# The Impact of Predator-Prey Processes in Bulk Microphysics Schemes on Simulated Aerosol-Cloud Interaction

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## Introduction

In bulk microphysics schemes, the interaction of microphysical processes is somewhat analogous to an ecological predator-prey system. For example, in the presence of rain, ice and snow, supercooled cloud water might be “consumed” by rain via accretion to form larger raindrops, or by ice or snow to form graupel or snow.

The evolution of each hydrometeorological species depends on the growth rate of the individual microphysical processes, which in turn is dependent upon the meteorological environment, the process formulation, and the assumed parameters that describe the species, such as particle size distribution.

The aerosol content of an air parcel is known to influence the lifetime and evolution of clouds.

We investigate the impact of varying the aerosol content on two microphysics parameterizations in the WRF model. The schemes used are the Thompson and Morrison parameterizations.

## The Aerosol Scheme

The Thompson microphysics scheme in WRF includes an option for aerosol interaction with microphysical processes.  For a fair comparison of the Thompson and Morrison schemes, the Thompson aerosol code was implemented in the Morrison microphysics parameterization.
This method includes:

- Prediction of number concentration for cloud water (Nc)
- Prediction of number concentration of two aerosol types: “water-friendly” and “ice-friendly”
- Default initial profiles of aerosols, dependent on height
- Sources and sinks of the aerosols include activation, wet scavenging and restoration of the available aerosols if evaporation takes place
- Pre-calculated lookup tables of activated fraction of aerosols, based on temperature, vertical velocity, aerosol availability, a specified hygroscopicity parameter, and aerosol radius

**Two idealized cases were used to study the impact of varying aerosol concentrations in the aerosol-aware Thompson and Morrison schemes: a 2d squall line and a shallow convection case.**

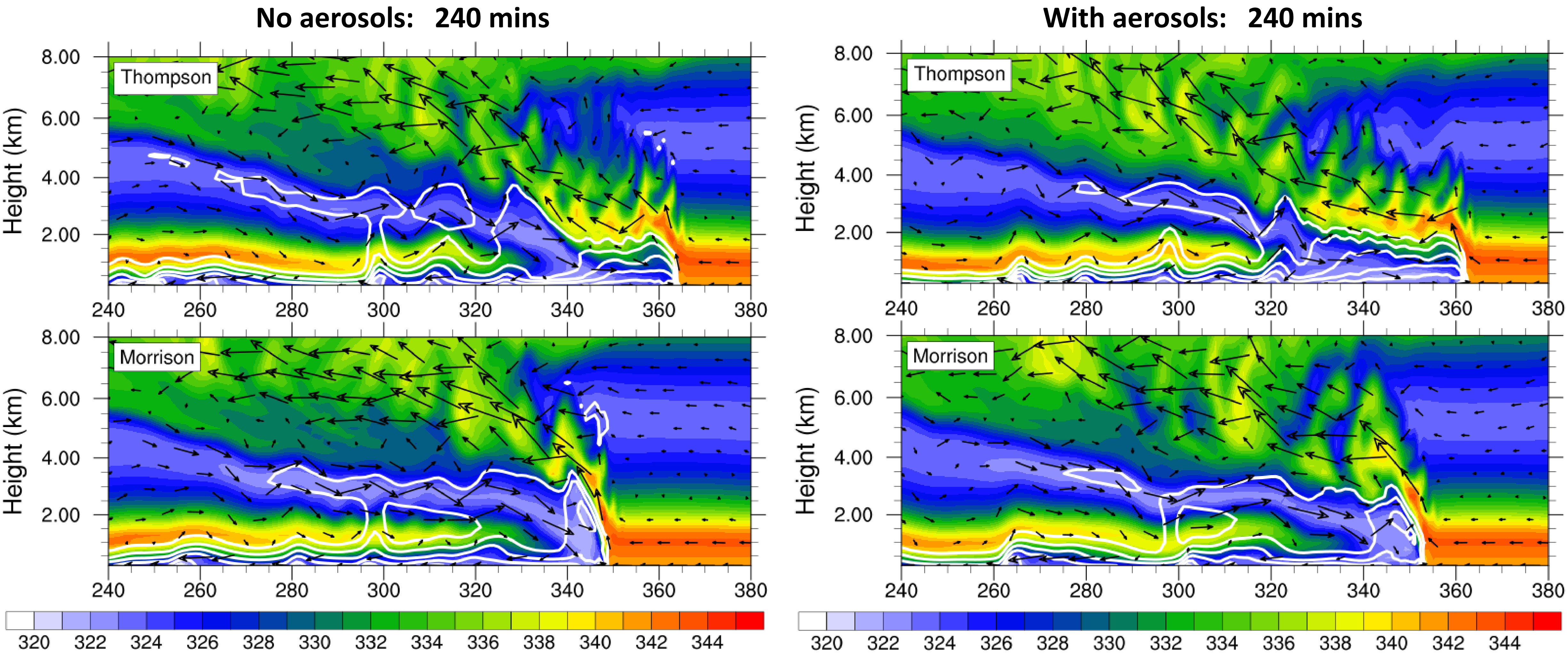
## 2d Squall line Case

$\Delta x$ = 1 km, dt = 3 s, 80 levels, model top at 20 km

Convection is initiated by adding a thermal with maximum perturbation potential temperature of 3K centered at a height of 1.5 km and varying as the cosine squared to the perturbation edge. The thermal has a horizontal radius of 4 km and a vertical radius of 1.5 km.

Both warm- and cold-rain processes are present after just 5 minutes.

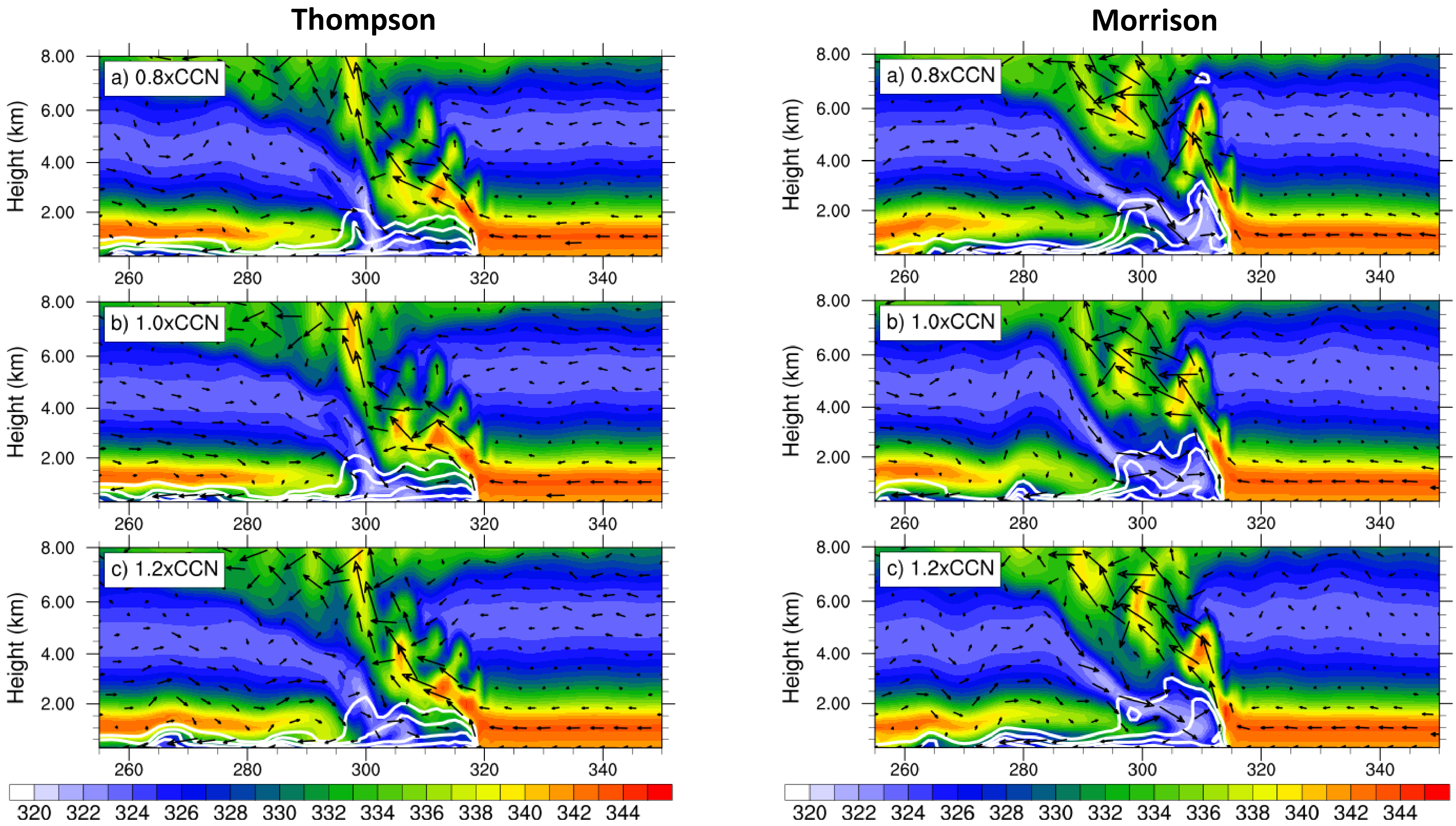
# Squall Line Case: Gust Front Propagation



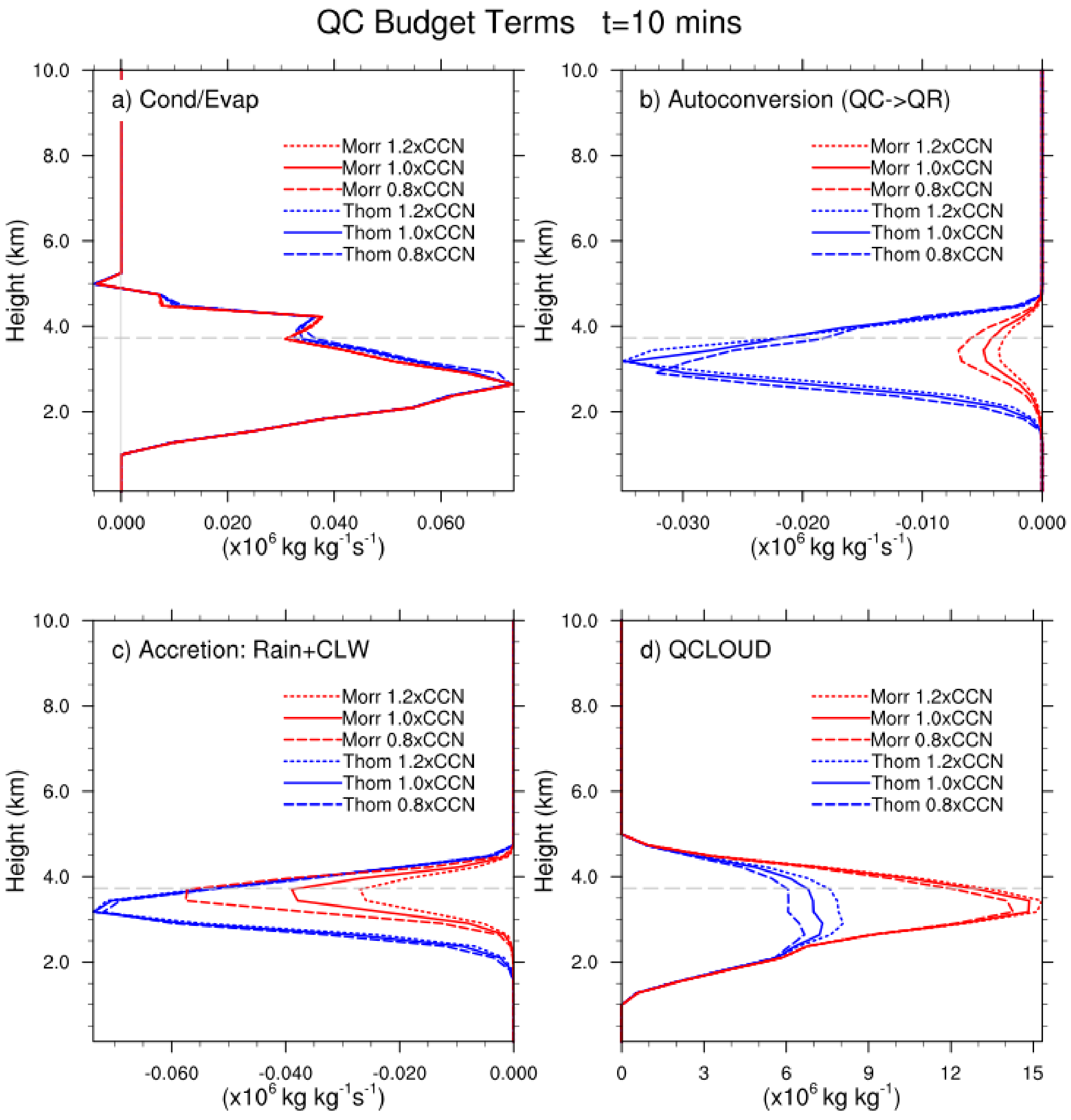

**Θe (colored), Θ' (white), vectors**

**Thompson case is slightly slower with aerosols; Morrison case is faster with aerosols**

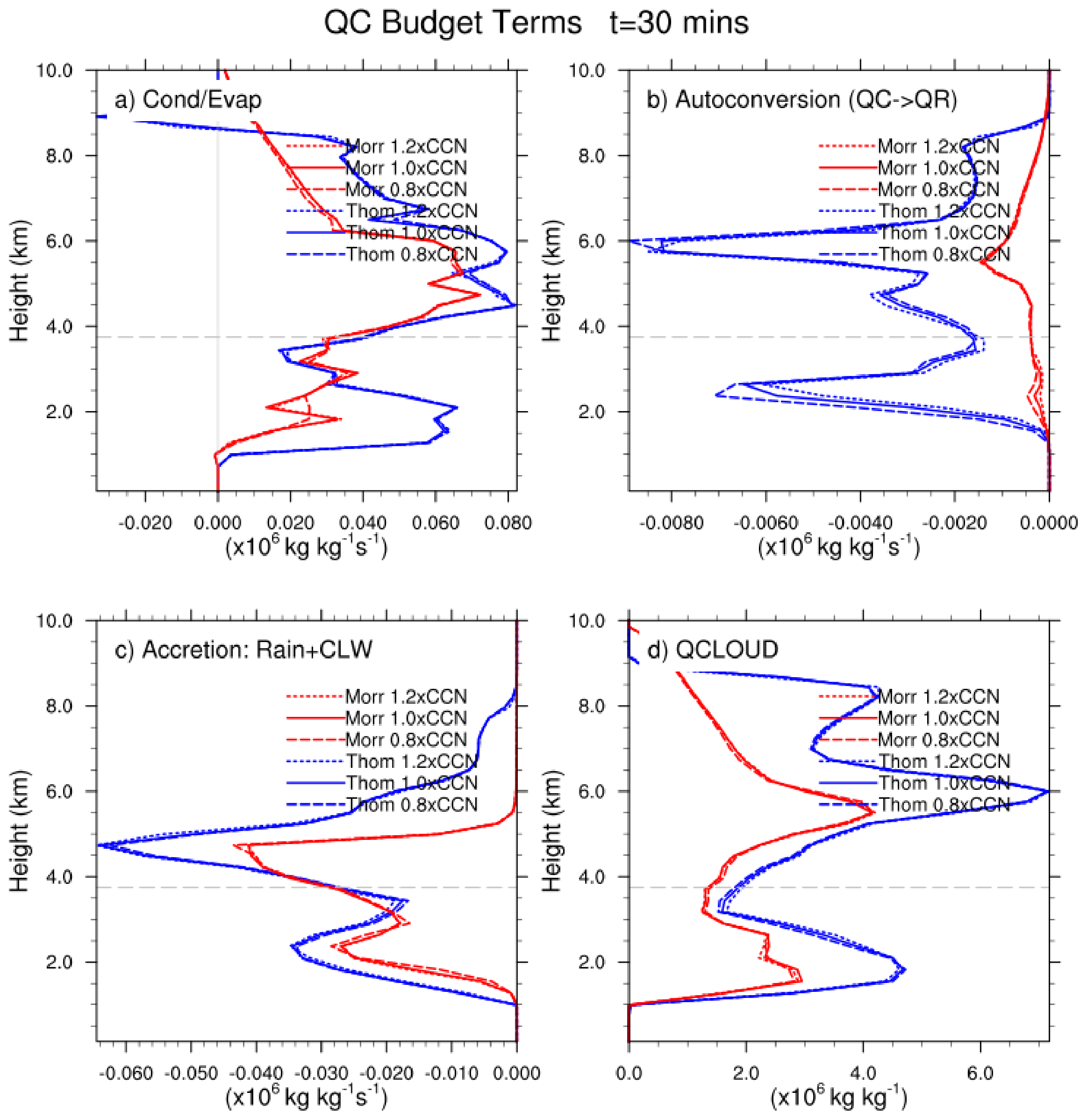
# Impact of varying initial aerosol content on squall line propagation



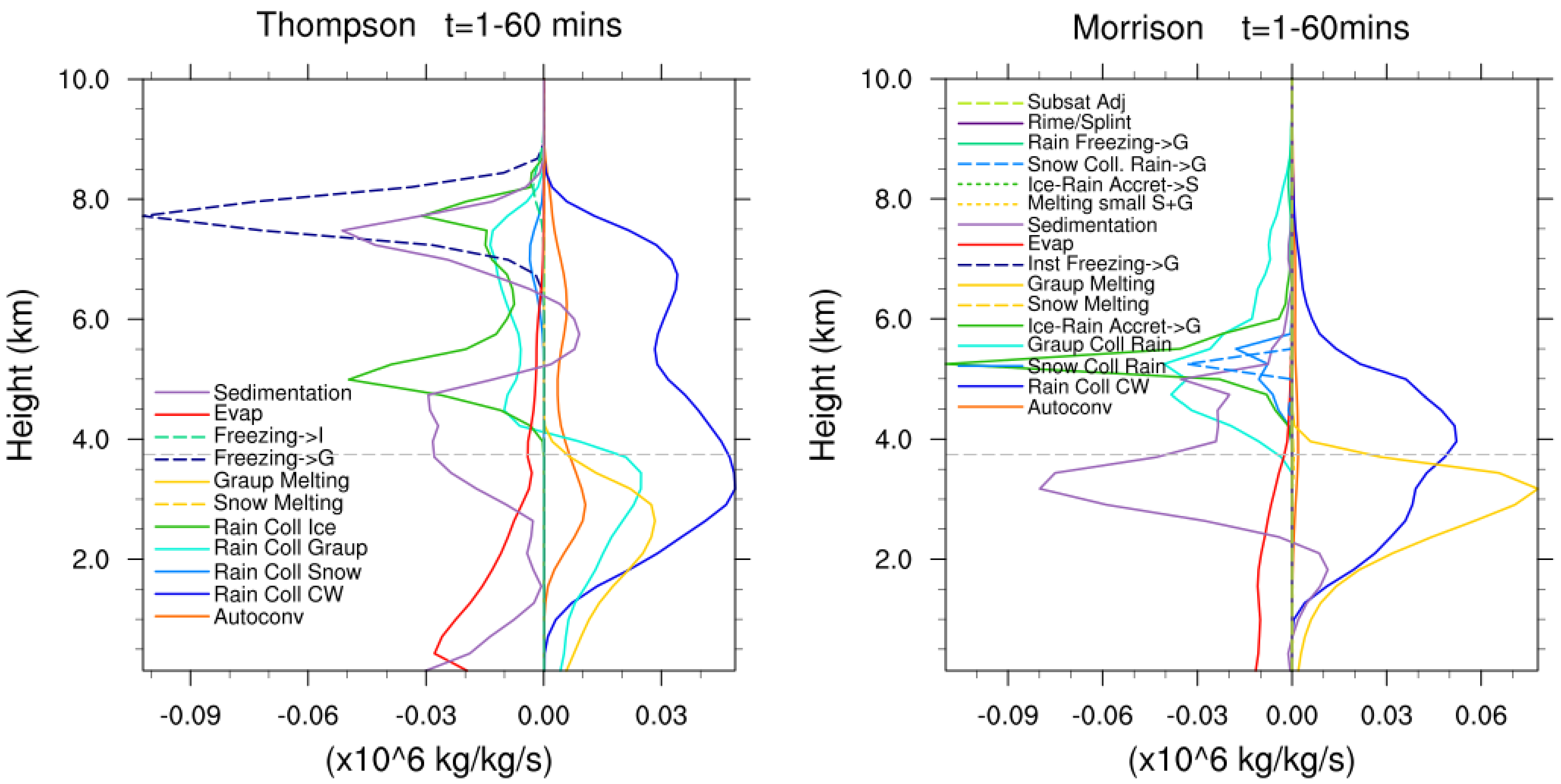

**Θe (colored), Θ′ (white), vectors t=120mins**




Thompson scheme converts cloud water to rain more quickly than the Morrison scheme initially.

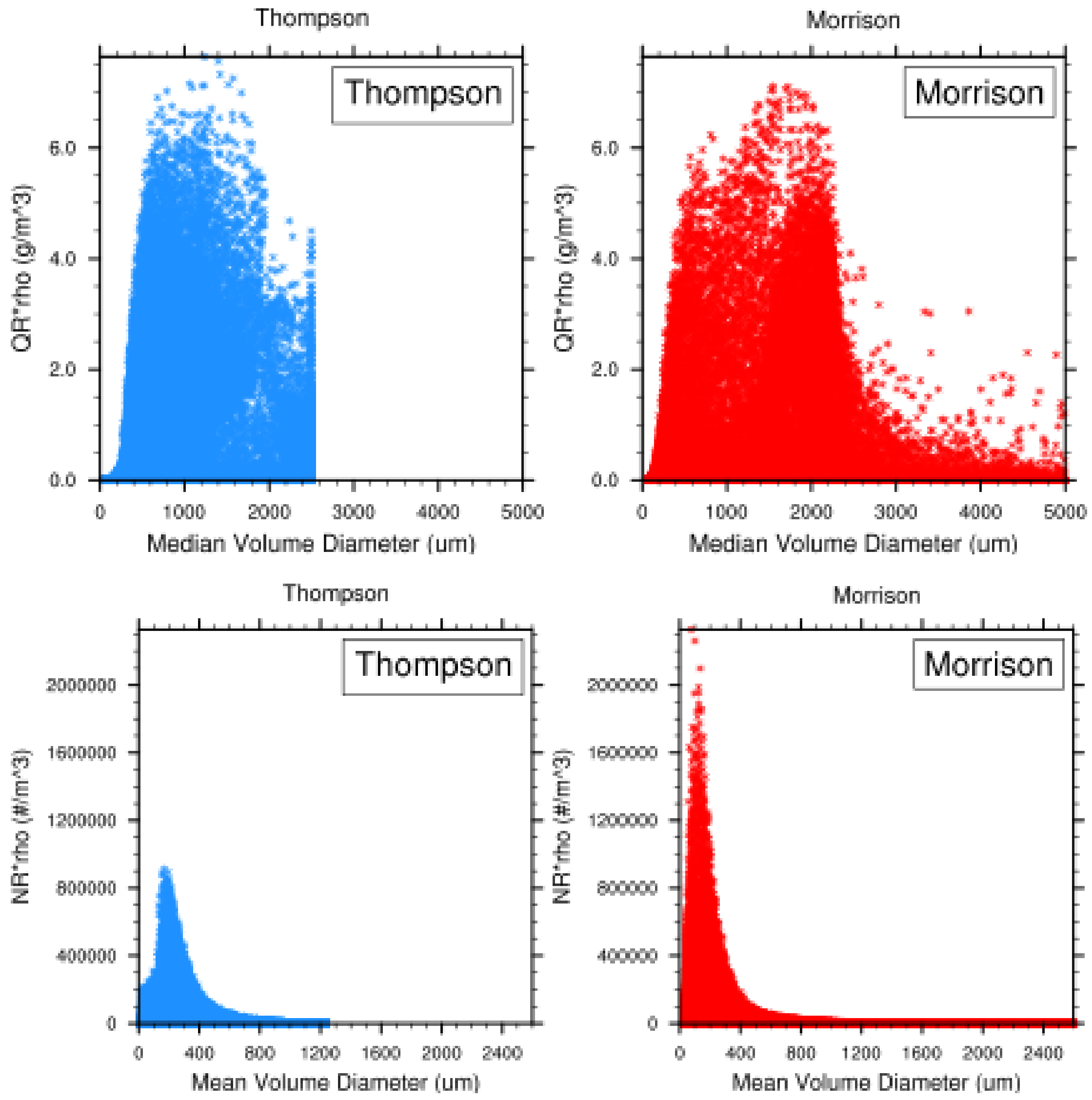



There is more difference between the schemes than between the runs with varying aerosol load.




Microphysical budget analysis for rain production in the two schemes during the first hour of the squall line simulations (time averaged). More evaporation of rain in the Thompson scheme enhances the low-level cooling and therefore the squall line propagation.

# Rain Drop Size Distributions




Differences in rain drop size distributions between the schemes.

Results are for the control (1*aer) runs and include all grid points with rain during the first two hours of the simulation.

Experiments with differing aerosol load showed very similar size distributions (not shown).

## 3d Shallow Convection Case

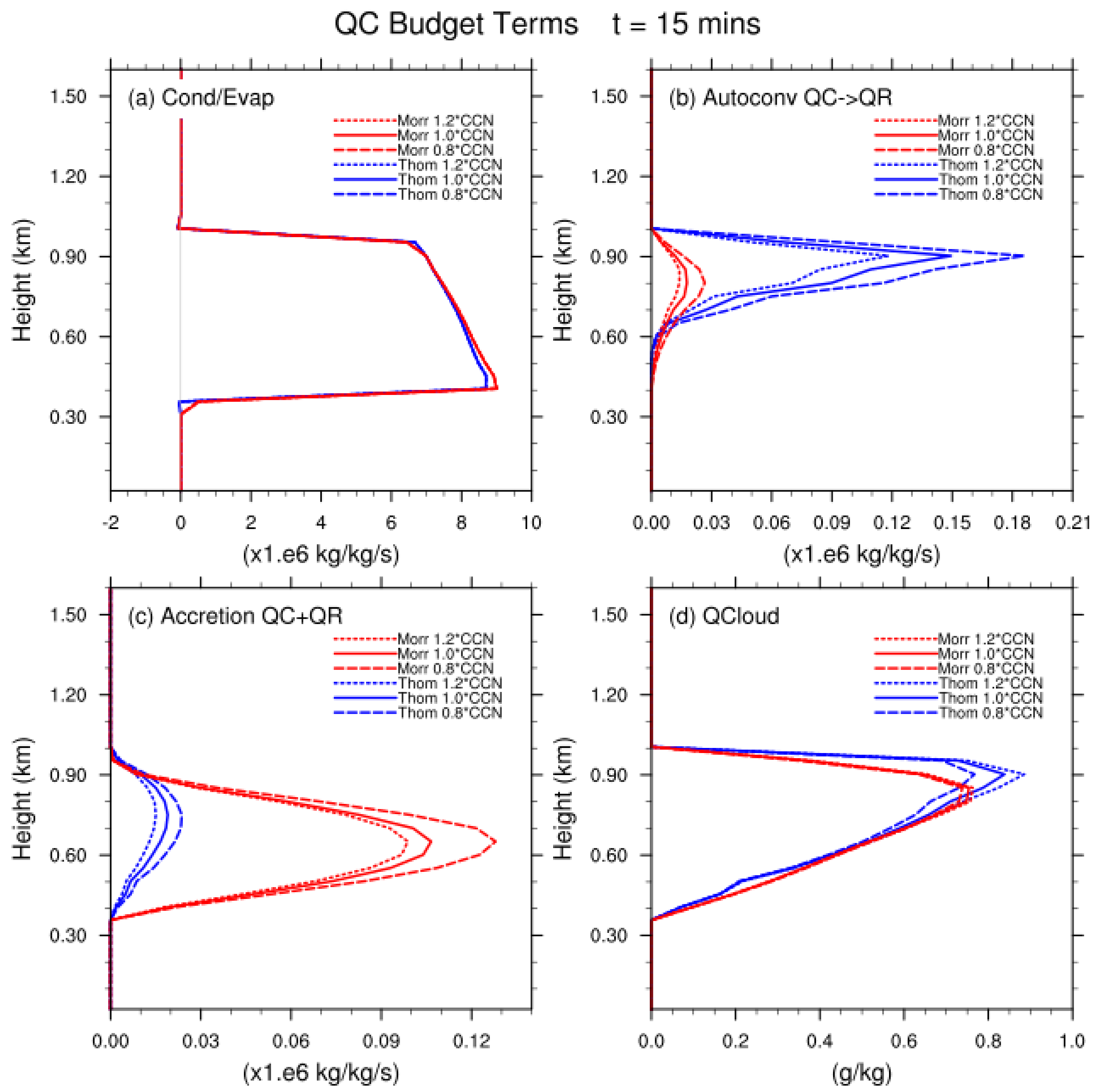
$\Delta x = \Delta y = 100$ m, $\Delta z = 50$m, dt = 1 s, 40 levels, model top at 2 km

Large-eddy simulation setup

Initialized with a sounding with warm SST below cooler air, u=10 m/s

Produces a shallow cloud layer capped by a strong inversion that grows in response to the warm SSTs.

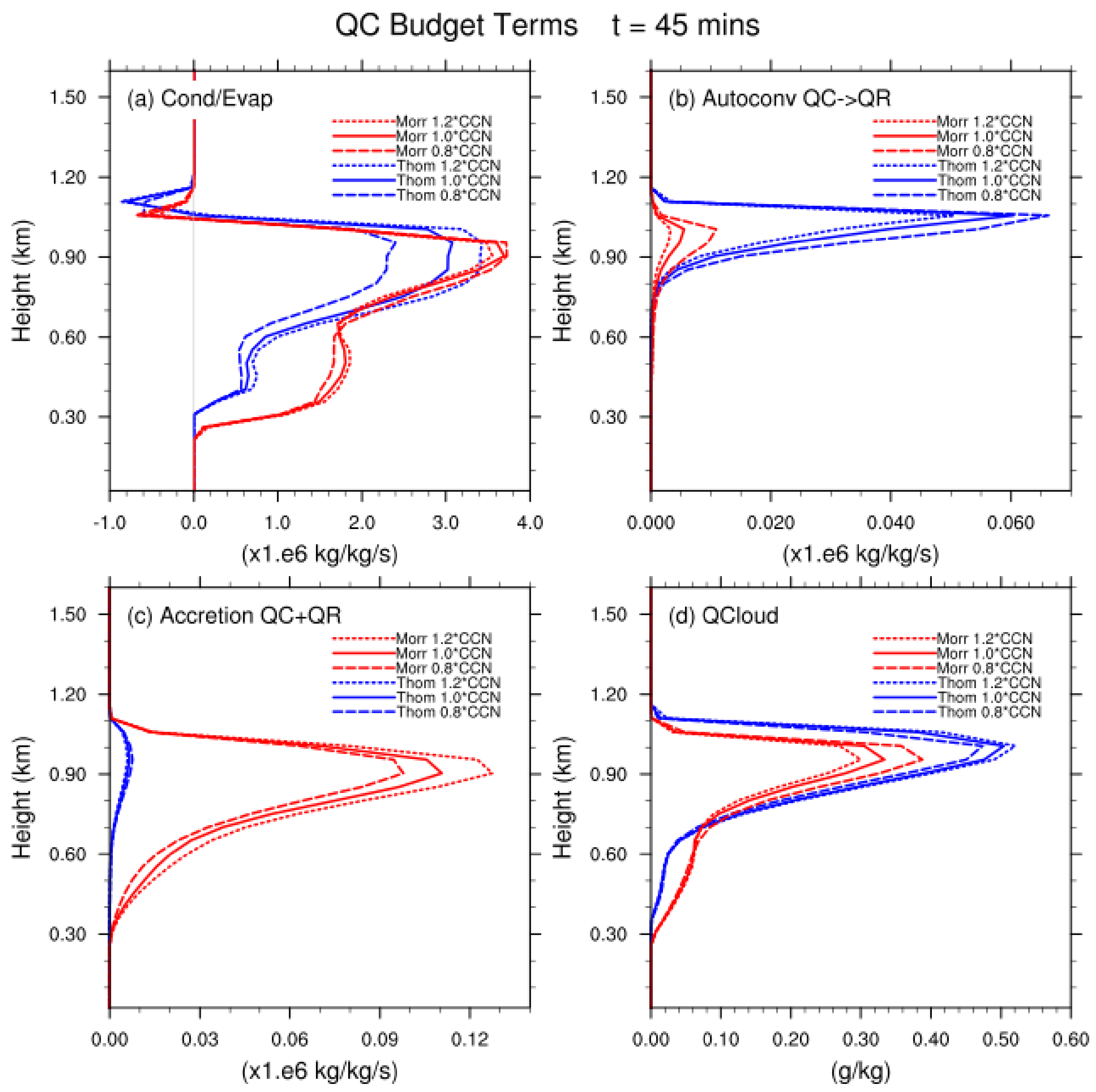
Warm-rain only, no frozen microphysical processes involved




# Shallow convection case: Domain-averaged Budget Terms for Cloud Water

At 15 minutes:

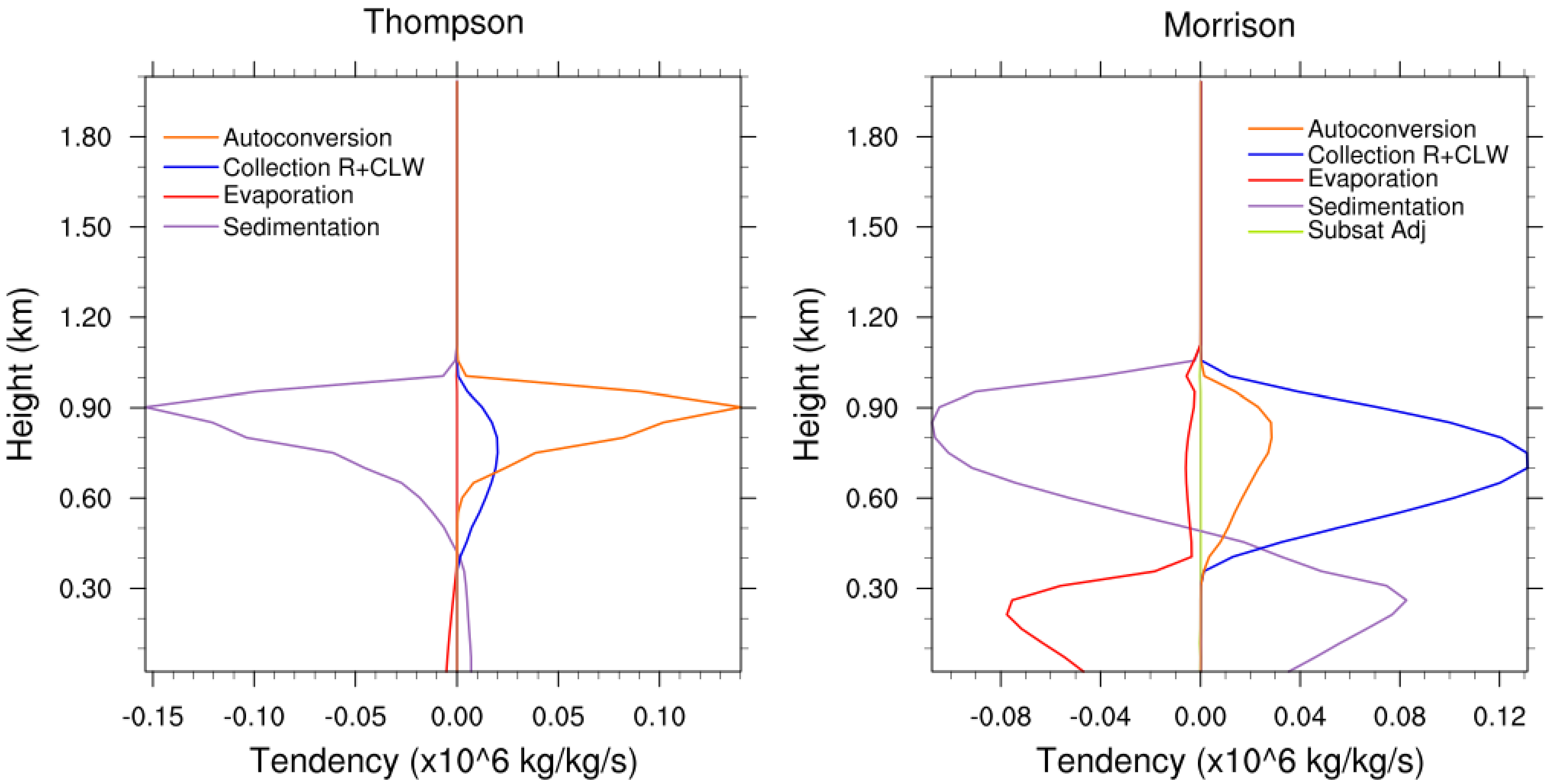
- Thompson runs have more autoconversion, less accretion than Morrison runs.
- Condensation is similar at early times, and is by far the largest term.
- Runs with 20% lower aerosol have higher rates of autoconversion and accretion, resulting in slightly less cloud water.



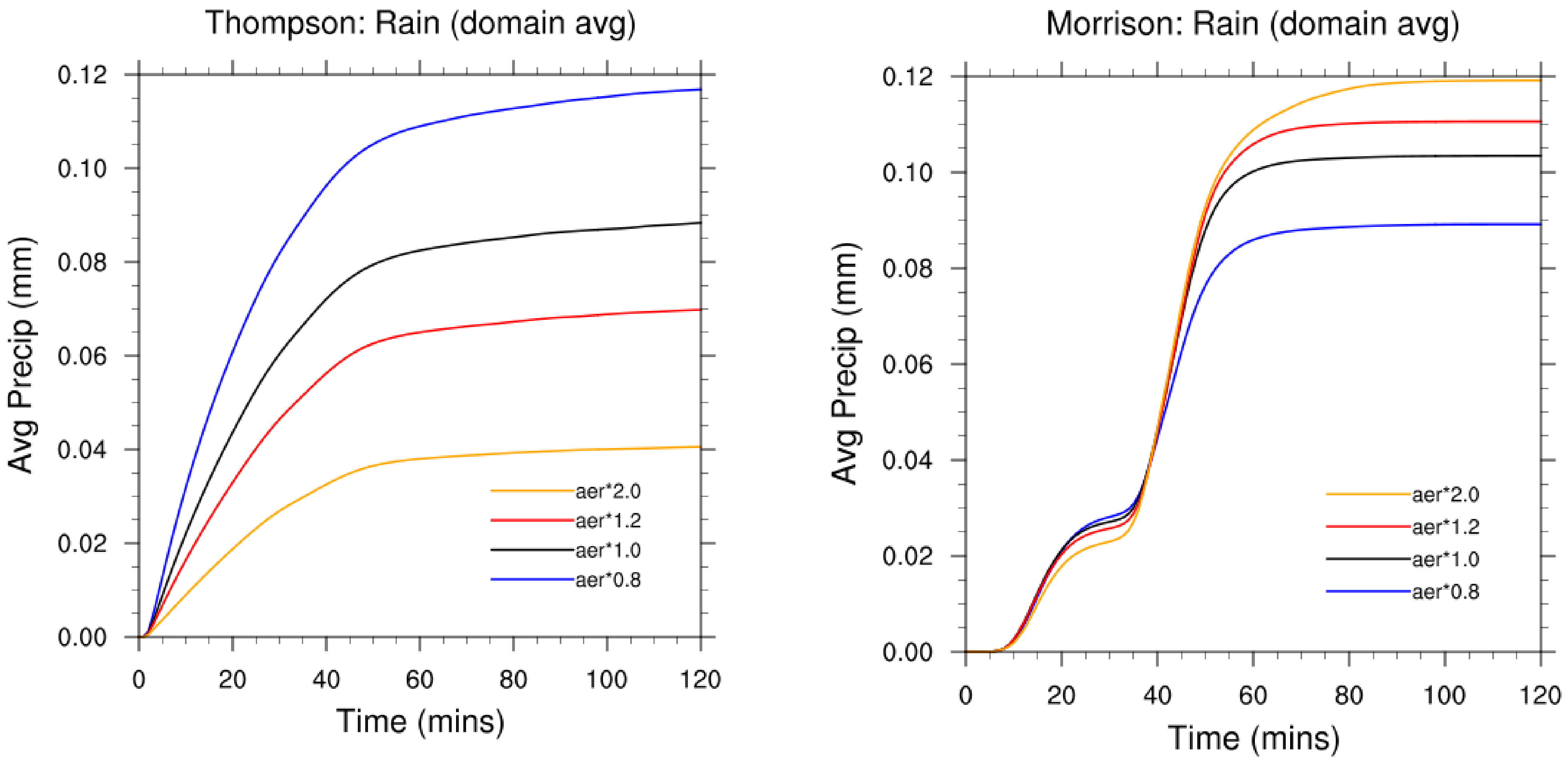

# Shallow Convection Case: Domain-averaged Budget Terms for Cloud Water

By 45 mins:

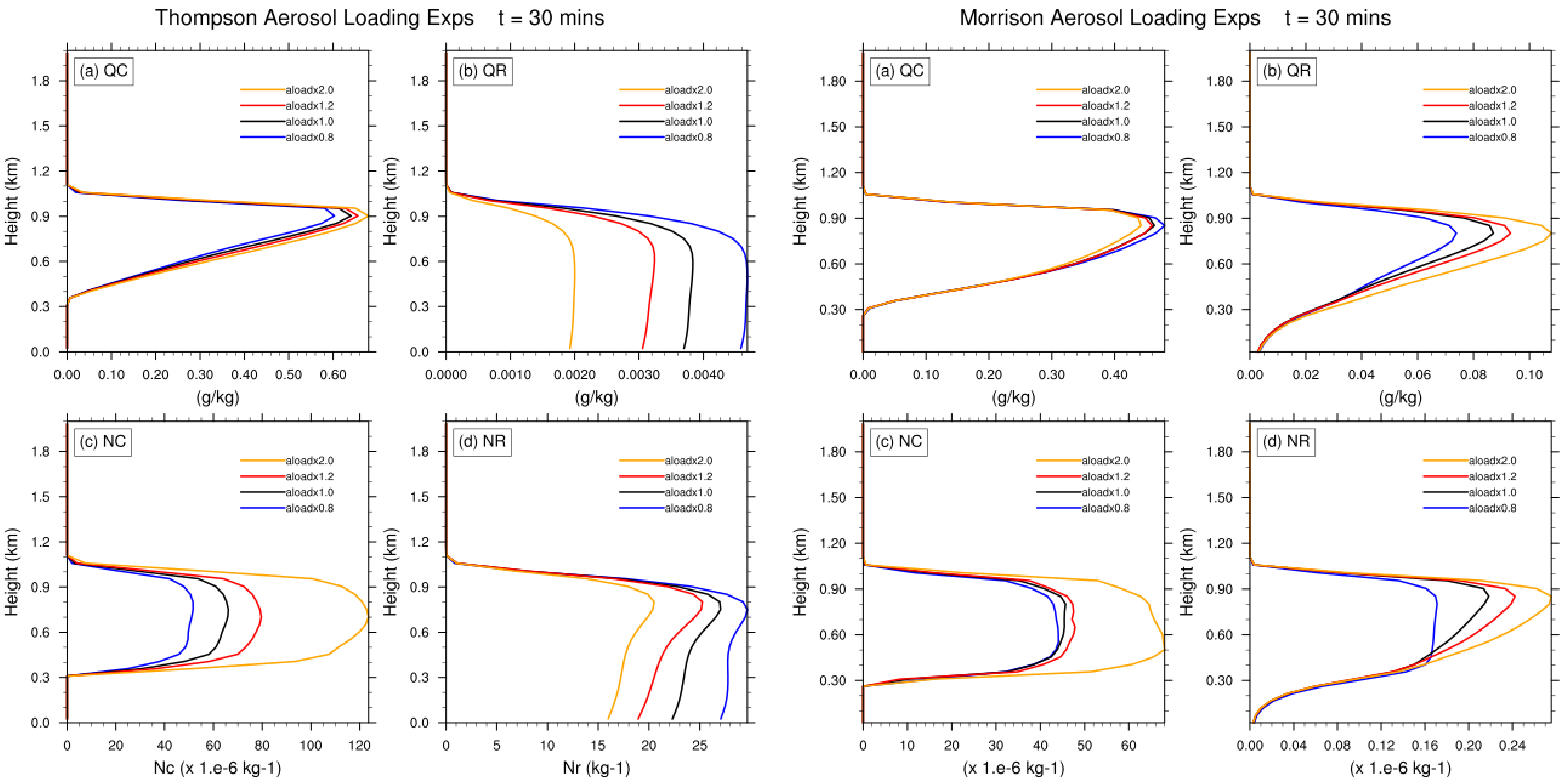
- In the Morrison runs, now more accretion is occurring in the runs with higher aerosol content.
- Thompson runs continue to have more autoconversion, less accretion than Morrison runs.
- More condensation is occurring in the Morrison runs, especially between 0.3 and 0.6 km.
- Accretion > autoconversion for Morrison, but for Thompson, autoconversion > accretion




Microphysical budget analysis for rain production in the two control experiments during the first 30 mins of the shallow convection runs (time averaged). For this case, the Morrison experiment has more evaporation at low levels, due to smaller raindrop size.

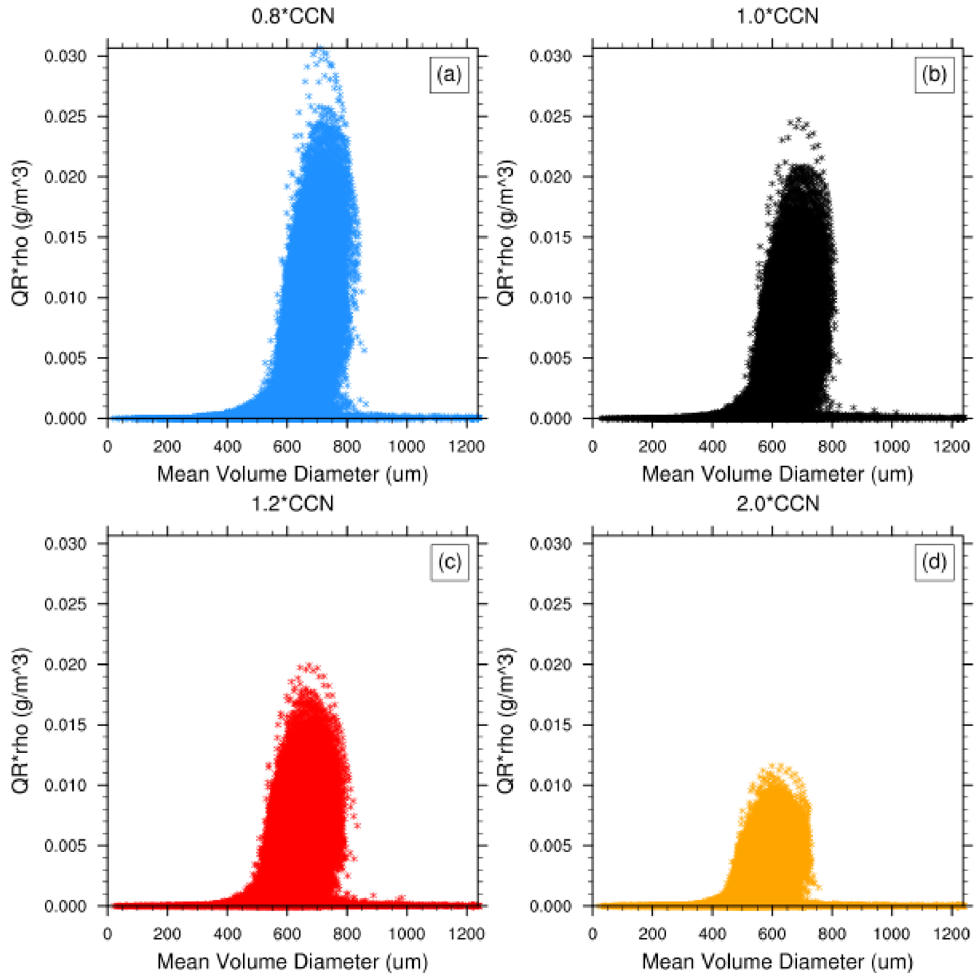



**Shallow convection case domain-averaged precipitation:**
In the Thompson scheme, precipitation amount increases as aerosol load decreases.
In the Morrison scheme, the behavior is similar for the first 35 mins, then a change occurs and the precipitation is greater with higher aerosol content.

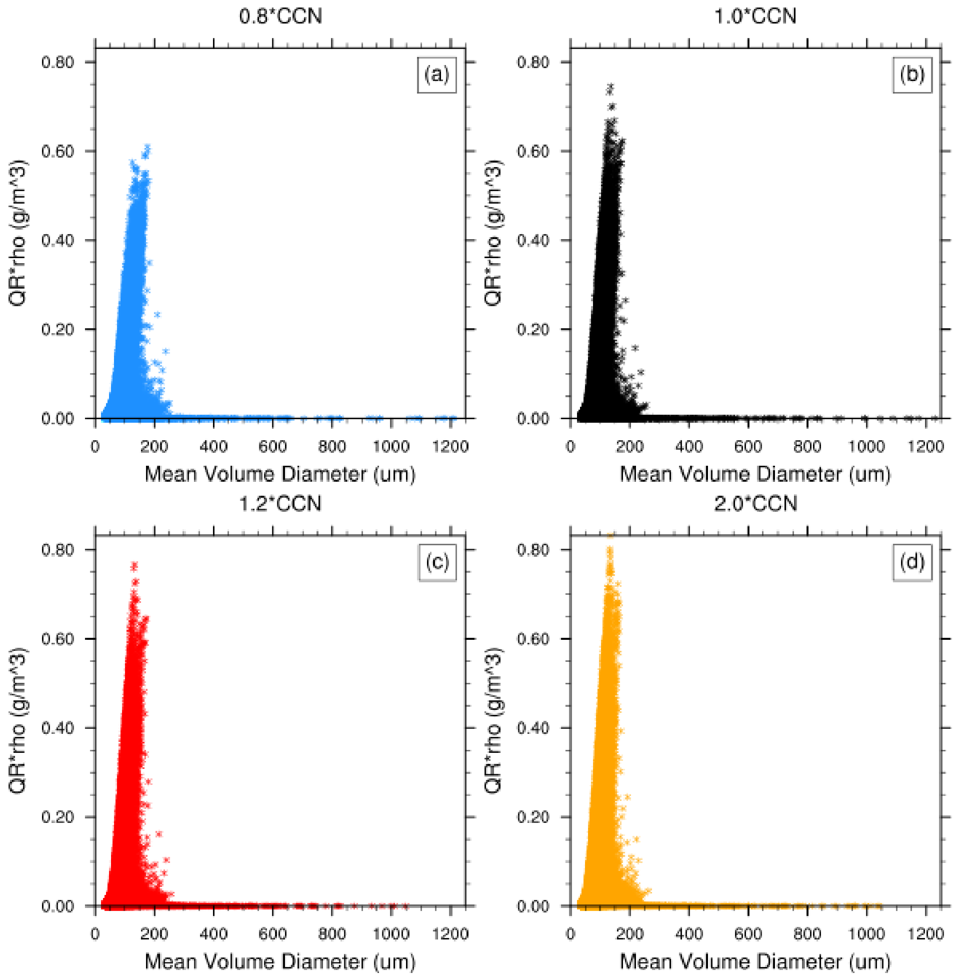



Shallow convection case: Aerosol impact is opposite (except on Nc) in these two schemes. Note the difference in the x-axes. Morrison runs have ~10000x more rain drops!

Thompson Rain MVD   t=30 mins.




Morrison Rain MVD   t=30 mins.




Shallow convection case:  Mean volume diameter (MVD) of raindrops is much larger for Thompson experiments, and rain content decreases with increase in aerosols.

# Summary and Conclusions

- The response of each scheme to aerosol loading change is case-dependent (shallow convection vs. 2D squall line).

- The Twomey and cloud-life effects are simulated differently by the two schemes due to the different size-dependent process parameterizations and assumptions of hydrometeor size distributions.

- In the case of shallow convection, the Thompson scheme shows the behavior of more aerosol leading to less total precipitation. In contrast, the behavior of the Morrison scheme is the opposite.

-In the case of the 2D squall line, the response of each scheme to aerosol loading change is more complicated than in the shallow convection case due to the interaction between warm- and cold-rain processes.

- The compensatory feedback between microphysical processes in each scheme that tends to soften the response to aerosol loading change is greater in the case when both warm- and cold-rain processes are co-present than the situation in which only warm-rain processes are present.

- The different behavior of the two schemes can be explained by the differences in the parameterized size-dependency of warm- and cold-rain processes between the schemes and their corresponding disparate impact on dynamical feedback to cloud formation.