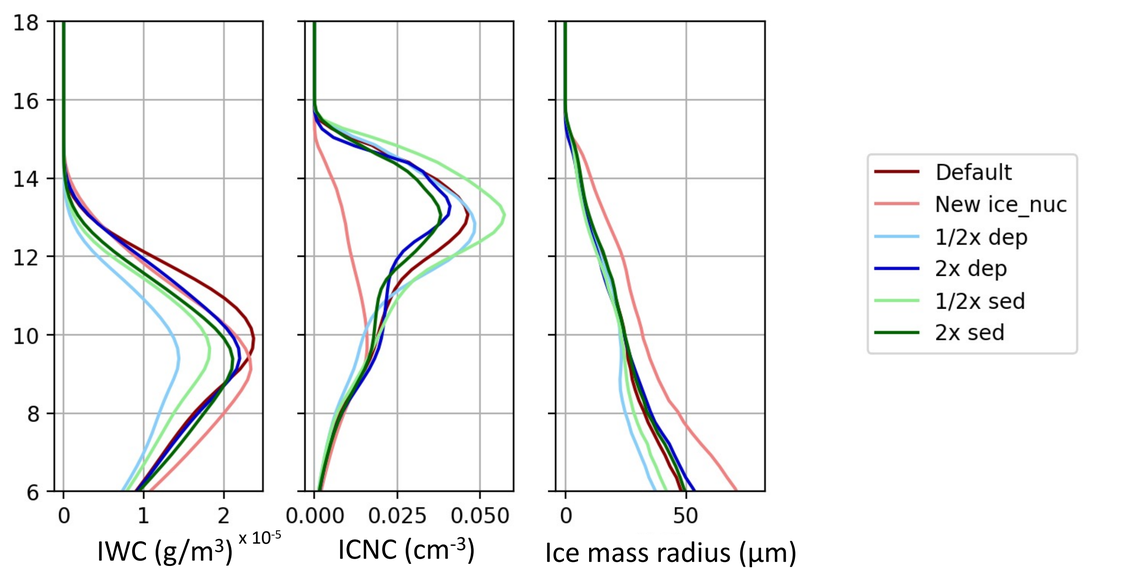
- 3.3 km horizontal resolution
- 100 km square domain
- Explicit convection
- 100 day simulations (last 60 days used for plots)
- Sensitivity of ice sedimentation, vapor deposition, and new freezing scheme

Surprisingly, **vapor deposition affects cirrus clouds more than sedimentation rate** when applied to small ice crystals.

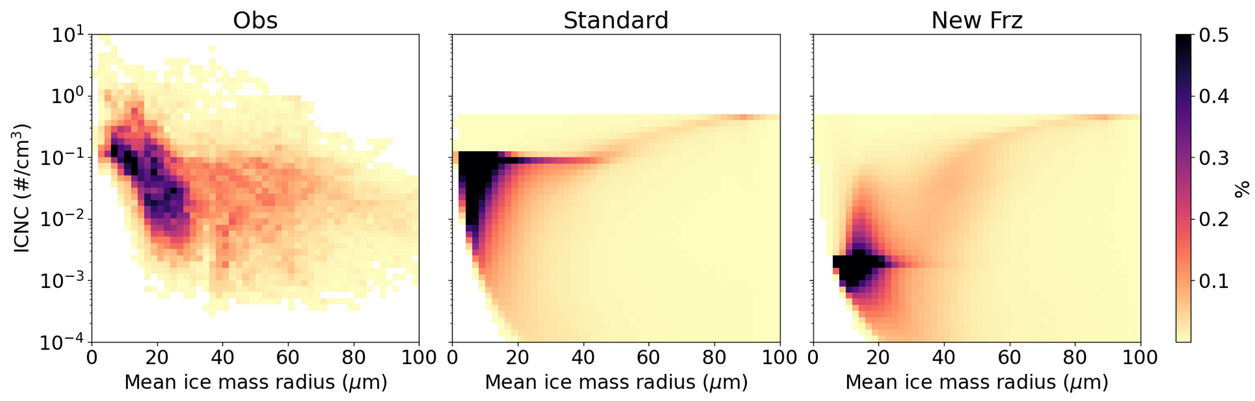


Spatial and temporal mean top-of-atmosphere outgoing longwave and shortwave radiation

Ice Cloud Properties



(left to right) Mean values of ice water content (IWC; g/m3), ice crystal number concentration (ICNC; 1/cm3), ice mass radius (Rice; µm) from 6 to 18 km in height



Joint histogram of ice crystal number concentration (ICNC; #/cm3) and ice mass radius (µm) for observations (left), the default or standard freezing scheme (middle), and the new ice nucleation scheme (right).

While neither parameterizations of ice nucleation capture the observations well, the **new freezing scheme allows for a more natural progression of ice** (reduces the artificial limits of the standard scheme).

Conclusions & Future Work

1. Top of atmosphere radiative fluxes are sensitive to changes in ice microphysical processes for cirrus clouds
2. Cirrus clouds and ice properties are also sensitive to changes in ice microphysics, especially ice crystal number concentration and ice mass radius.

Future work will expand on the sensitivity study and add further complexity to the ice nucleation scheme (option for pre-existing ice). We will also move to 1 km resolution, larger domain, add large scale ascent for more realistic TTL, and add tracers for time since nucleation and time since convection detrainment.

A guiding question:

What processes are crucial to improving the representation of cirrus clouds in storm-resolving models?

Acknowledgements & References

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