Coupling Spectral-bin Cloud Microphysics with the MOSAIC Aerosol Model: Simulation of Warm Clouds from VOCALS

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Motivation

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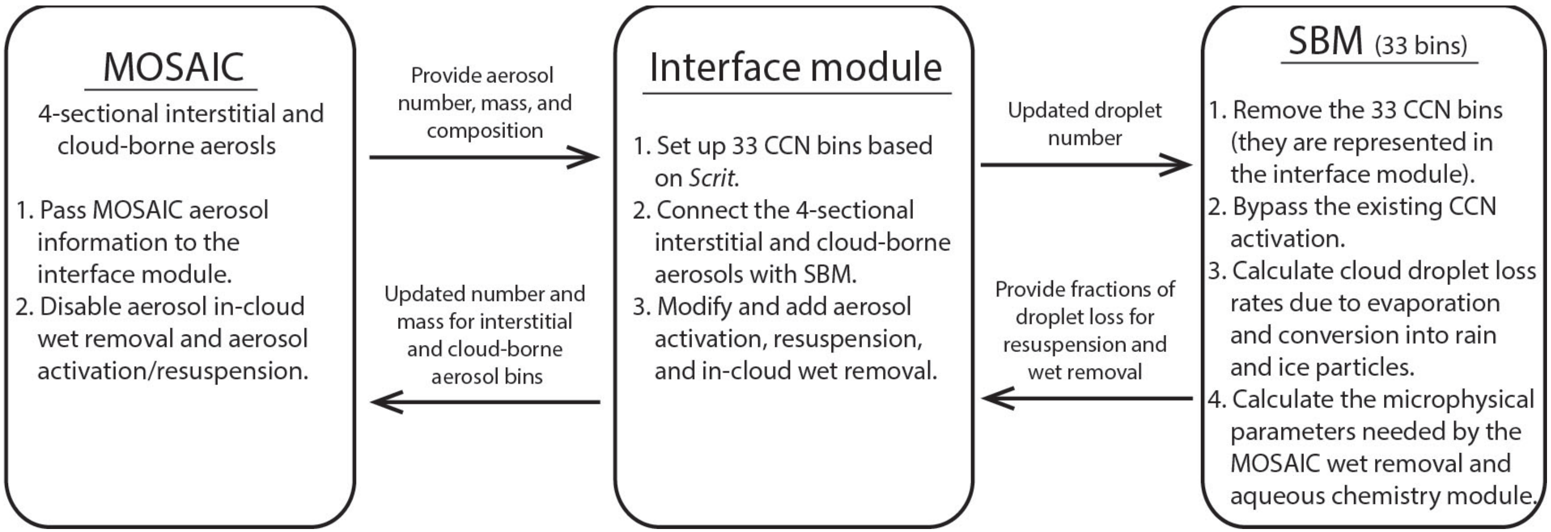
- To better represent aerosol-cloud interactions (ACI) and aerosol-radiation interactions (ARI), both aerosol and cloud lifecycle processes are important.
- Current WRF-Chem uses bulk cloud microphysics, which has significant limitations in representing ACI. Bin cloud microphysics is often run with very limited aerosol processes (often with prescribed aerosol properties).
- The purpose of this study is to **better represent both ACI and ARI** by coupling spectral-bin microphysics (SBM) with the sectional aerosol model (MOSAIC) based on the framework of WRF-Chem.

Coupling of SBM - MOSAIC



Major changes on processes:

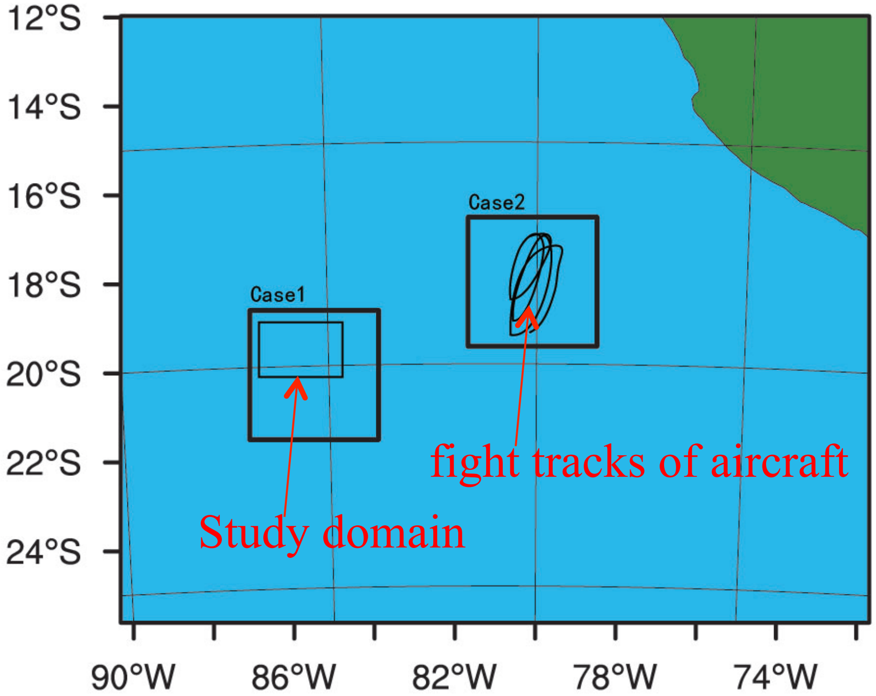
Aerosol activation: 4 MOSAIC bins *Scrit* → 33 CCN bins in SBM, then the activation is calculated with the model predicted supersaturation.

Aerosol resuspension: calculate the droplet loss fraction due to evaporation in SBM and the same fraction is applied to transfer aerosols from the MOSAIC cloud-borne aerosol bins to the interstitial aerosol bins.

In-cloud wet-removal: calculate the droplet loss fraction due to conversion of cloud drop to rain and ice particles in SBM, and the same fraction is applied to all cloud-borne aerosol bins to remove the aerosols wet-removed.

Evaluation of the coupled SBM-MOSAIC

- Simple cloud case: marine stratocumuli (Sc)
- Evaluate the modified processes with prescribed aerosols so that it can be compared with WRF-SBM (**Case 1**)
- Evaluate the overall performance of the newly-coupled model with full chemistry with real-case simulations using observations (**Case 2**).



- **Case 1: Oct. 15, 2008, uniform aerosols and simple aerosol composition, good for tests with prescribed aerosols.**
- **Case 2: Oct. 28, 2008, more polluted case with in-situ aircraft measured cloud and aerosol properties.**

- 1-km resolution and 4-s dynamic timestep
- For prescribed aerosol set up: sulfate, and the size distribution at the initial and boundary conditions is obtained from a previous WRF-Chem simulation in Yang et al. 2011.
- For real-case set up: use MOZART for aerosol initial and boundary conditions, and CBM-Z

Model simulations

Case 1 simulations	
BASE	**MOSAIC aerosols coupled with SBM microphysics using prescribed aerosols.**
NRSP	Based on BASE except the **aerosol resuspension process is turned off**.
NIWR	Based on BASE except the **in-cloud wet removal process is turned off**.
ACTV	Based on BASE with **both the aerosol resuspension and in-cloud wet removal processes turned off**.
SBMO	**WRF-SBM** using prescribed aerosols.
Case 2 simulations	
SBMC	WRF-SBM-MOSAIC.
MORC	Original WRF-Chem with Morrison bulk microphysics.

ACTV vs. SBMO: to evaluate aerosol activation processes

BASE vs. NRSP: to evaluate and study the resuspension process

BASE vs. NIWR: to evaluate and study the in-cloud wet removal processes

Aerosol Activation

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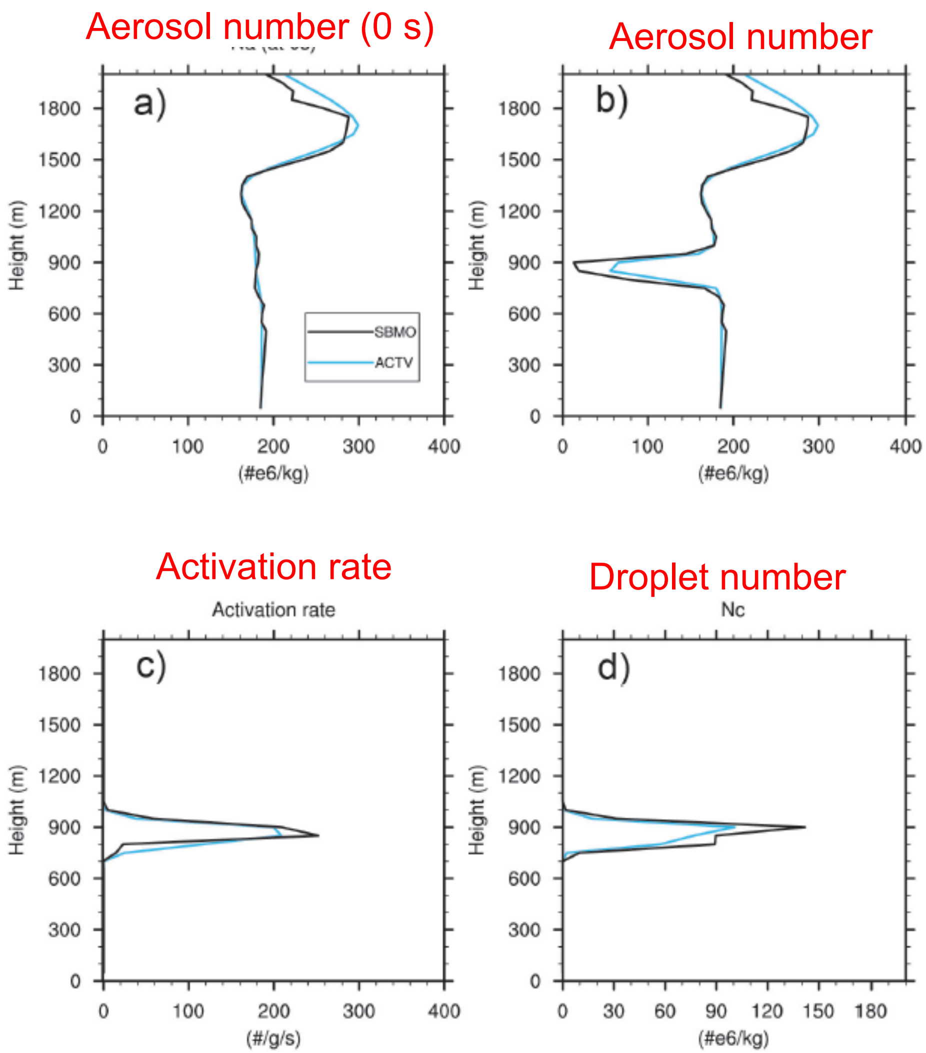
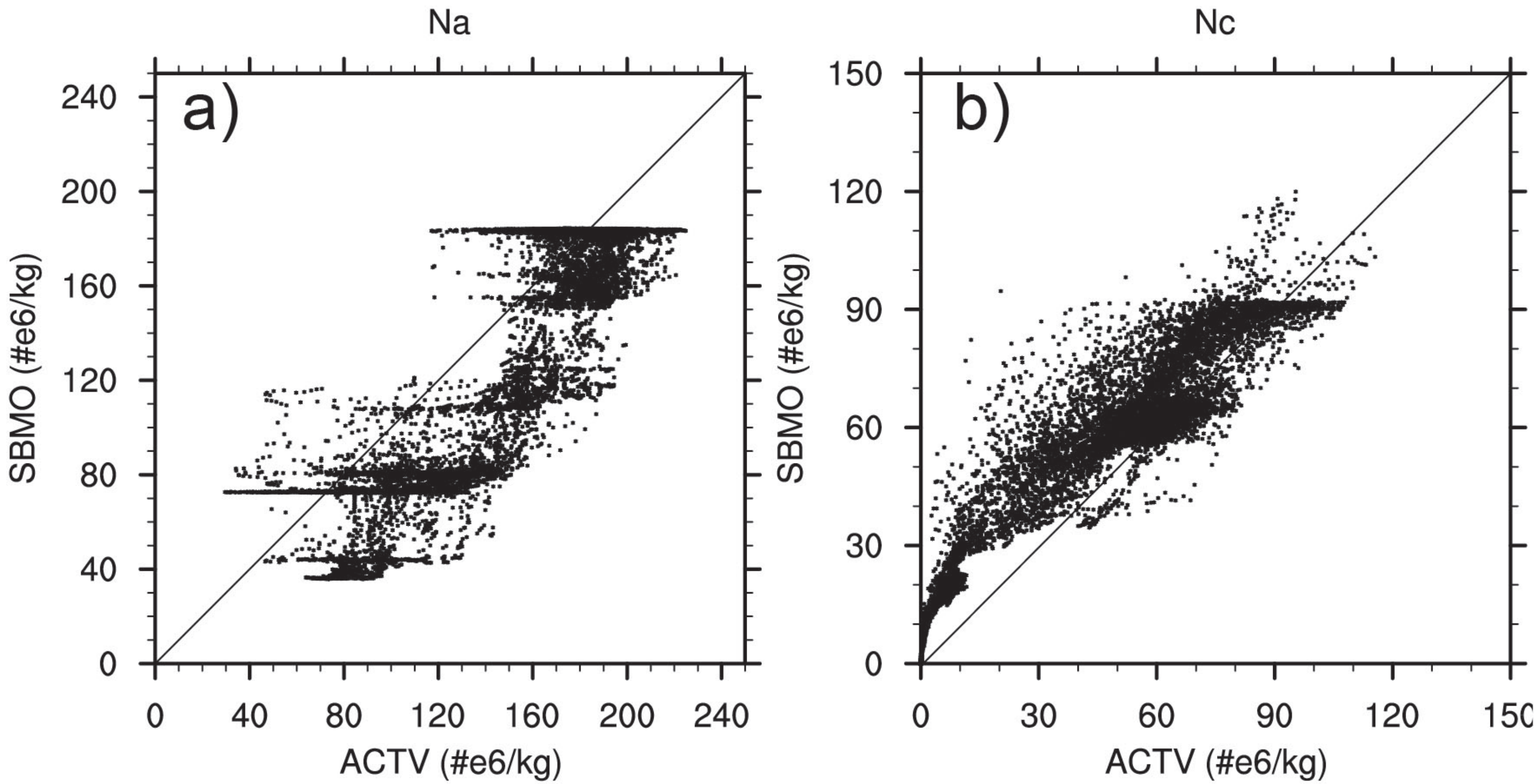


ACTV vs. SBMO

- The aerosol activation rate in the ACTV is similar to that with the uncoupled SBM.
- A little smaller activation rate in ACTV corresponds well with a little higher aerosols and .

The averages are done during the initial 10-min simulations with outputs of every 5-s.

ACTV vs. SBMO

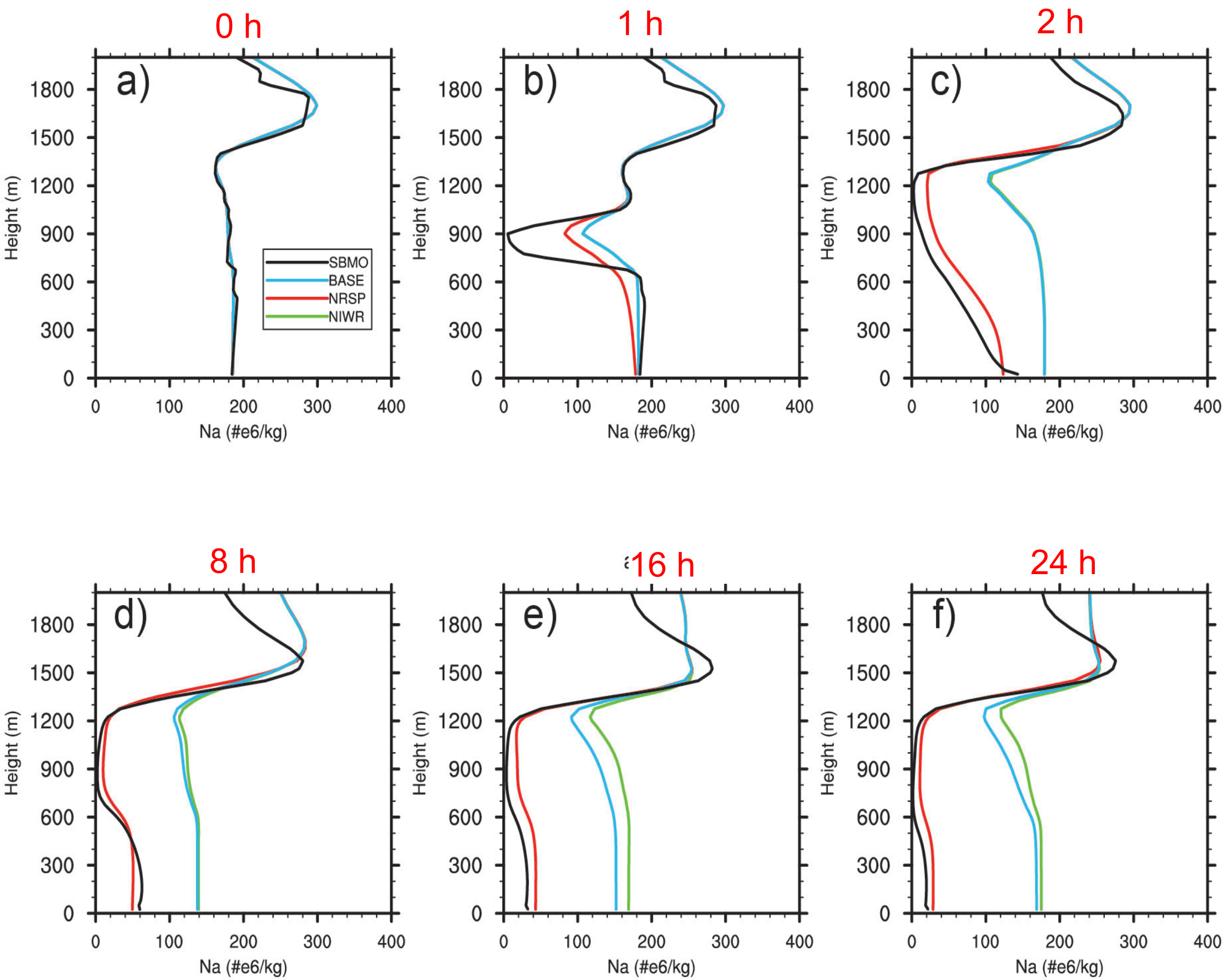


Differences can be caused by

- Difference of prescribed aerosol size spectrum between ACTV and SBMO (4-bin vs 33-bin)
- Uncertainty associated with mapping the aerosols from MOSAIC into the 33 CCN bins

Aerosol resuspension and in-cloud wet removal

Aerosols at different time



NRSP vs. BASE:
N_a in NRSP (no aerosol resuspension) is much lower than in BASE after 1-h, but close to that in SBMO, implying the resuspension plays an important role in replenishing aerosols in the maritime Sc.

NIWR vs. BASE:
N_a in NIWR (no in-cloud removal) is similar to that in BASE until 12 h when precip is significant.

Na increases in about 10%, indicating small impact of in-cloud wet-removal in maritime Sc.

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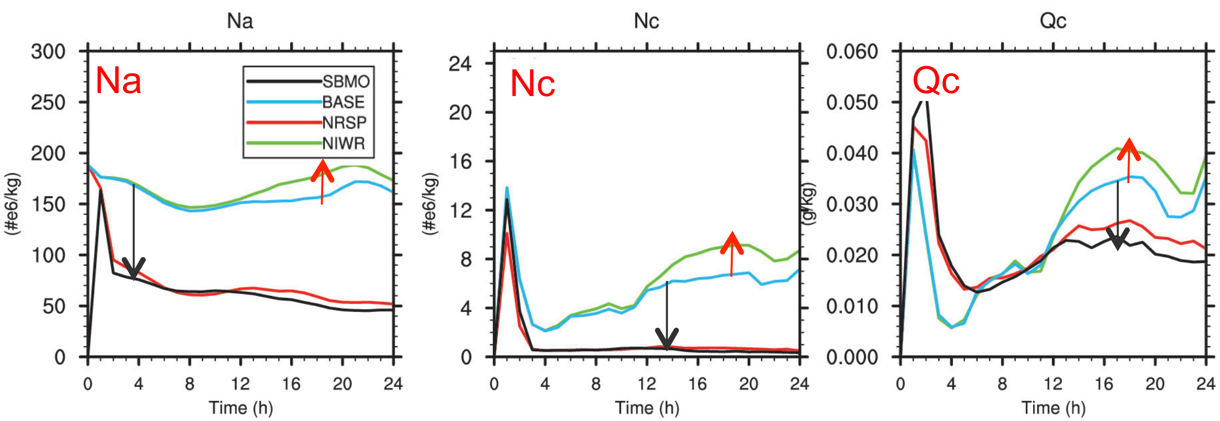
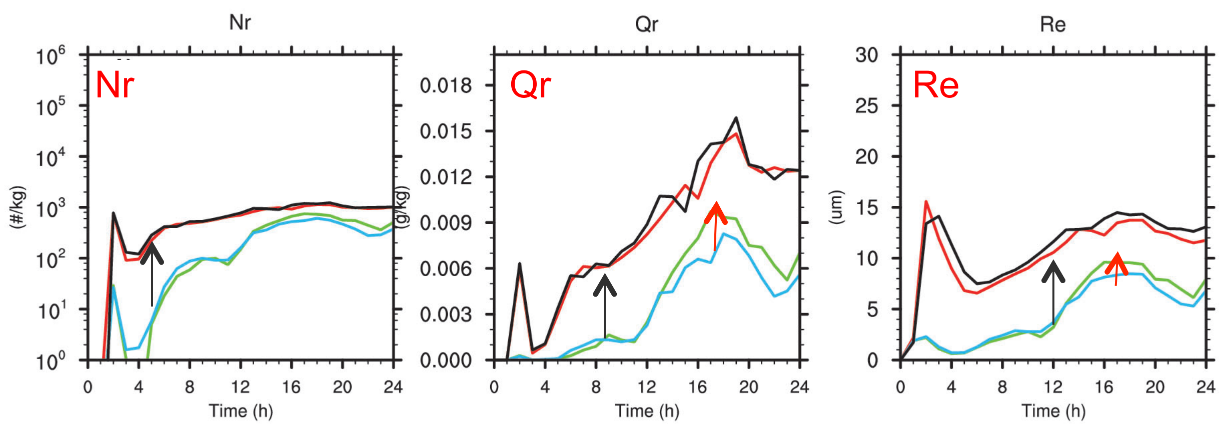
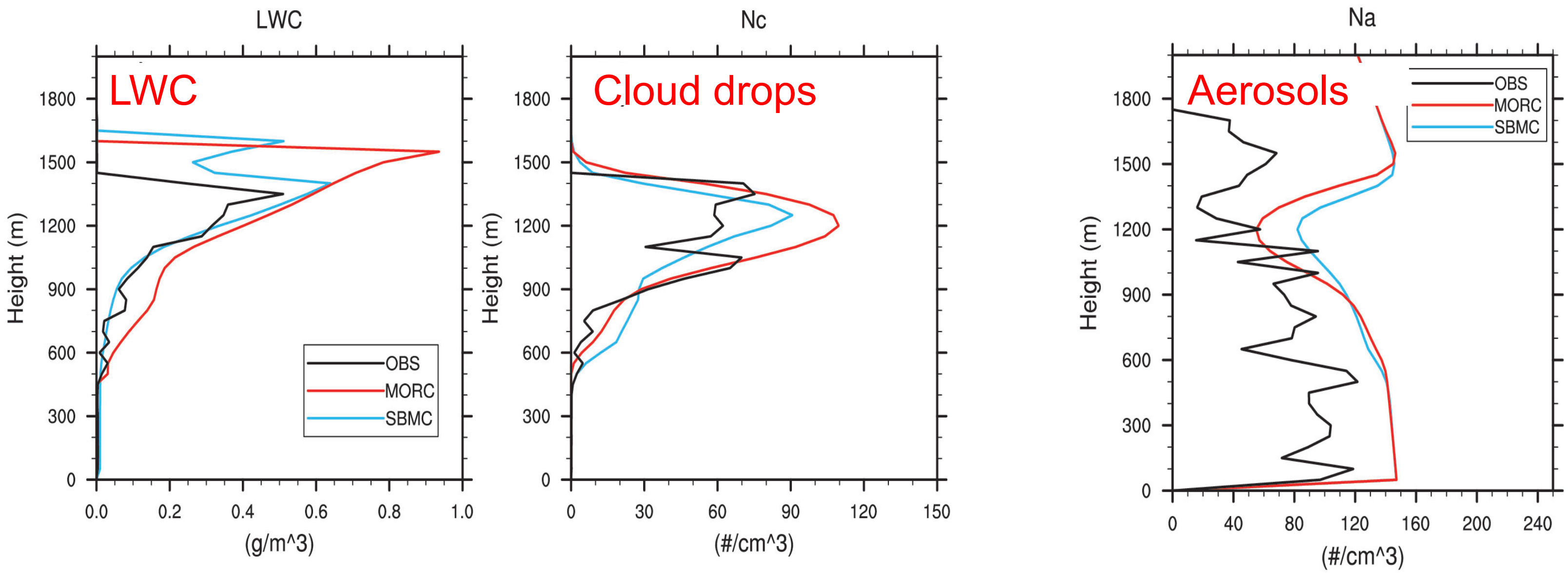


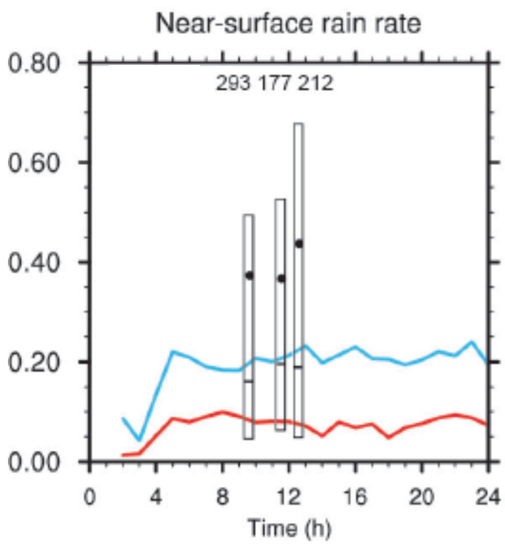
- Without aerosol resuspension, Nc is very low after 1 h due to rapid reduction of aerosols, then rain drop mass and number are much larger. Cloud properties are very similar to SBMO.



- Without in-cloud wet removal, during the precipitation period, Na is increased, which then increases droplet number and LWC. Rain is increased as well.

Evaluation of the Fully-Coupled Simulation





- At cloud layer, the newly-coupled model shows much improved simulation in LWC and cloud drop number, especially in the upper part of cloud.
- The larger drop number in the original WRF-Chem simulation is mainly due to larger activation rate, as suggested by the smaller Na and previous studies..

Conclusion

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- The modified processes in the newly-coupled SBM-MOSAIC **work reasonably as expected**. The aerosol activation is consistent with that in the uncoupled SBM with prescribed aerosols.

- **Aerosol resuspension plays an important role** in replenishing aerosols and maintaining droplet concentrations in marine Sc clouds. **In-cloud wet removal of aerosols is a much less significant process** compared with resuspension, even for precipitating marine Sc.

- The newly coupled model significantly **improves the simulations of cloud properties and precipitation** compared with the original WRF-Chem for real-case simulations of marine Sc.