Advanced Particle Microphysics (APM)

Model

Hands-on computer lab

JGR Atmospheres

RESEARCH ARTICLE
10.1029/2025JD044021

Key Points:

- Integrated sectional aerosol model enhances the ability to track size-dependent aerosol properties
- Coupled model increases computational demand by 83% but enables high-fidelity aerosol number simulations
- Model predictions align well with observations on particle number concentrations and size distributions

Improved Simulation of Particle Number Concentrations Over the US: Integrating a Size-Resolved Advanced Particle Microphysics Model Into CMAQ

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(Mao, Yu, et al., 2025, https://doi.org/10.1029/2025JD044021)

Treatment of Aerosols in coupled CMAQ-APM

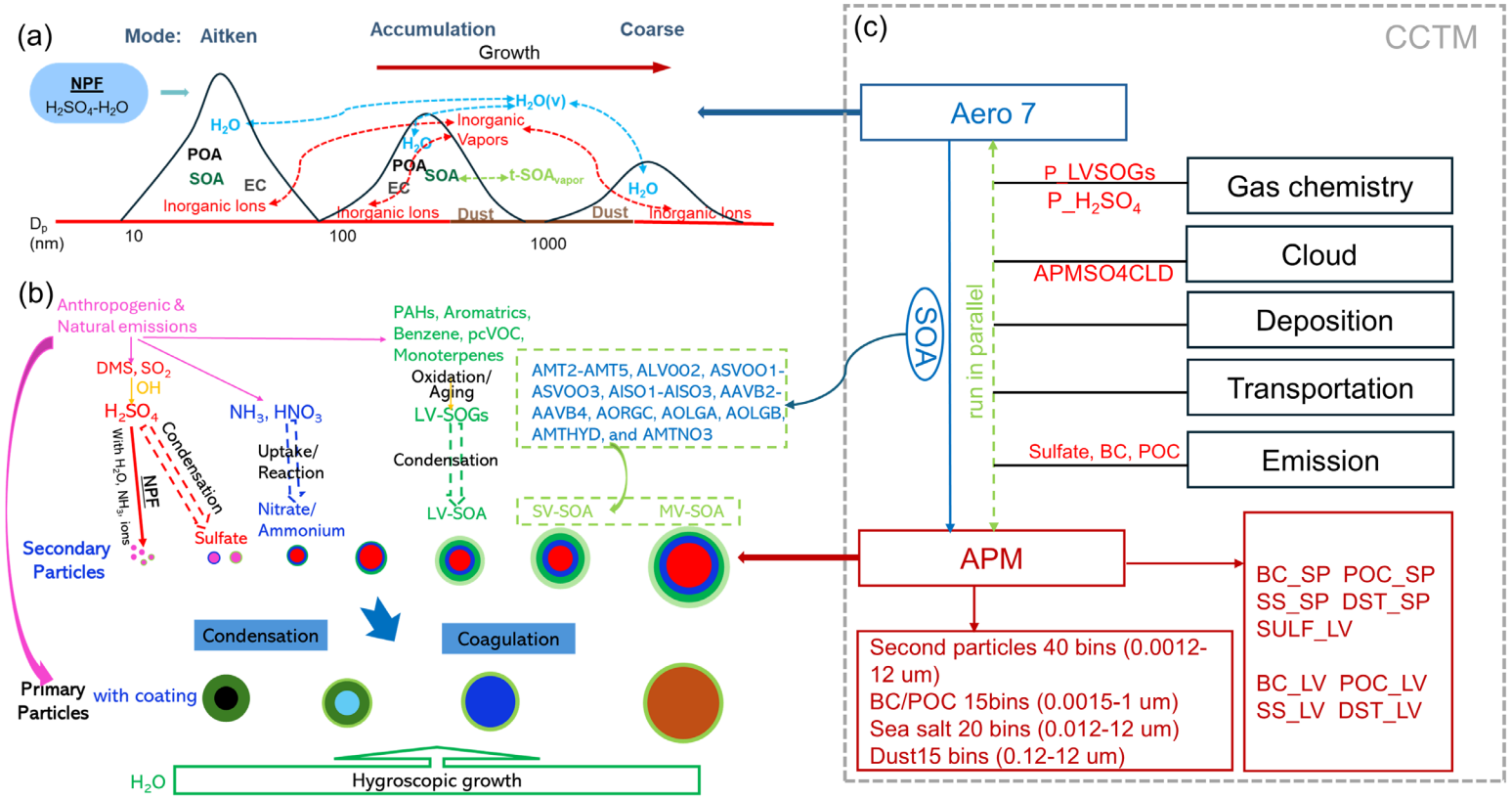
(Yu and Luo, 2009; Luo and Yu, 2011; Murphy, 2015; Appel et al., 2021)

The original CMAQ Release Model contains:

- One new particle formation pathway via binary sulfuric acid nucleation
- No dedicated “nucleation” mode

Coupled model includes:

- Nucleation (H_2SO_4–H_2O–NH_3 ternary ion-mediated nucleation (TIMN) scheme), condensation, coagulation, equilibrium/partition, and deposition processes



- 40 size-bins for secondary particle,15 size-bins for OC and BC, 20 size-bins for sea salt, and 15 size-bins for dust

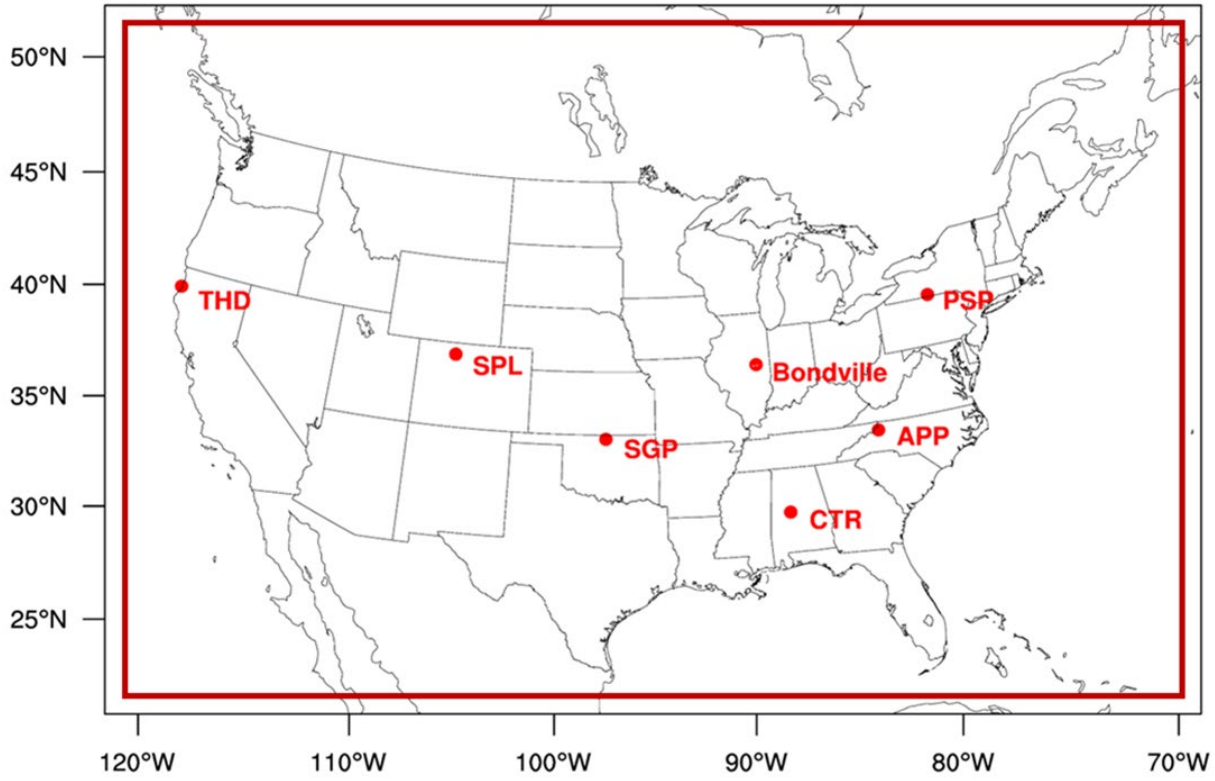
Model configurations

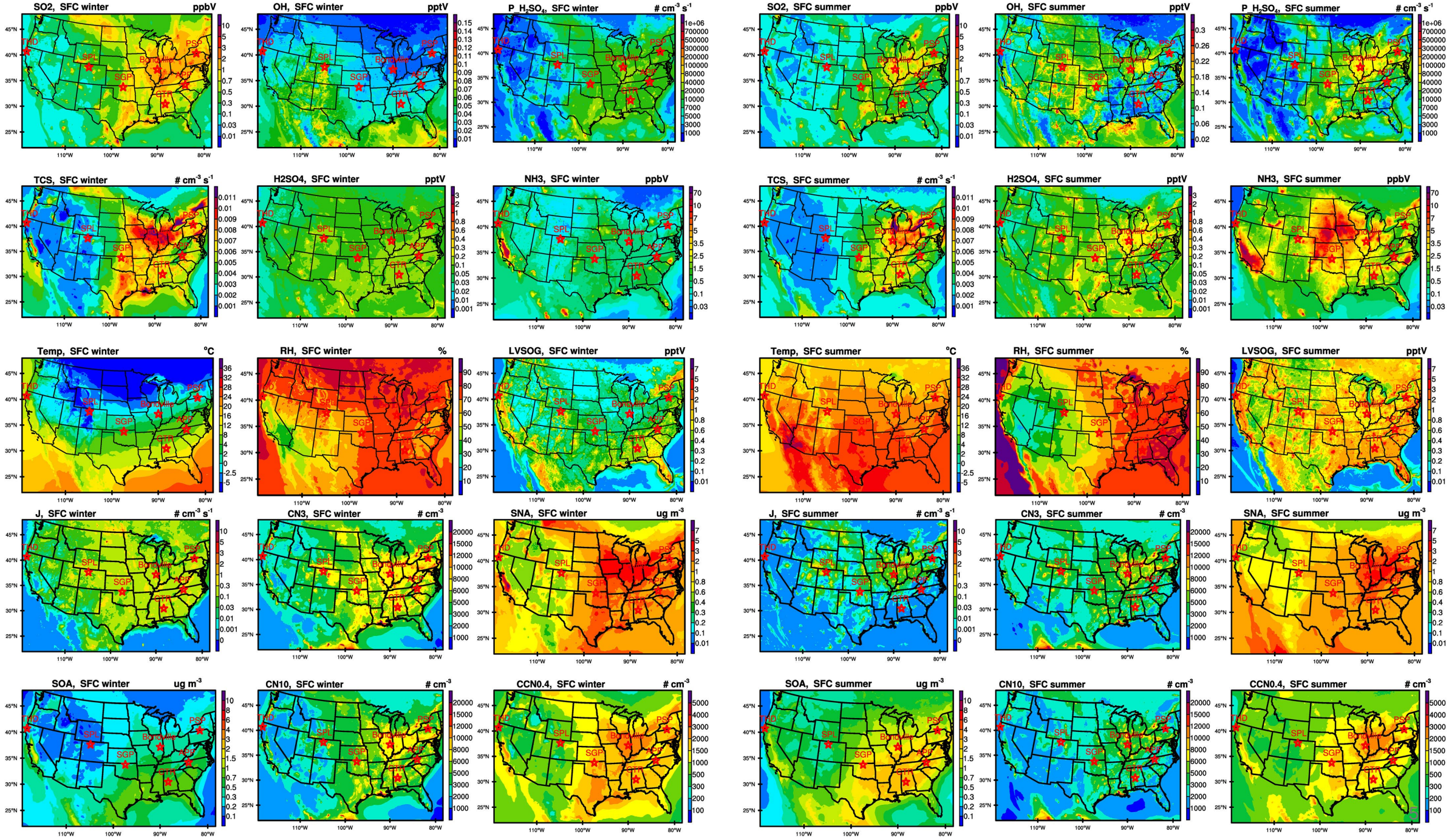
CMAQ-APM

Mechanism: cb6r5_ae7_aq
Resolution: 12km
Simulation period:
1) Winter Case: Nov. 1- Dec. 30, 2013
2) Summer Case: Jun. 1 – July 31, 2013

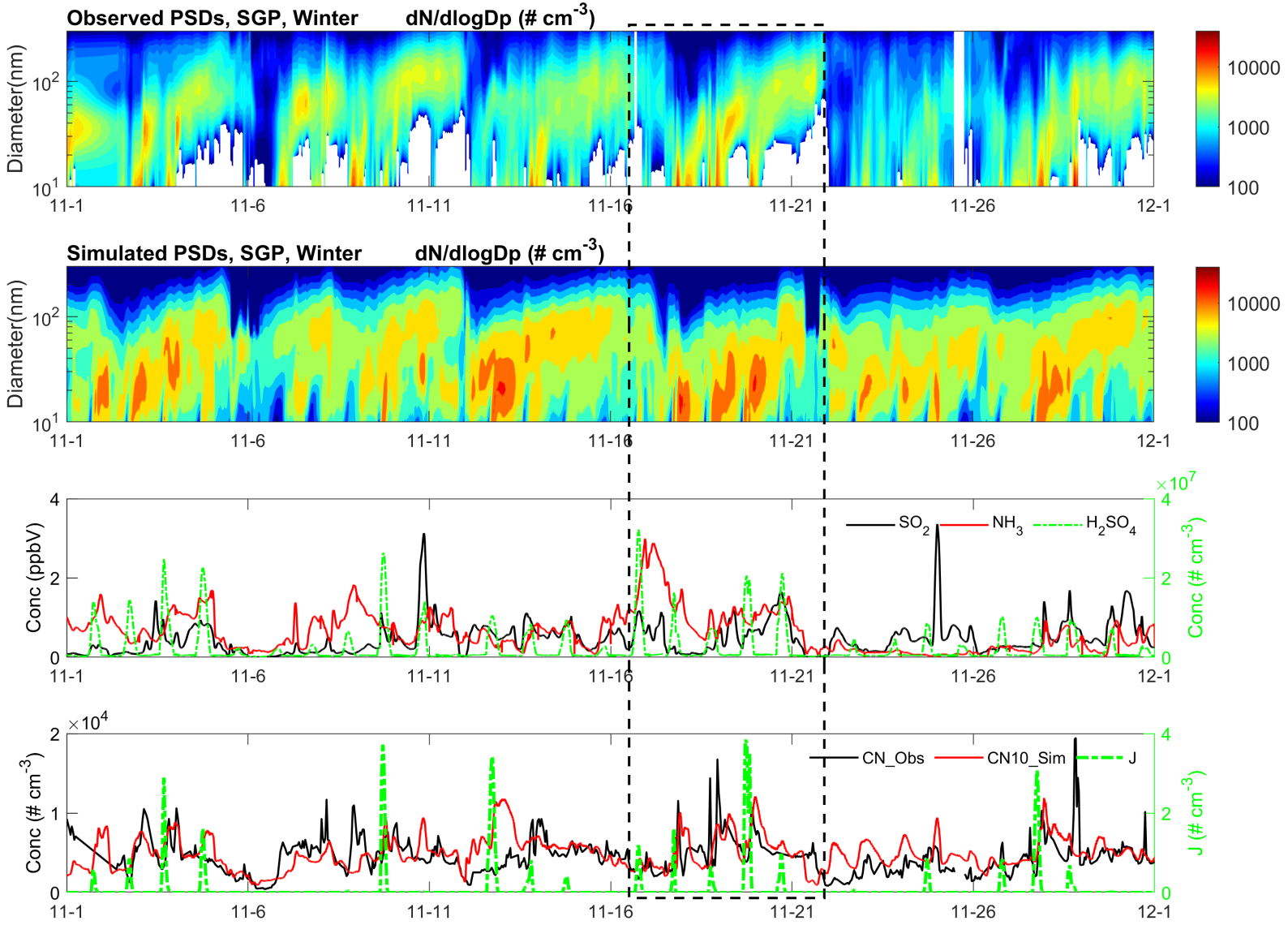
Observations

Measured SO2, CN10, PSDs, CCN
Sites: seven sites located in CONUS



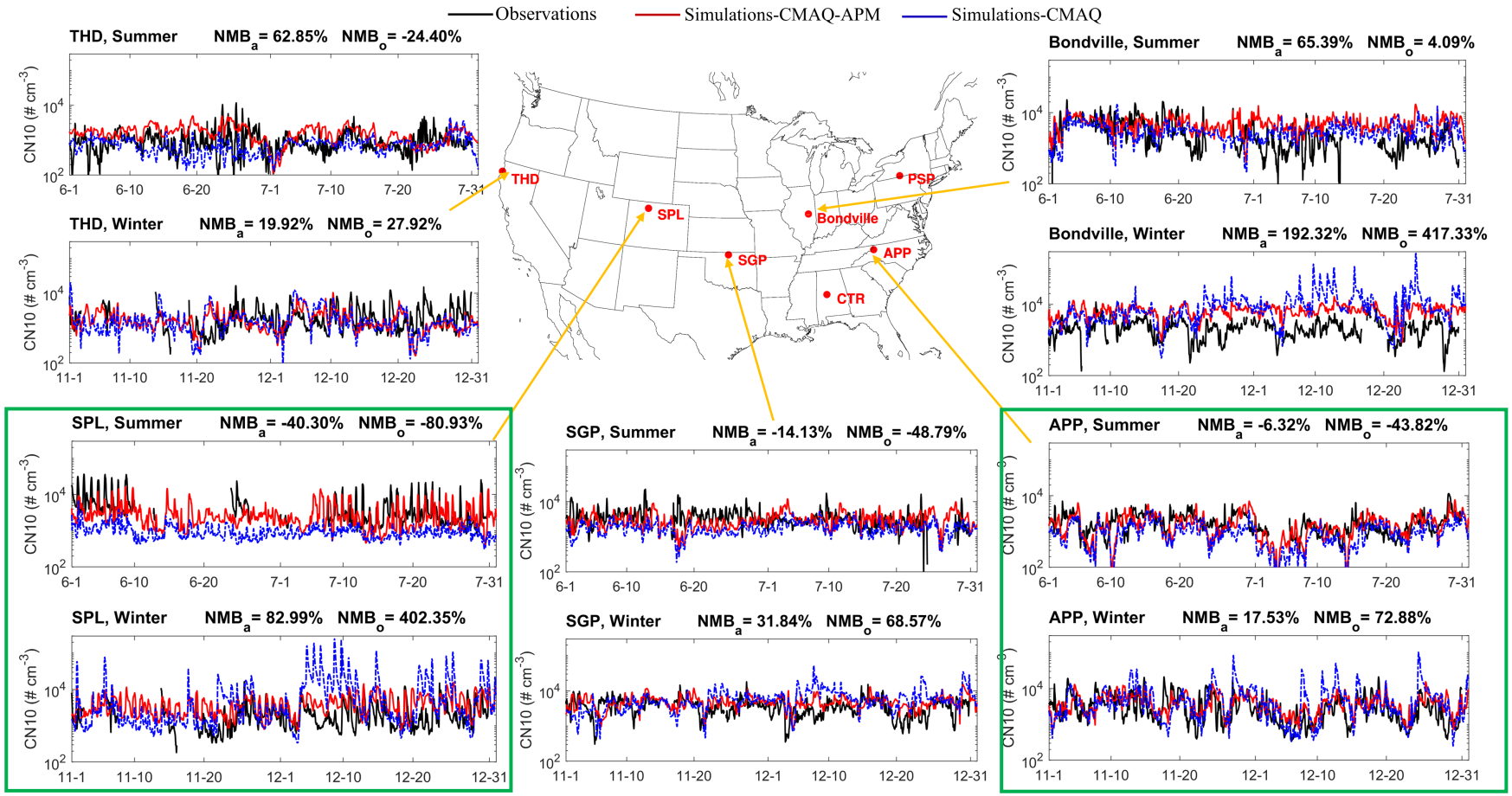

SO2, SFC winter ppbV
OH, SFC winter pptV
P_H2SO4, SFC winter # cm-3 s-1
SO2, SFC summer ppbV
OH, SFC summer pptV
P_H2SO4, SFC summer # cm-3 s-1
TCS, SFC winter # cm-3 s-1
H2SO4, SFC winter pptV
NH3, SFC winter ppbV
TCS, SFC summer # cm-3 s-1
H2SO4, SFC summer pptV
NH3, SFC summer ppbV
Temp, SFC winter °C
RH, SFC winter %
LVSOG, SFC winter pptV
Temp, SFC summer °C
RH, SFC summer %
LVSOG, SFC summer pptV
J, SFC winter # cm-3 s-1
CN3, SFC winter # cm-3
SNA, SFC winter ug m-3
J, SFC summer # cm-3 s-1
CN3, SFC summer # cm-3
SNA, SFC summer ug m-3
SOA, SFC winter ug m-3
CN10, SFC winter # cm-3
CCN0.4, SFC winter # cm-3
SOA, SFC summer ug m-3
CN10, SFC summer # cm-3
CCN0.4, SFC summer # cm-3
THD
SPL
SGP
BOT
PSU
ACT
GTH
45°N
40°N
35°N
30°N
25°N
110°W
100°W
90°W
80°W

Particle size distributions



- Particle size distributions(PSDs) show intensive nucleation and growth events on some days, resulting in a significant increase of condensation nuclei larger than 10 nm (CN10).
- The model can reasonably predict frequent NPF events, aligning with field observations.

CN10 abundance



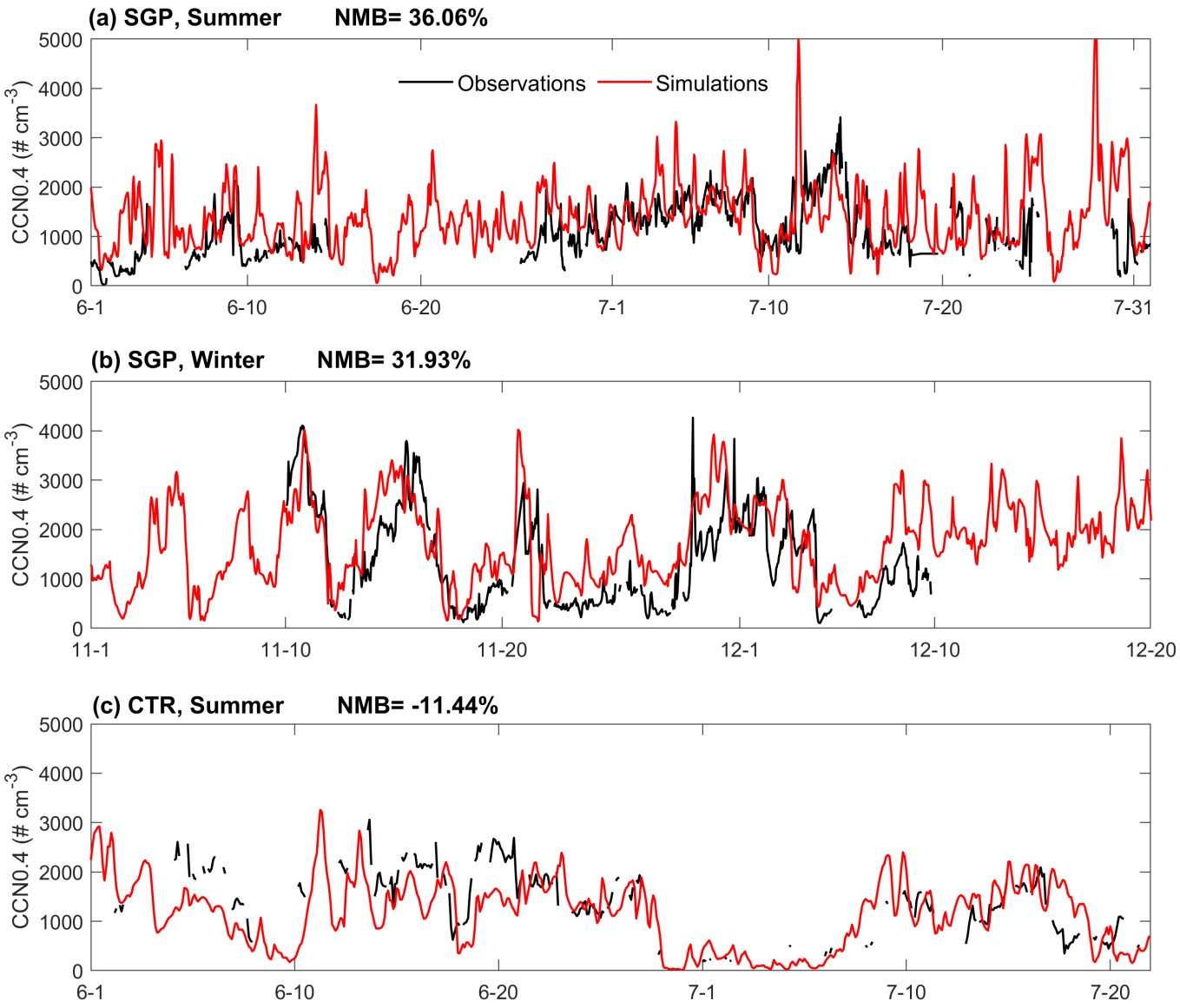
Pearson Correlation Coefficients (r) for CN10

Sites	Summer case CMAQ-APM (CMAQ)	Winter case CMAQ-APM (CMAQ)
Bondville	0.30(0.22)	0.39(-0.10)
APP	0.57(0.50)	0.66(0.09)
SGP	0.02(-0.03)	0.40(-0.08)
THD	0.15(-0.02)	0.12(0.18)
SPL	0.53(0.15)	0.59(0.13)

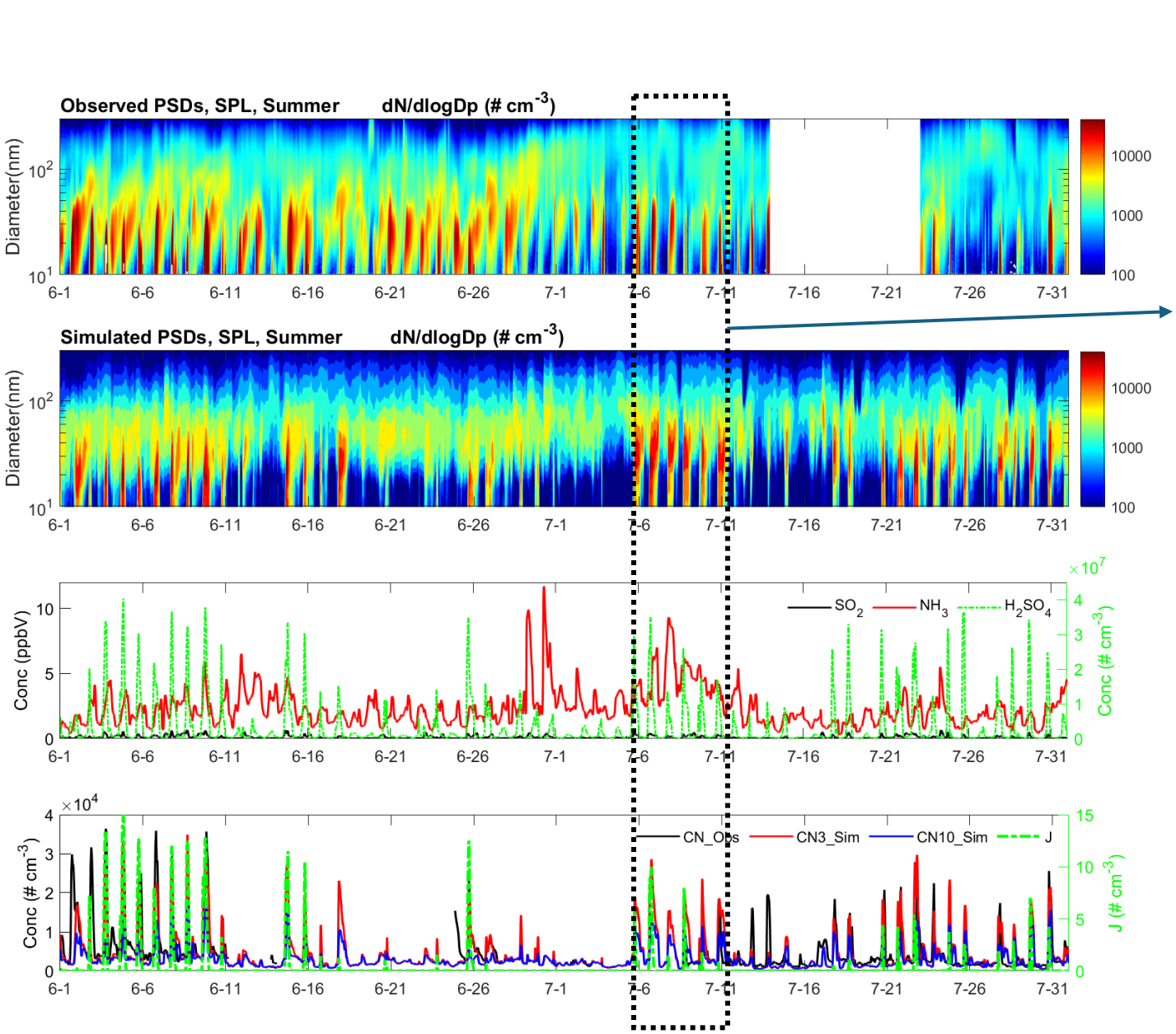
- The mean Normalized Mean Bias for **CMAQ-APM** (NMBa) is 41.24% (-6.42% to 192.32%).
- Compared to the original CMAQ, the **CMAQ-APM** model significantly improves CN10 simulations, particularly at the **APP and SPL sites**.

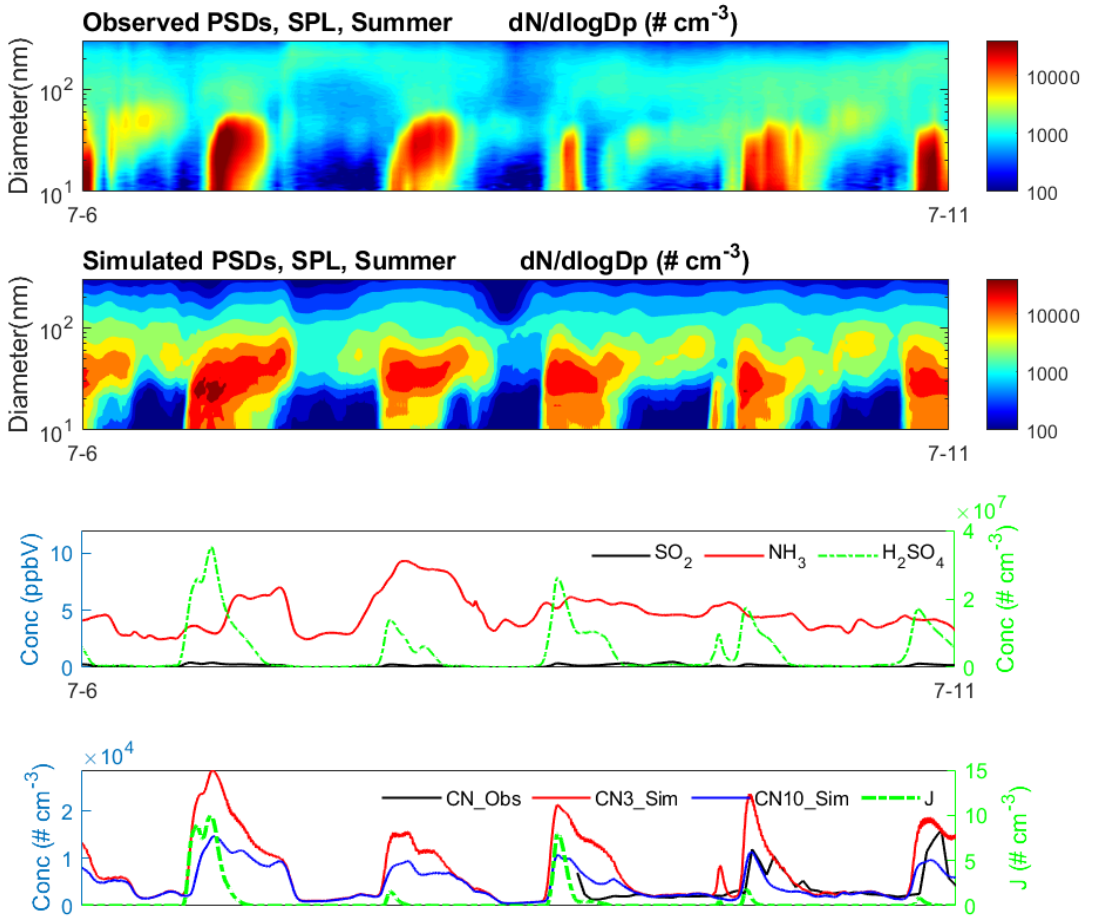
- At APP and SPL sites, the coefficient (r) with CMAQ-APM is 0.66 and 0.59, respectively, compared to 0.09 and 0.13 with the original CMAQ.
- **CMAQ-APM** successfully captures the temporal variability of CN10, aligning well with observations.

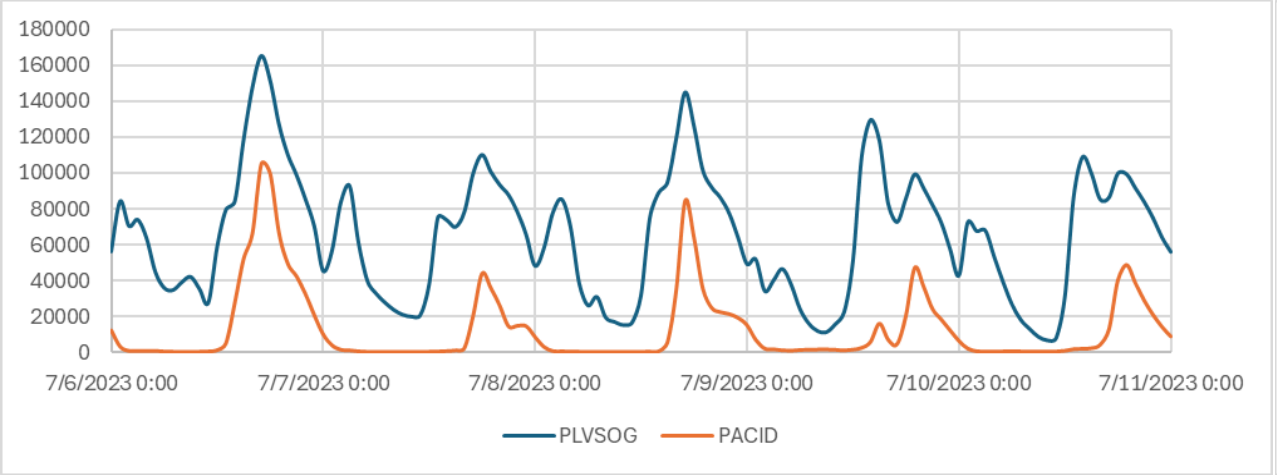
CCN abundance



- CMAQ-APM is capable of representing CCN.
- CCN0.4 and their daily fluctuations are generally in agreement with observations.


Observed PSDs, SPL, Summer dN/dlogDp (# cm-3)
Diameter(nm)
Simulated PSDs, SPL, Summer dN/dlogDp (# cm-3)
Conc (ppbV)
Conc (# cm-3)
SO2
NH3
H2SO4
CN_Obs
CN3_Sim
CN10_Sim
J
J (# cm-3)
6-1
6-6
6-11
6-16
6-21
6-26
7-1
7-6
7-11
7-16
7-21
7-26
7-31


Observed PSDs, SPL, Summer dN/dlogDp (# cm-3)
Diameter(nm)
Simulated PSDs, SPL, Summer dN/dlogDp (# cm-3)
Conc (ppbV)
Conc (# cm-3)
SO2
NH3
H2SO4
CN_Obs
CN3_Sim
CN10_Sim
J
J (# cm-3)
7-6
7-11


180000
160000
140000
120000
100000
80000
60000
40000
20000
0
7/6/2023 0:00
7/7/2023 0:00
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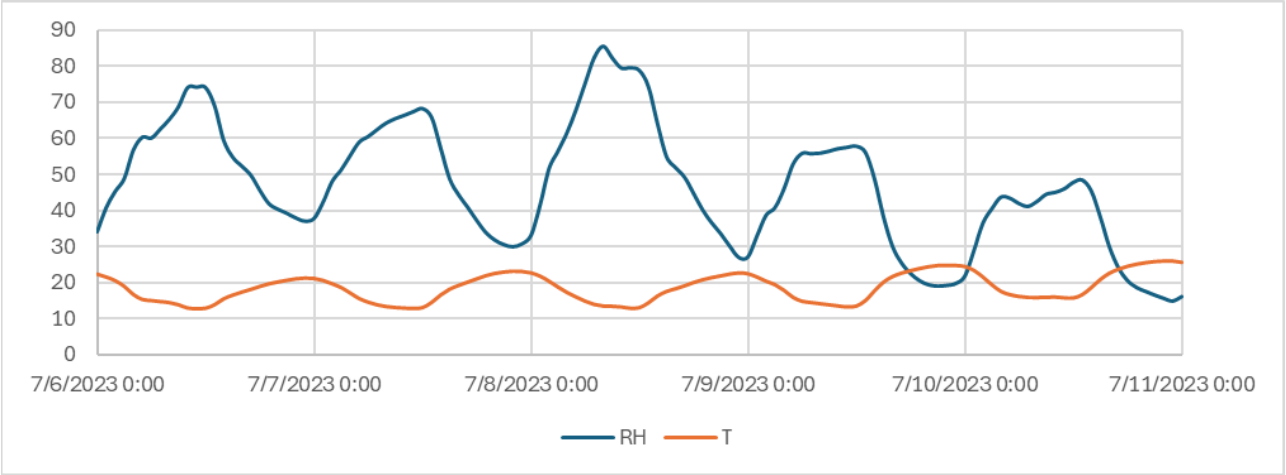
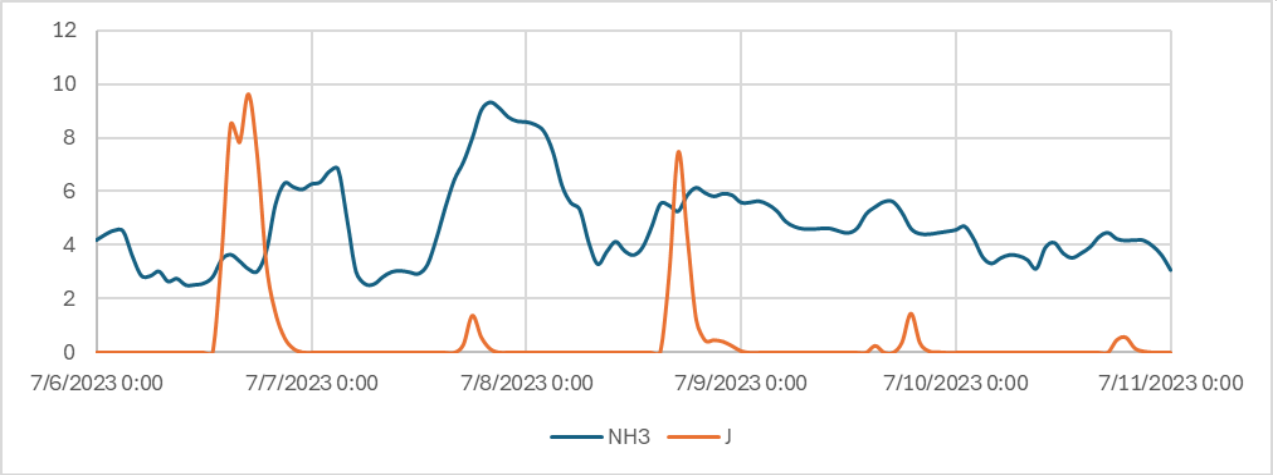
7/9/2023 0:00
7/10/2023 0:00
7/11/2023 0:00
PLVSOG
PACID


90
80
70
60
50
40
30
20
10
0
7/6/2023 0:00
7/7/2023 0:00
7/8/2023 0:00
7/9/2023 0:00
7/10/2023 0:00
7/11/2023 0:00
RH
T


12
10
8
6
4
2
0
7/6/2023 0:00
7/7/2023 0:00
7/8/2023 0:00
7/9/2023 0:00
7/10/2023 0:00
7/11/2023 0:00
NH3
J

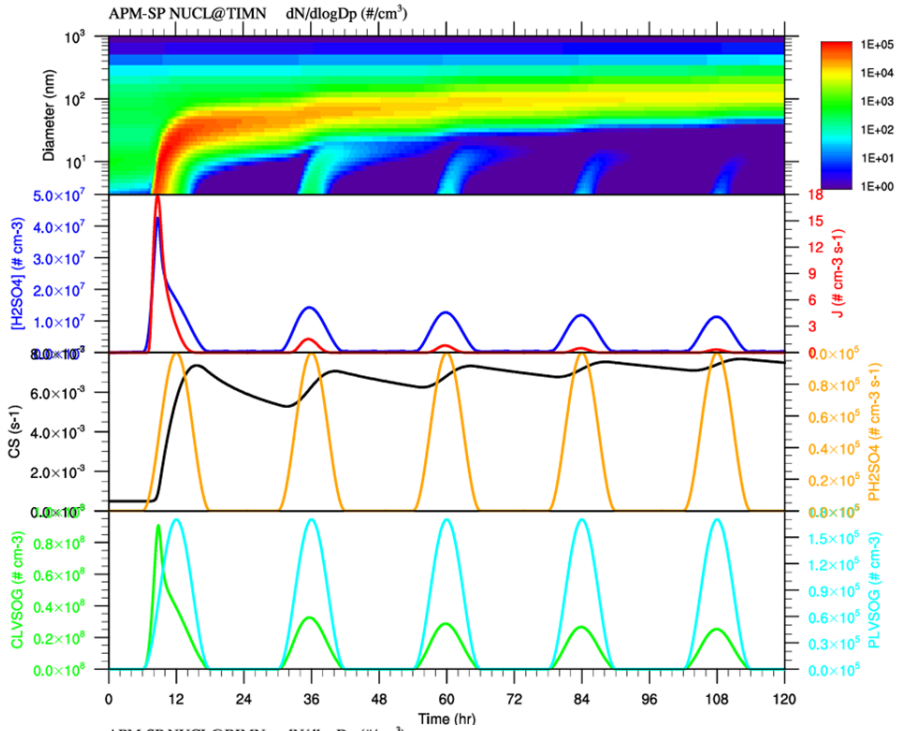
Summer case:

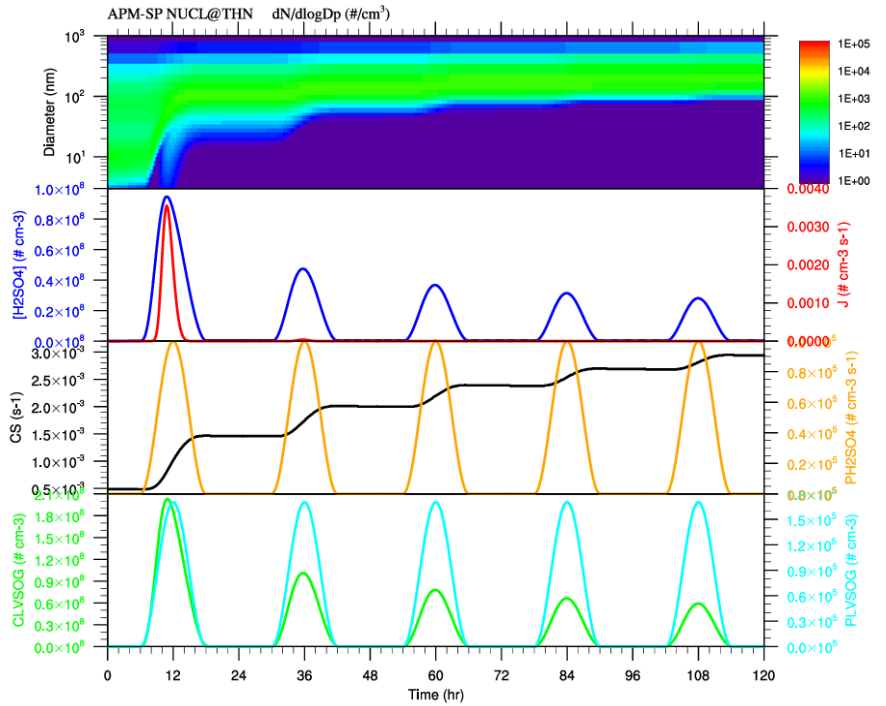
TK (K),RH (%),XQ (ion pairs cm-3 s-1),CNH3(ppbv)
291., 47., 12., 4.7

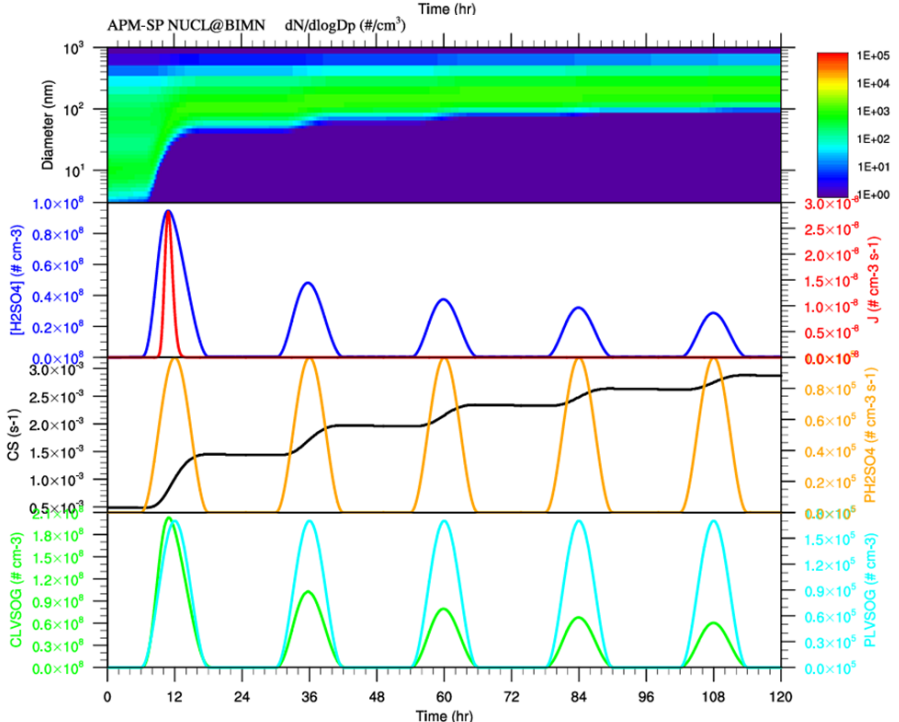
MSO4,MBC,MOC,MDST,MSEA (ug/m3)
0.65,0.06,0.08,1.d-20,0.02

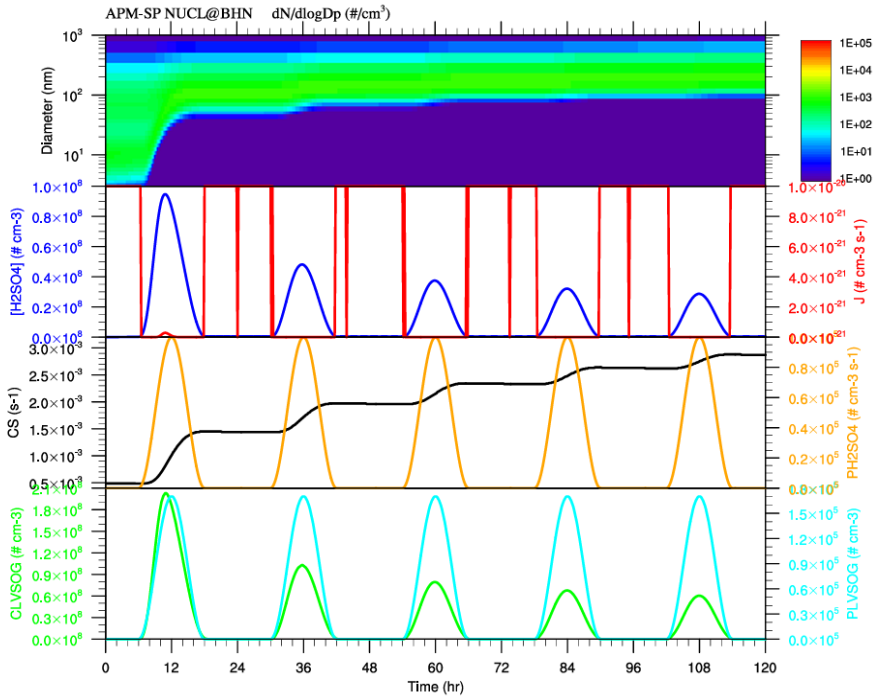
PH2SO4max,PLVSOGmax (# cm-3 s-1)
1.d5, 1.7d5

NUCLEATION SCHEMES:
TIMN, THN, BIMN, BHN


APM-SP NUCL@TIMN dN/dlogDp (#/cm3)
Diameter (nm)
[H2SO4] (# cm-3)
J (# cm-3 s-1)
CS (s-1)
PH2SO4 (# cm-3 s-1)
CLVSOG (# cm-3)
PLVSOG (# cm-3)
Time (hr)


APM-SP NUCL@THN dN/dlogDp (#/cm3)
Diameter (nm)
[H2SO4] (# cm-3)
J (# cm-3 s-1)
CS (s-1)
PH2SO4 (# cm-3 s-1)
CLVSOG (# cm-3)
PLVSOG (# cm-3)
Time (hr)


APM-SP NUCL@BIMN dN/dlogDp (#/cm3)
Diameter (nm)
[H2SO4] (# cm-3)
J (# cm-3 s-1)
CS (s-1)
PH2SO4 (# cm-3 s-1)
CLVSOG (# cm-3)
PLVSOG (# cm-3)
Time (hr)


APM-SP NUCL@BHN dN/dlogDp (#/cm3)
Diameter (nm)
[H2SO4] (# cm-3)
J (# cm-3 s-1)
CS (s-1)
PH2SO4 (# cm-3 s-1)
CLVSOG (# cm-3)
PLVSOG (# cm-3)
Time (hr)

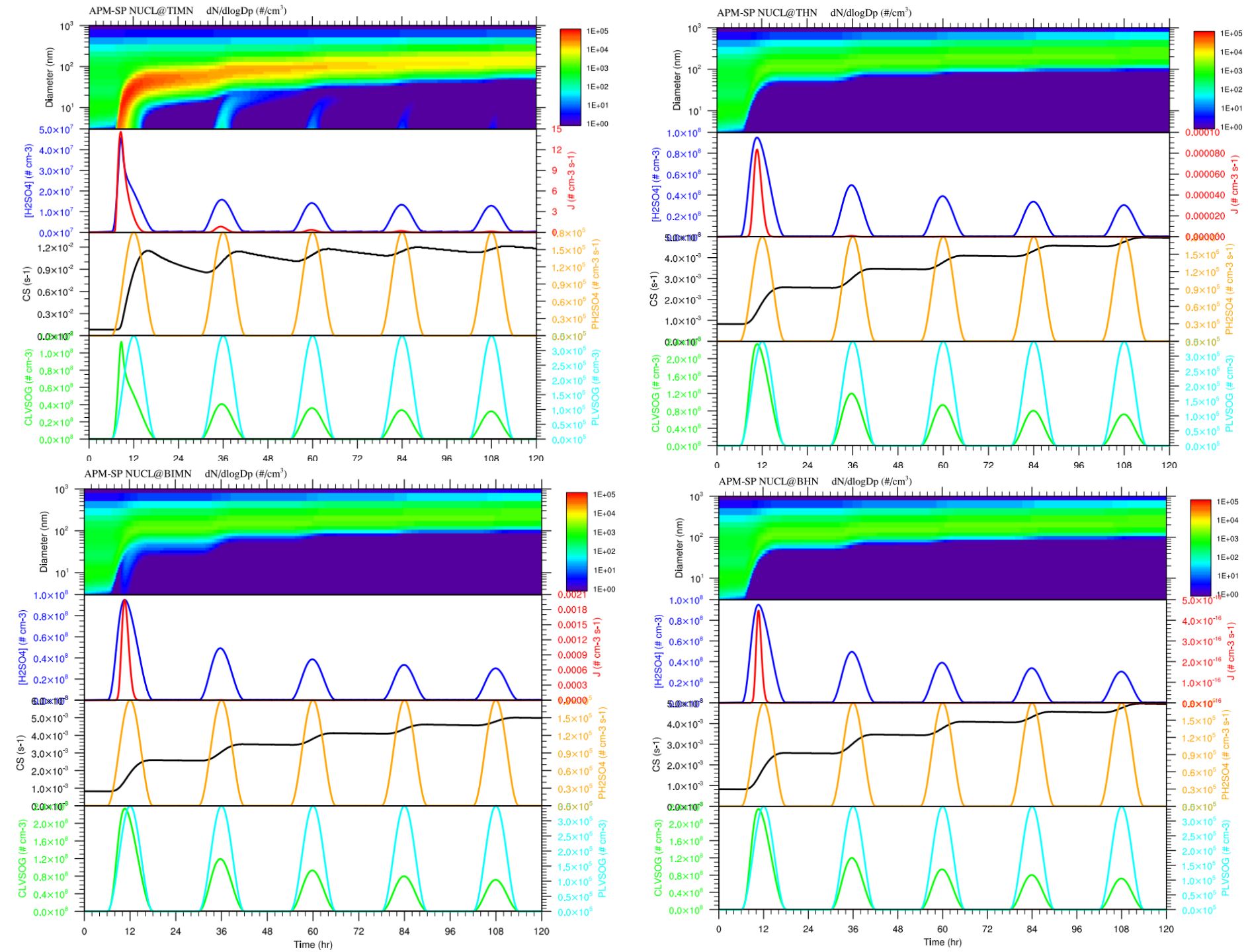
Winter case:

TK (K),RH (%),XQ (ion pairs cm-3 s-1),CNH3(ppbv)
285., 52., 10., 1.1

MSO4,MBC,MOC,MDST,MSEA (ug/m3)
1.0,0.15,0.23,1.d-20,0.03

PH2SO4max,PLVSOGmax (# cm-3 s-1)
1.8d5, 3.5d5

NUCLEATION SCHEMES:
TIMN, THN, BIMN, BHN


APM-SP NUCL@TIMN dN/dlogDp (#/cm3)
APM-SP NUCL@THN dN/dlogDp (#/cm3)
APM-SP NUCL@BIMN dN/dlogDp (#/cm3)
APM-SP NUCL@BHN dN/dlogDp (#/cm3)
Diameter (nm)
[H2SO4] (# cm-3)
J (# cm-3 s-1)
CS (s-1)
PH2SO4 (# cm-3 s-1)
CLVSOG (# cm-3)
PLVSOG (# cm-3)
Time (hr)