Extreme supersaturation in E3SMv1 and CESM2 simulations: sensitivity to time-stepping and impact on model climate

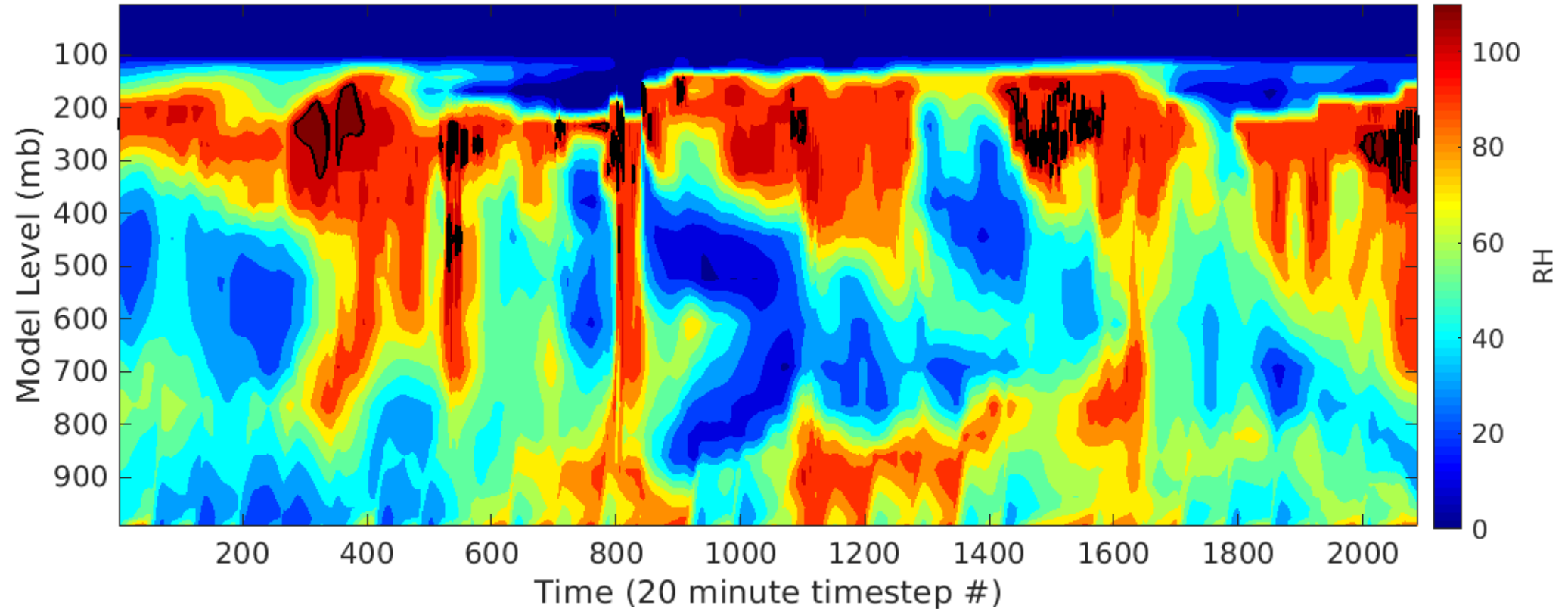Ross D. Dixon[1], Shixuan Zhang[2], Xubin Zeng[1], Hui Wan[2], Madeleine Holland[1]

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Southern Great Plains (ARM97) Single Column Simulation from CESM2

Findings from default configuration of SCAM6 produce extreme supersaturations

Do extreme supersaturations occur in other single column models? Full GCMs?
Are supersaturations sensitive to the timestep and coupling of model components?
Do these extreme supersaturations have an impact on model climate?

SCAM6 Default Configuration

Δt_{model} = 20 min
Δt_{PDC} = 20 min
$\Delta t_{physics}$ = 40 min
Δt_{mac} = 5 min
Δt_{mic} = 10 min

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Sensitivity Experiments

Microphysics, macrophysics, and physics-dynamics coupling have same timestep:
Δt_{mic}= Δt_{PDC}= Δt_{mac}= 5 min, 2 min, and 12 sec

Reduce all timestep sizes proportionally:
Decrease Δt_{PDC}, Δt_{mac}, Δt_{mic} by factors of 2 & 4

Shorten physics-dyamics coupling:
Δt_{mac}= 5 min, Δt_{mic}= 10 min for all simulations, vary Δt_{PDC}= 30, 20, and 10 min

Shorten microphysics timestep:
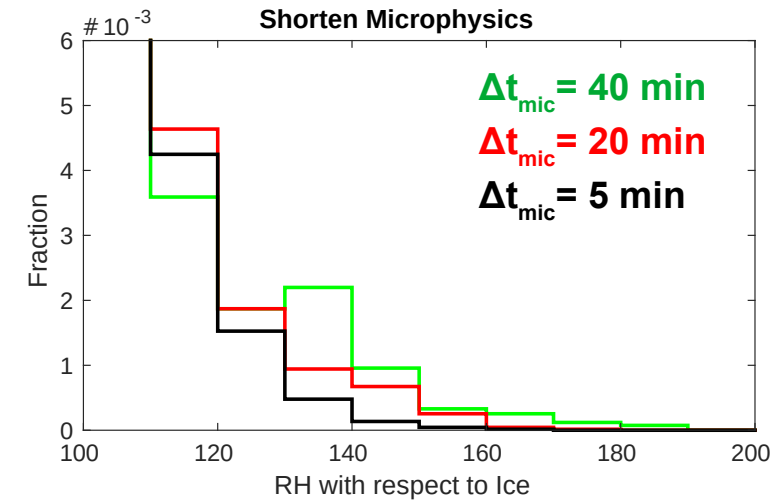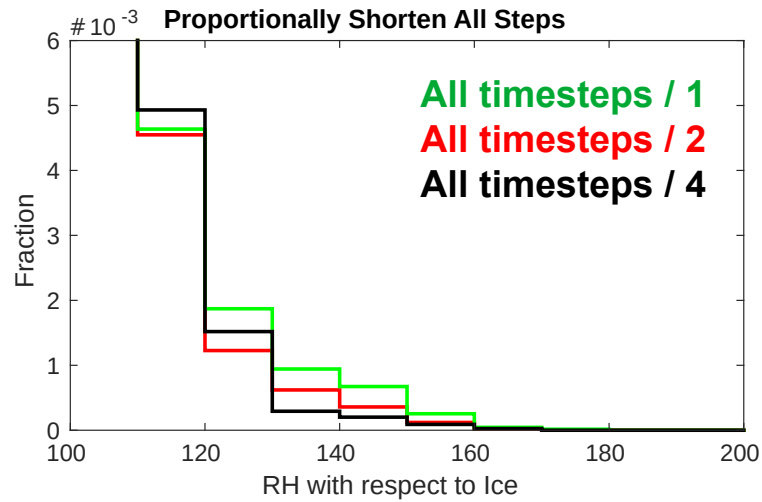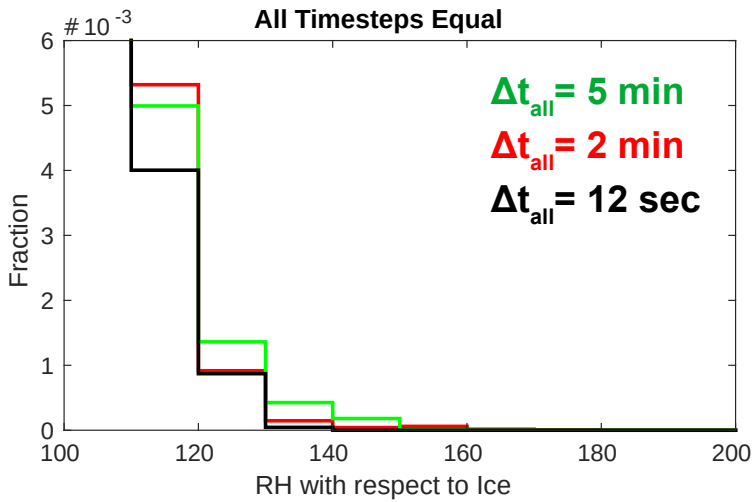Δt_{mac}= 5 min, Δt_{PDC}= 20 min for all simulations, vary Δt_{mic}= 40, 20, and 5 min

Shorten macrophysics timestep:
Δt_{mic}= 5 min, Δt_{PDC}= 20 min for all simulations, vary Δt_{mac}= 5 min, 1 min, and 1 sec

SCM experiments in CESM2

All Timesteps Equal

Δt_{all}= 5 min
Δt_{all}= 2 min
Δt_{all}= 12 sec

Proportionally Shorten All Steps

All timesteps / 1
All timesteps / 2
All timesteps / 4

Shorten Microphysics

Δt_{mic} = 40 min
Δt_{mic} = 20 min
Δt_{mic} = 5 min

Shorten Physics-Dynamics Coupling

Δt_{PDC}= 30 min
Δt_{PDC}= 20 min
Δt_{PDC}= 10 min

Shorten Macrophysics

Δt_{mac}= 5 min
Δt_{mac}= 1 min
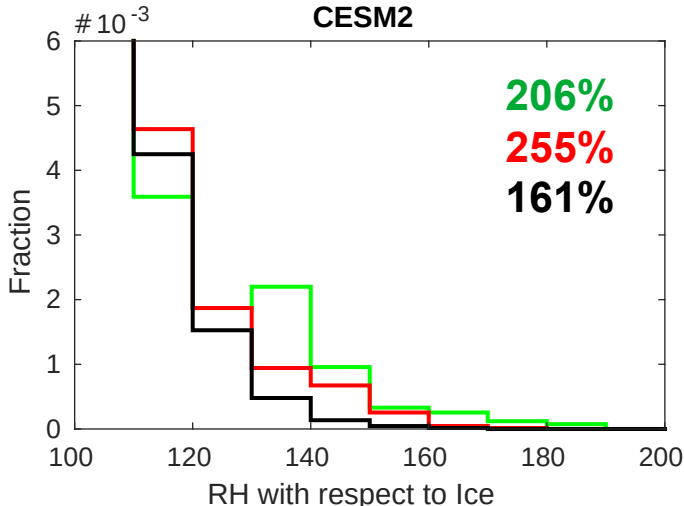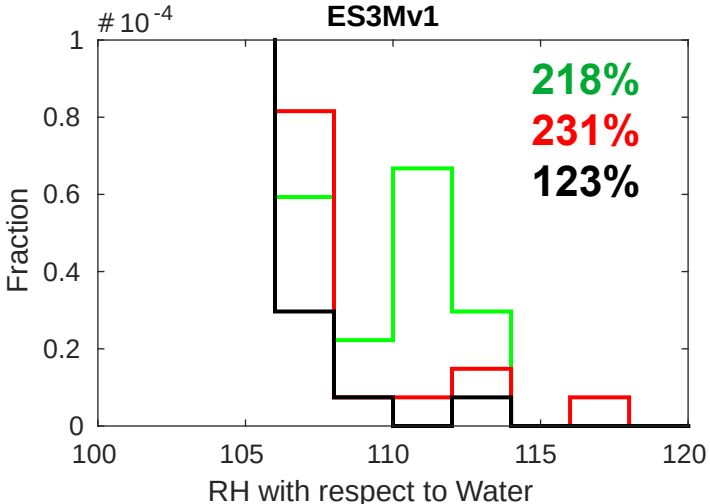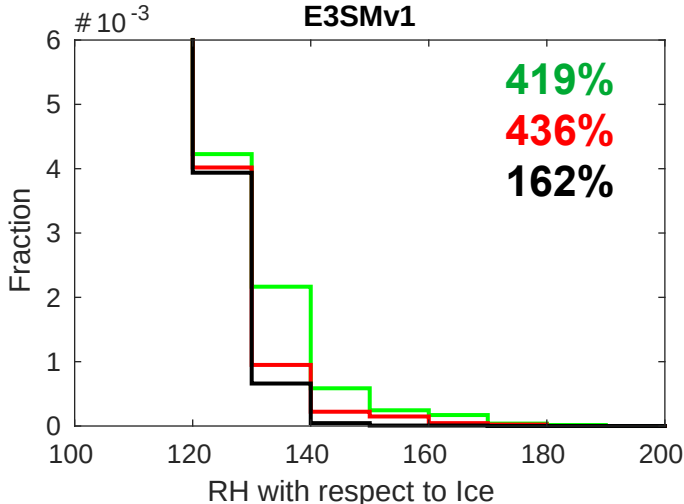Δt_{mac}= 1 sec
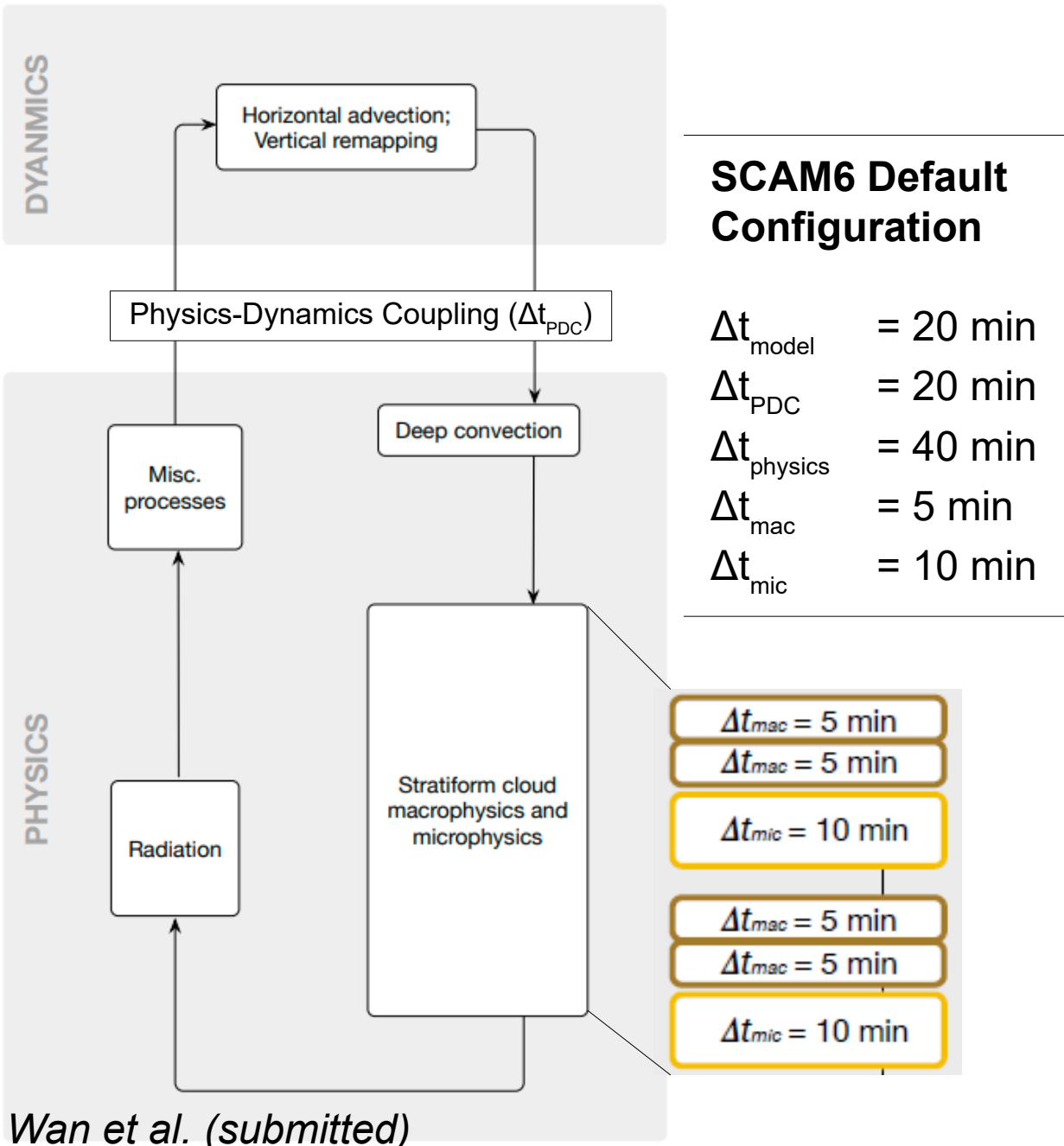
Reducing timesteps reduces the extreme values of supersaturation

Reducing the microphysical timestep results in the strongest decrease in extreme supersaturation

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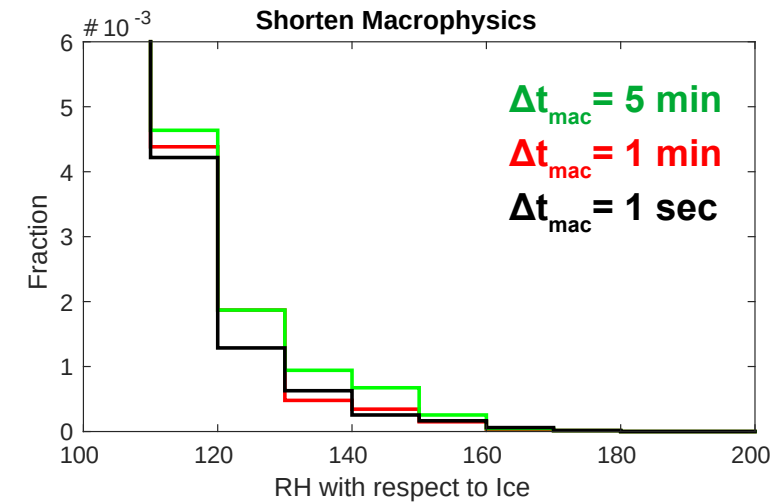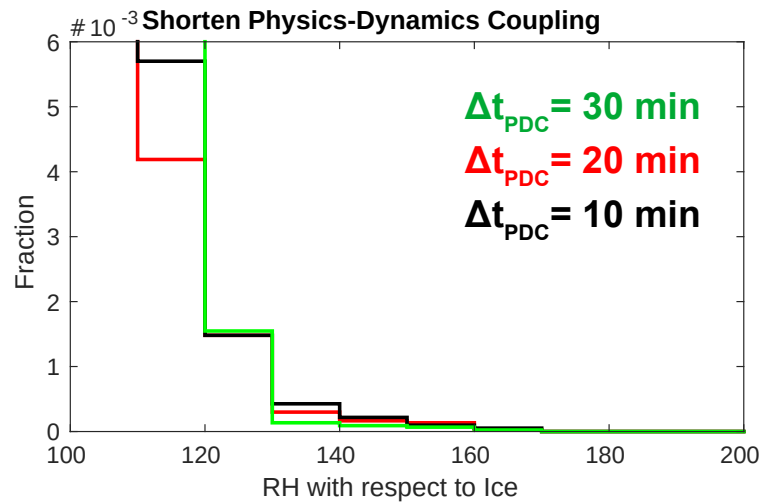
SCM experiments in E3SMv1

**Δt$_{mic}$= 40 min**   **Δt$_{mic}$= 20 min**   **Δt$_{mic}$= 5 min**
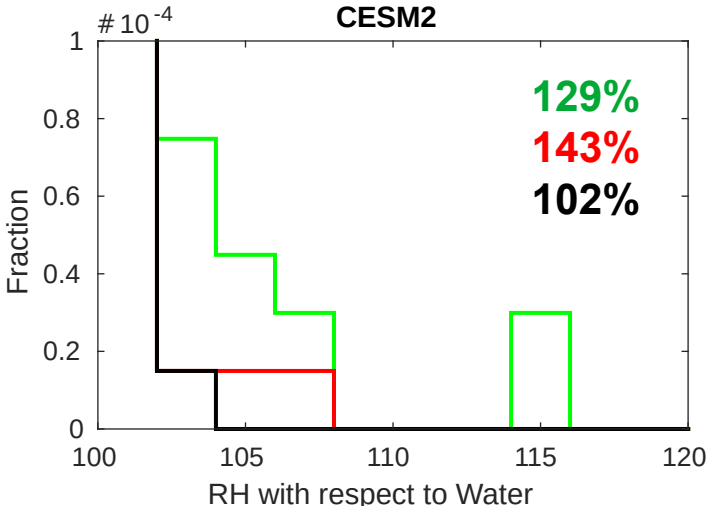
Reducing the microphysical timestep results in a decrease in extreme RH in both E3SMv1 and CESM2

E3SMv1 produces less extreme RH with respect to ice, but more extreme RH with respect to water
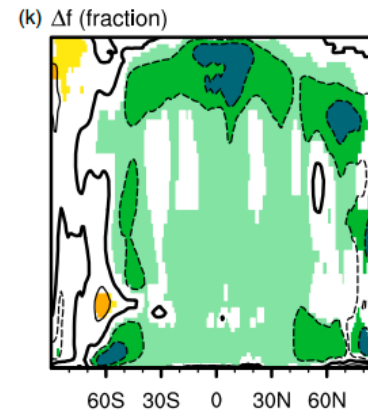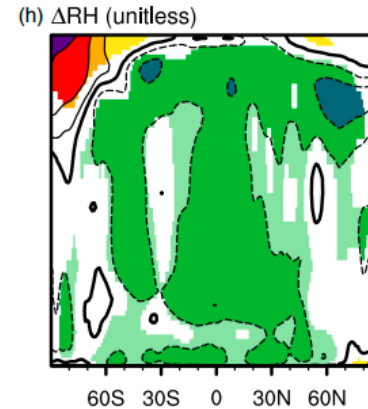
The importance of micro-macro physical timestep in E3SMv1

Changes in upper level RH and cloud fraction in full E3SMv1 simulations where all timesteps are shortened are primarily due to the shortening of the micro and macrophysics timestep
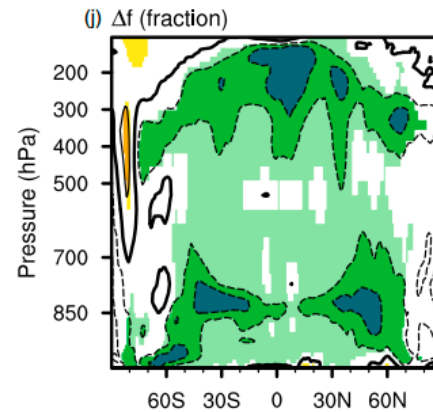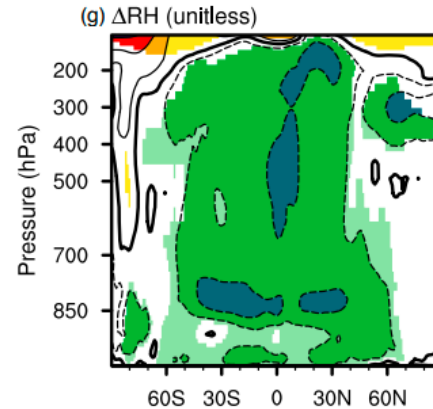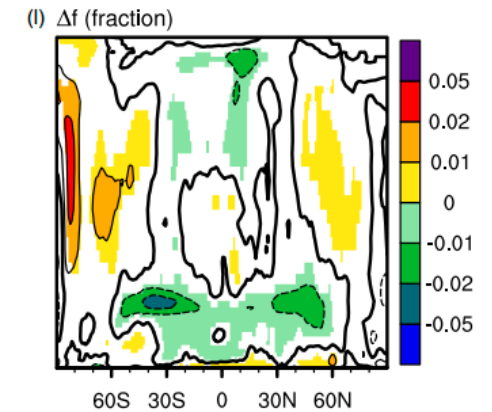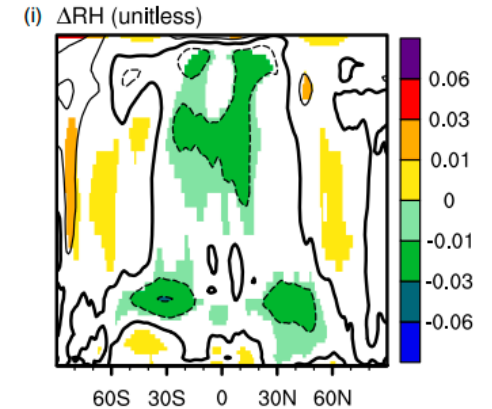

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E3SMv1 – Global Simulations: Δt_{PDC} = 30 min, Δt_{mac} = 5 min, Δt_{mic} varies
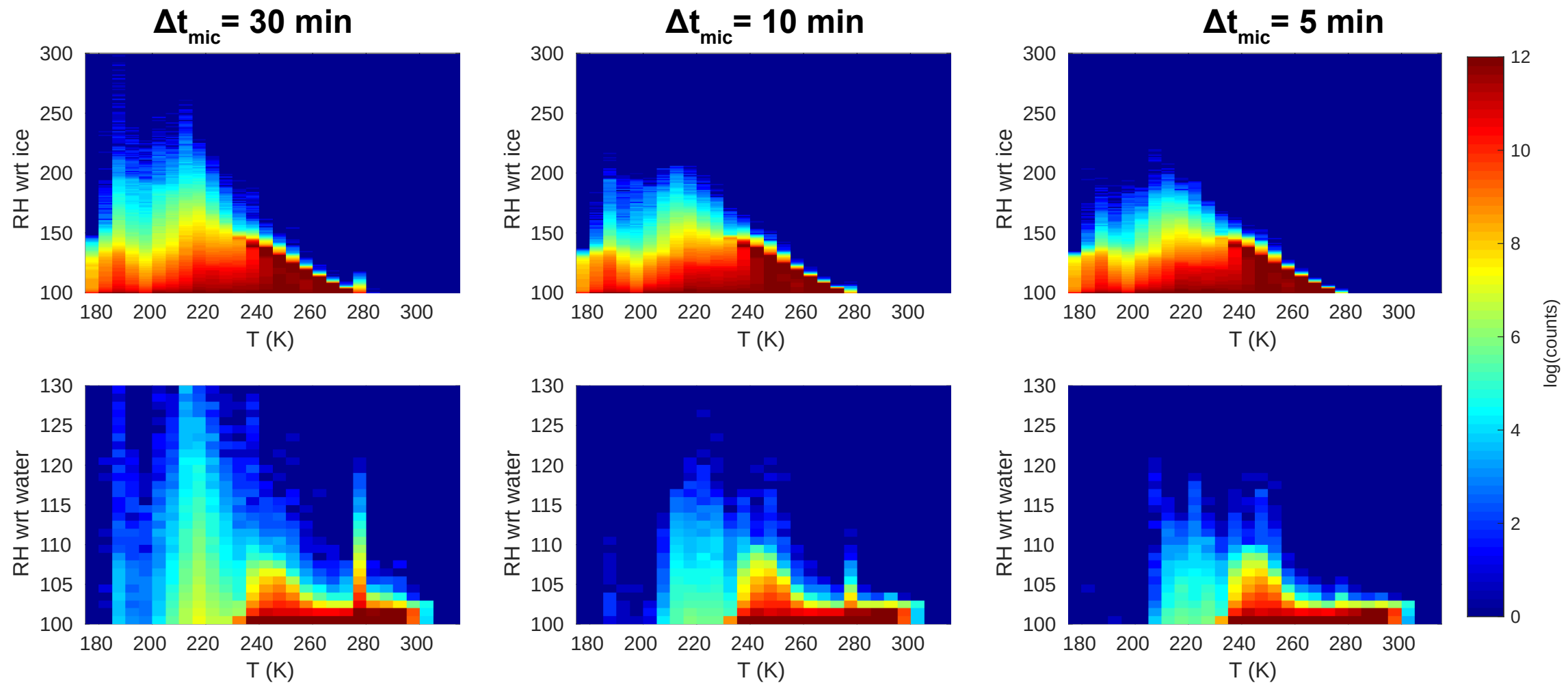
Five day simulations with timestep output (output from last 3 days used)
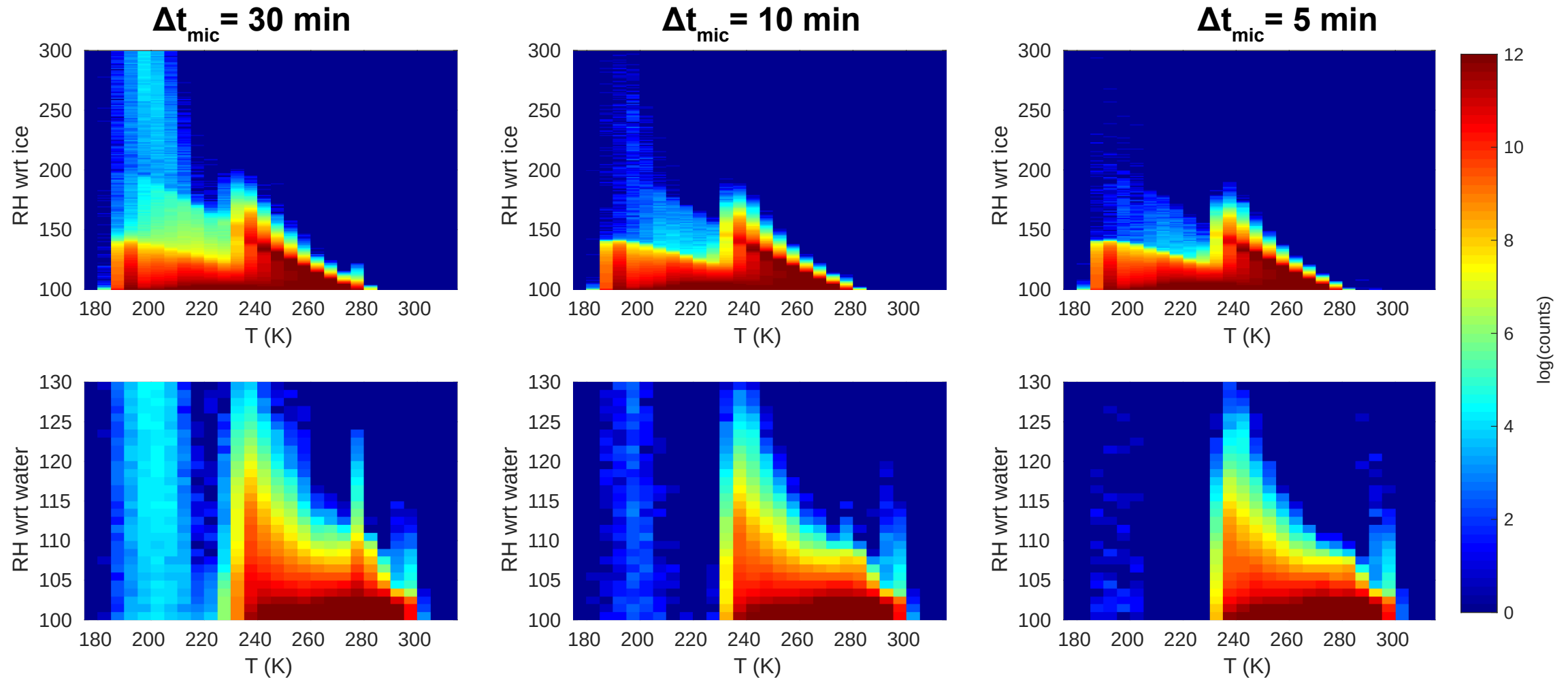
Supersaturation distribution sensitive to model timestep and thresholds of physical processes (i.e. freezing (273K), homogeneous nucleation (233K))

# CESM2 – Global Simulations: Δt_{PDC} = 30 min, Δt_{mac} = 5 min, Δt_{mic} varies

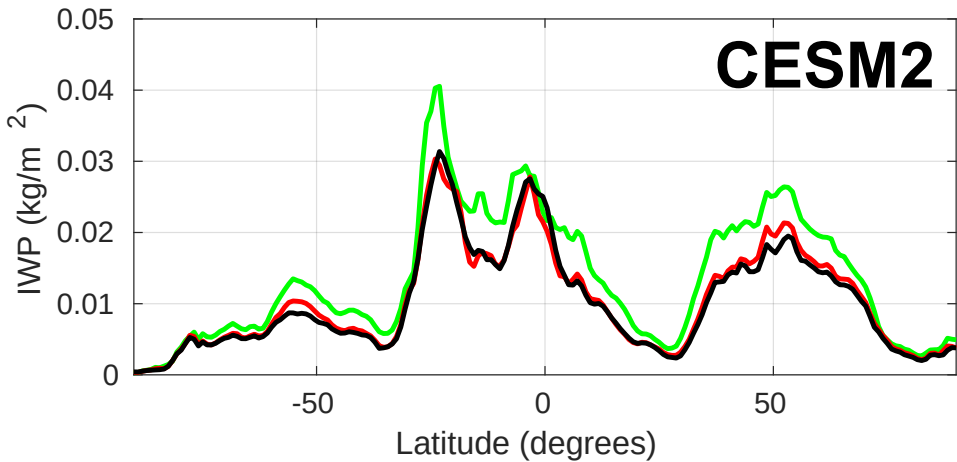Five day simulations with timestep output (output from last 3 days used)
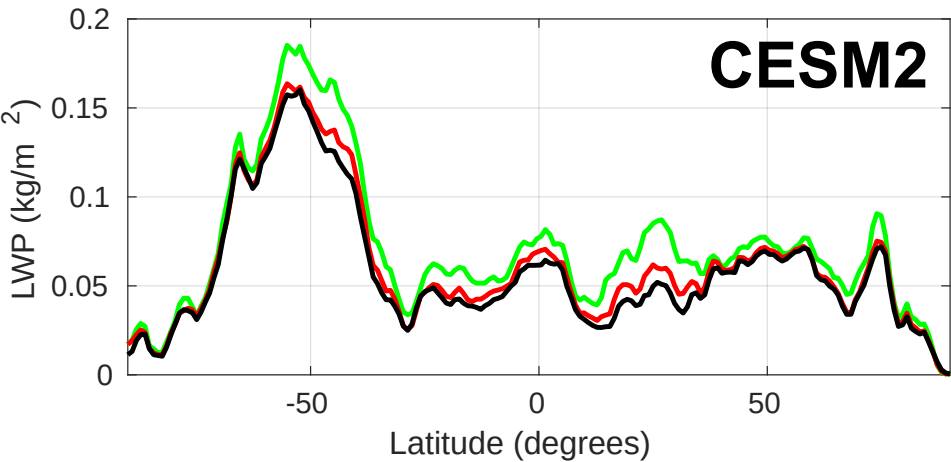

CESM2 and E3SMv1 differ in the distribution of supersatuations

In the global models, what is the impact of decreasing the microphysical timestep from 10 minutes to 5 minutes?

Zonally Averaged Liquid Water Path (LWP) — E3SMv1

Zonally Averaged Ice Water Path (IWP) — E3SMv1
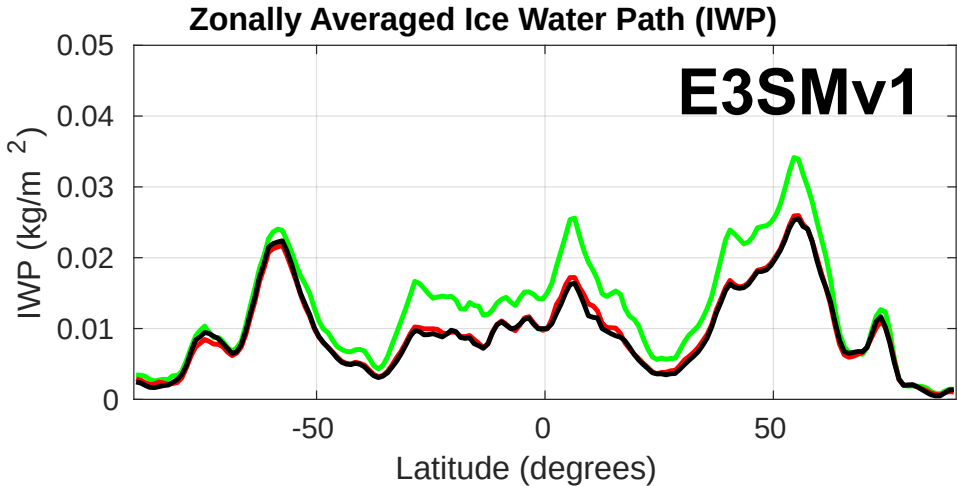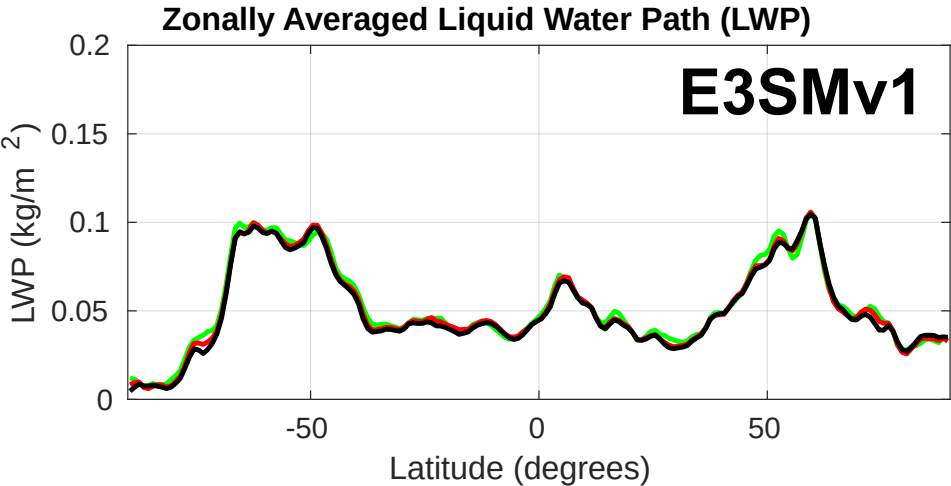
CESM2
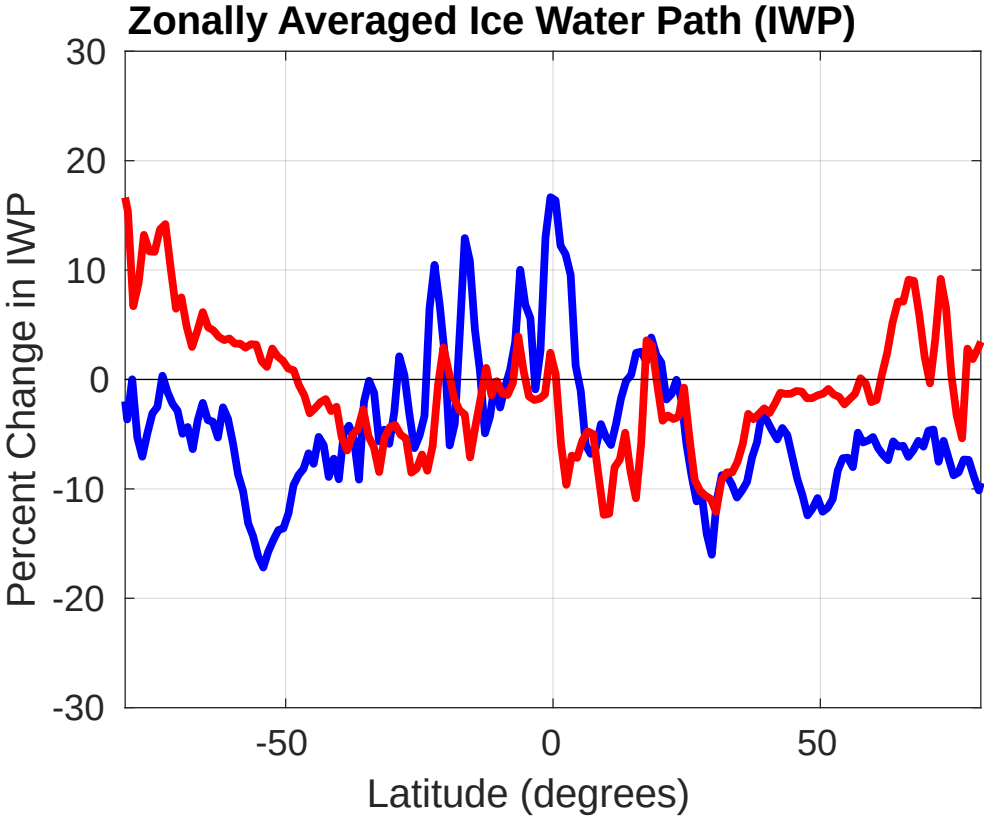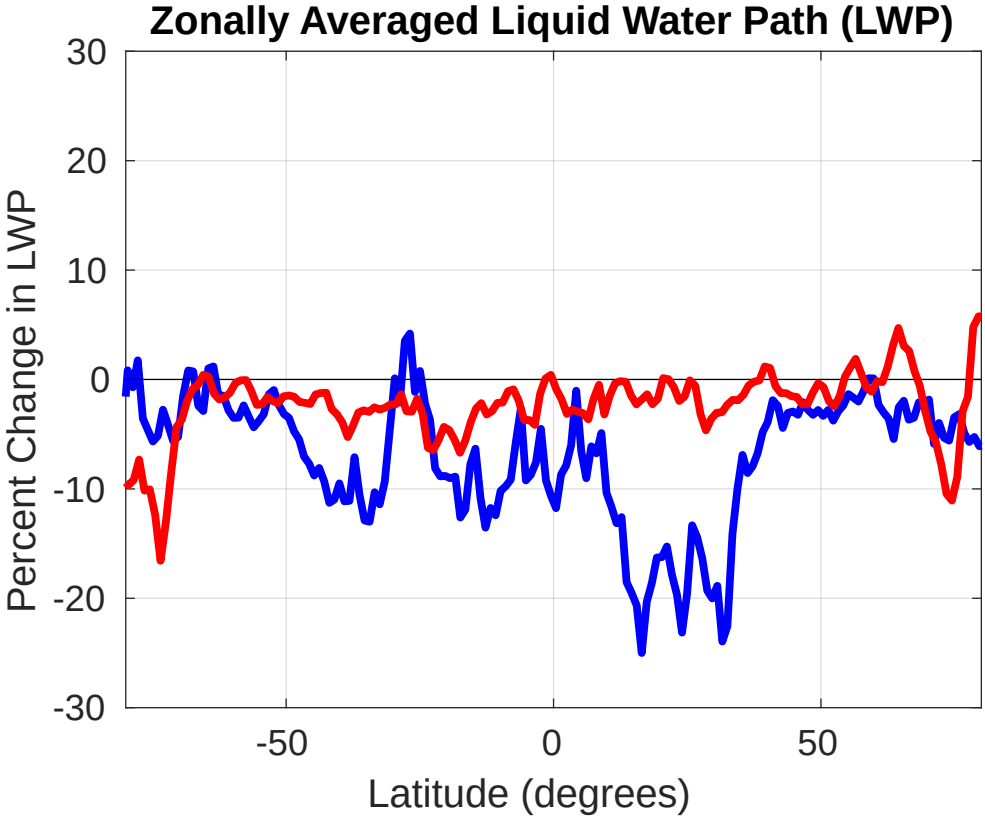
CESM2

Δt_{mic} = 30 min

Δt_{mic} = 10 min

Δt_{mic} = 5 min

In the global models, what is the impact of decreasing the microphysical timestep from 10 minutes to 5 minutes?

Zonally Averaged Liquid Water Path (LWP) and Zonally Averaged Ice Water Path (IWP) for E3SMv1 (red) and CESM2 (blue).

Extreme supersaturations occur in both SCM and full GCMs.

        RH above 110% wrt water and above 150% wrt ice occurs in
                both E3SMv1 and CESM2

Supersaturations are sensitive to the choice of model timesteps.

        Supersaturation is particularly sensitive to shortening the
                microphysical timestep indicating the importance of micro-
                macrophysics coupling

Supersaturations are sensitive to the choices of how physical processes are represented.

        For example, phase transitions at freezing and homogeneous nucleation

Extreme RH may have an impact on model climate.