Observation and Numerical Modeling of Aerosol Effects on HIWC

Preliminary Results

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HIWC2022 Workshop
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NCAR

Today’s Talk

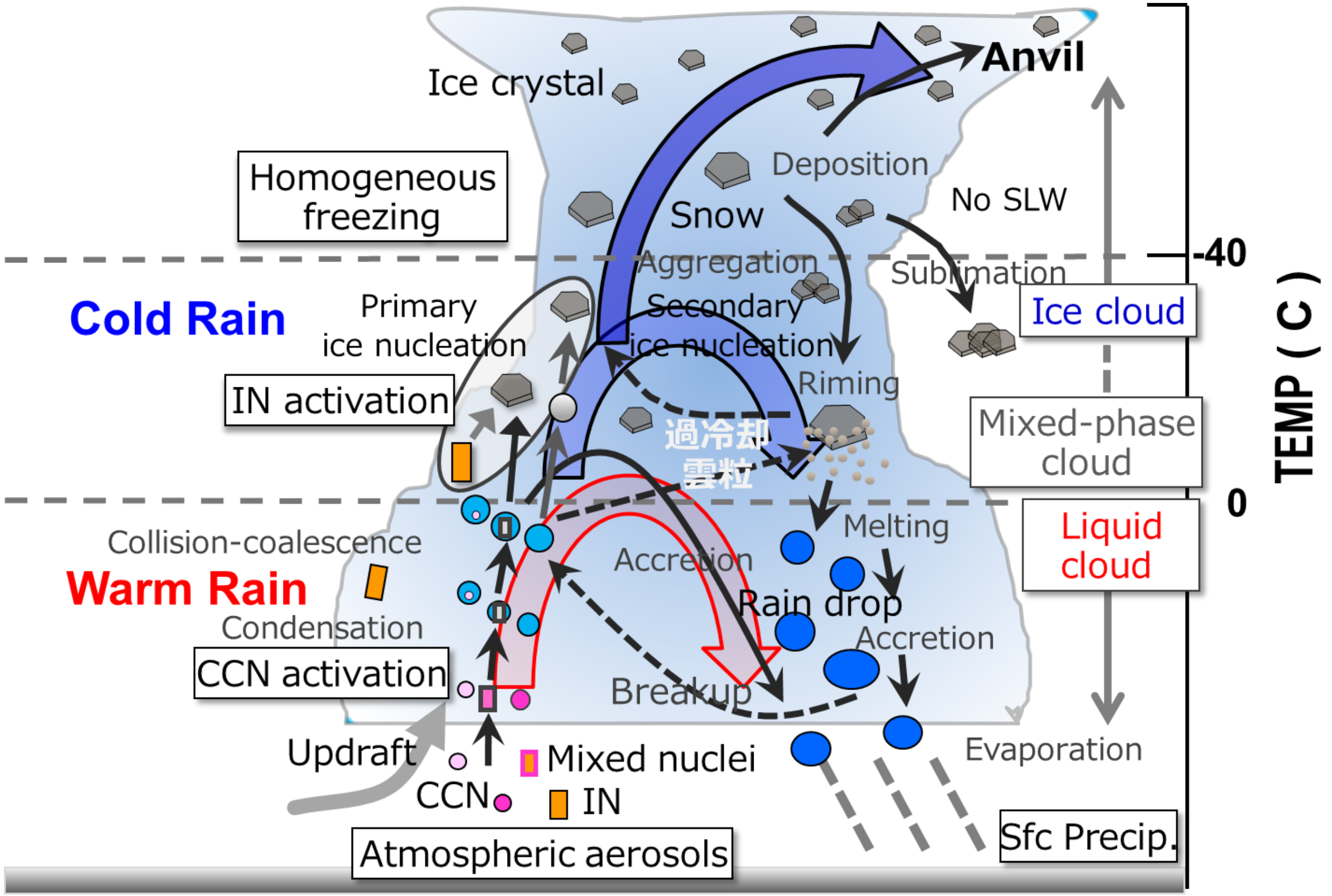
- Introduction　（Aircraft Observation）
- Idealized Sensitivity Experiments
- Hindcast Experiment for 30 July 2022 Case
- Summary
- Next Step toward the Workshop

Introduction

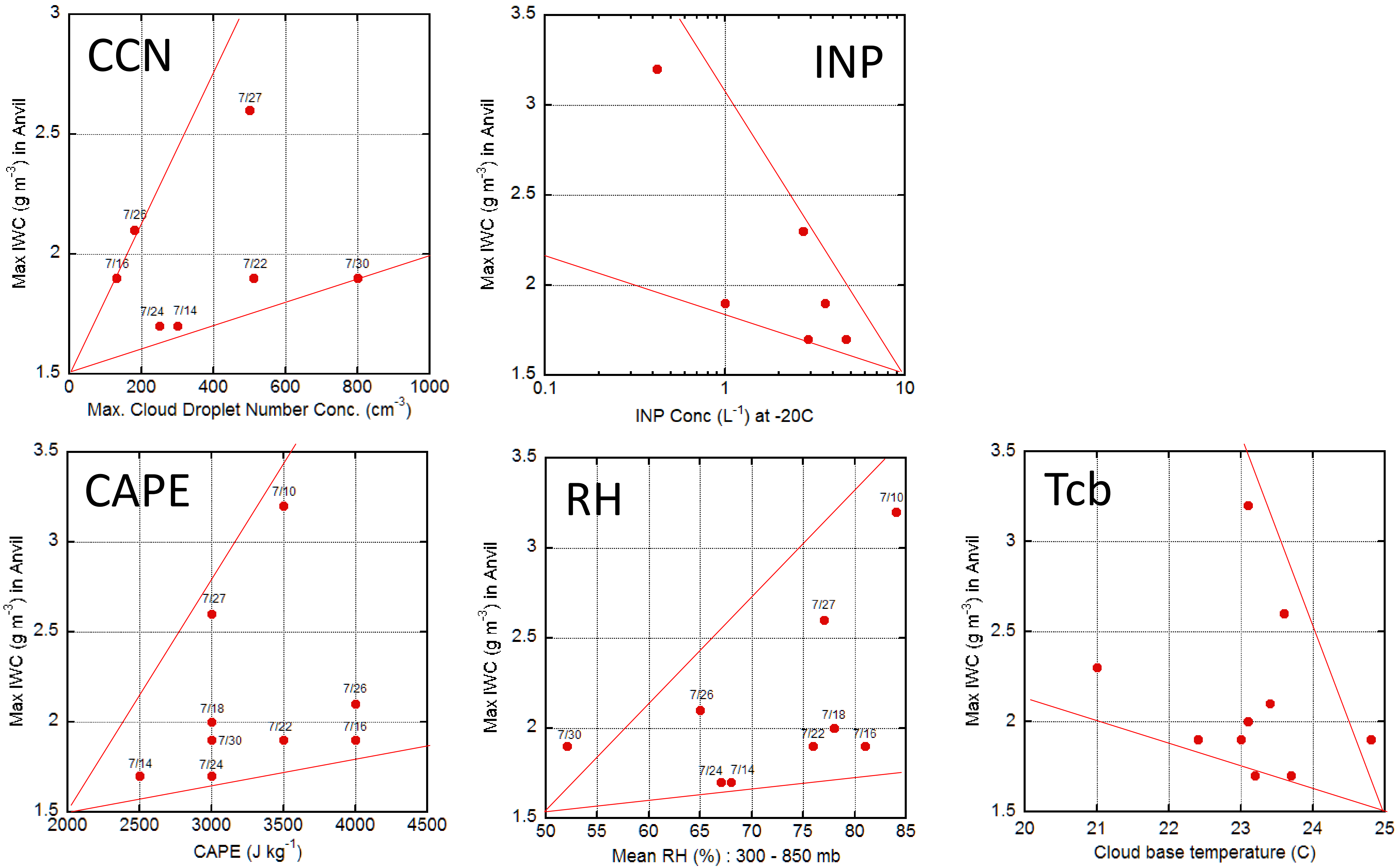
Factors Controlling IC Conc. in Anvil Cloud

Factors	Feedback
Tcb	+/-
W	+
CCN	+
INP	-
DryAir	-

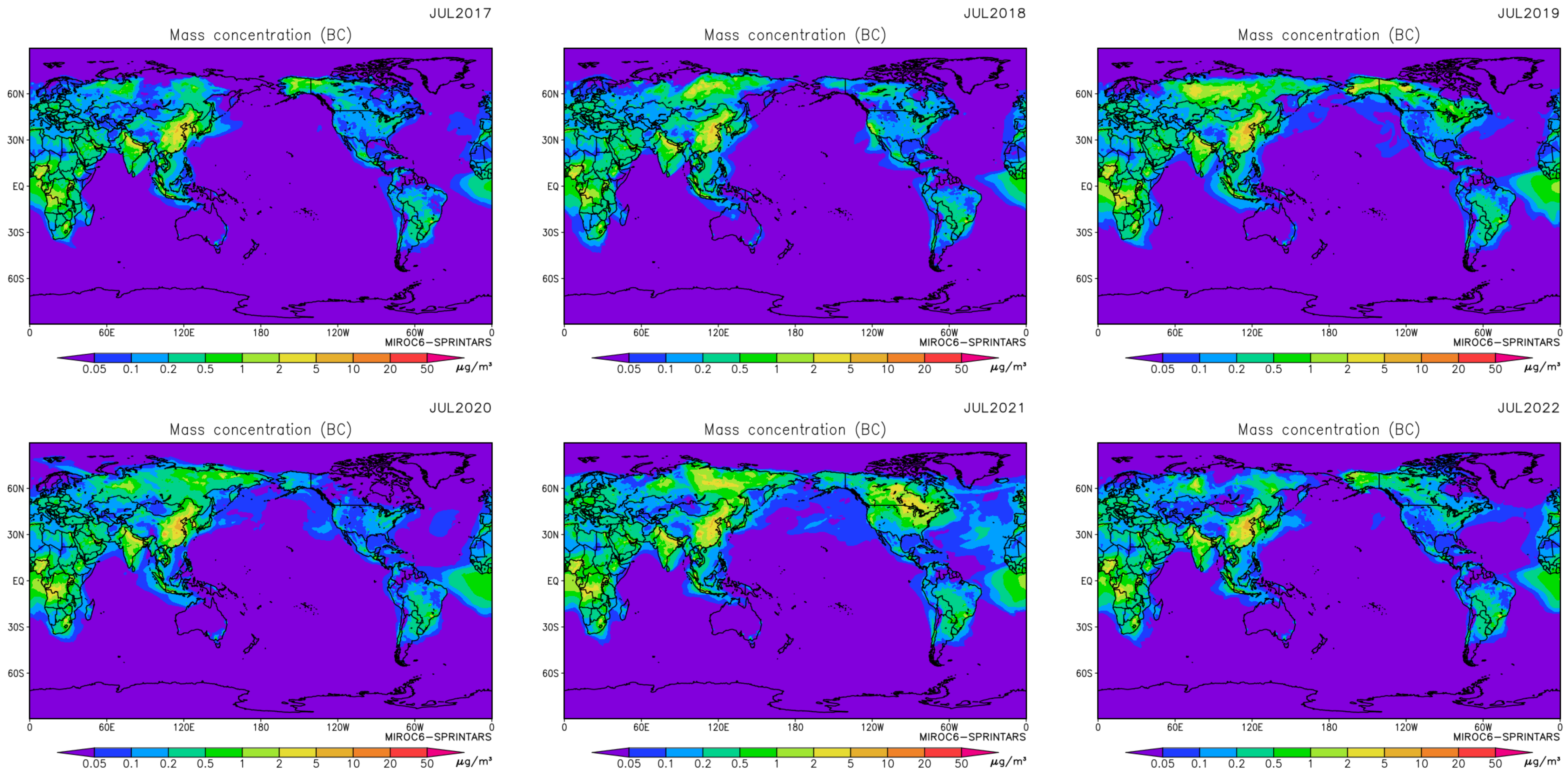
	Continental		Maritime
Tcb	+		-
W		>	
CCN		>?	
INP		>?	
DryAir		>?	



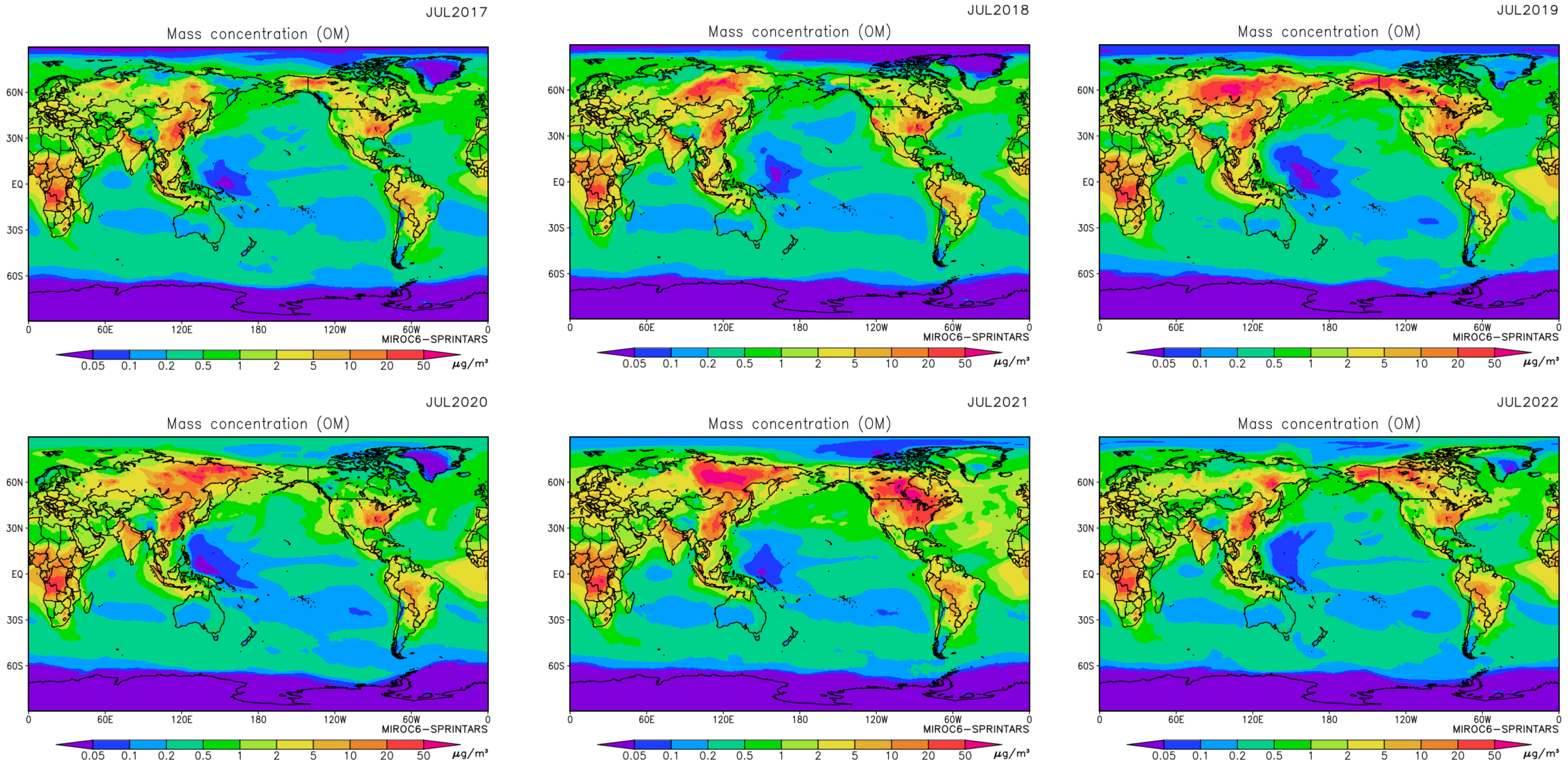
Relation between IWC and Parameters



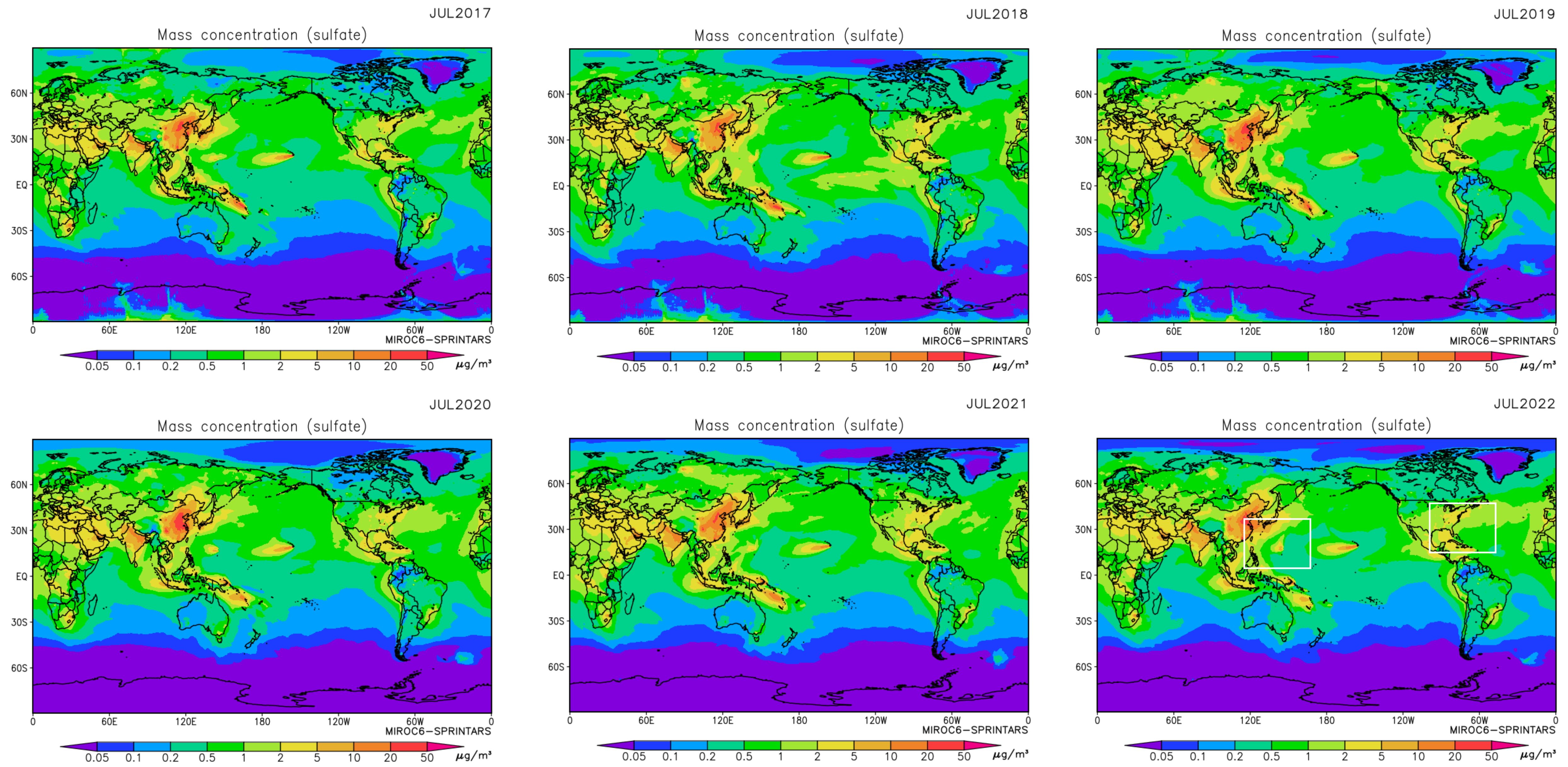
Monthly Average of BC (from SPRINTARS)



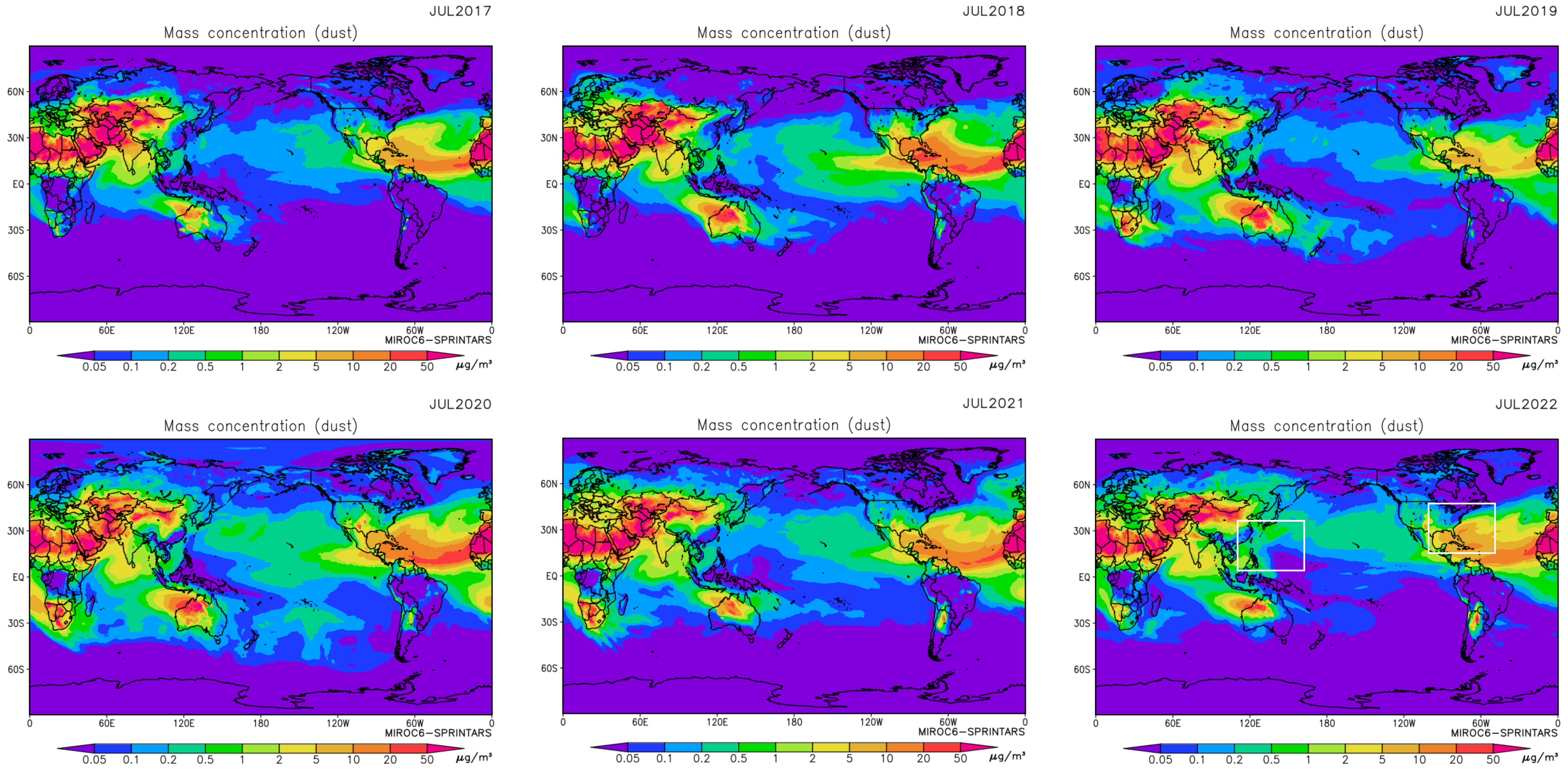
Monthly Average of OM (from SPRINTARS)



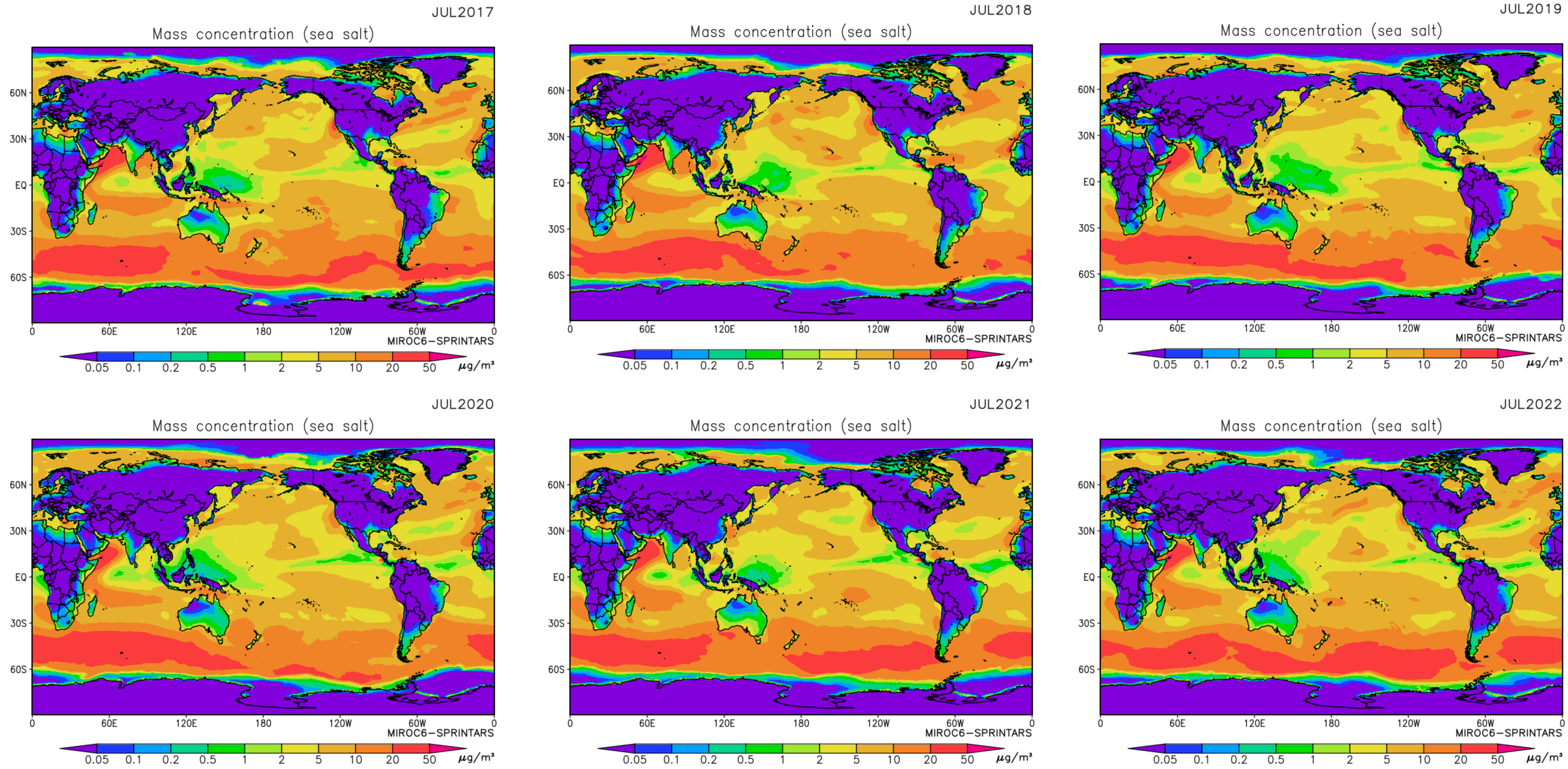
Monthly Average of Sulfate (from SPRINTARS)



Monthly Average of Dust (from SPRINTARS)



Monthly Average of Sea Salt (from SPRINTARS)



Idealized Sensitivity Experiments

Numerical Model
（Aerosol-Cloud-Precipitation Integrated Parameterization)
Purpose：Planned and Inadvertent Weather Modification Research

CReSS-4ICE-CCN

Effects of Aerosols acting as CCN on Clouds and Precipitation（Simplified version）

6 types of Hydrometeors (including hail), Double-moment Gamma size distributions,

New CCN Activation Scheme

Initial Condition for CCN Aerosol：　Uniform in the Domain, or Vertical Profile of CCN Activation Spectra

Hygroscopic seeding scheme is available

CReSS-4ICE-AEROSOL

Effects of Aerosols acting as CCN/INP on clouds and Precipitation

Up to 20 Aerosol Types in air and 6 Hydrometeors > Prognostic Variables

Double-moment Log-normal size distributions > Prognostic Variables

Each Aerosol Type has CCN (hygroscopicity) and INP (INAS density) Ability

$INAS_{imm/cond}(T) = bb\ exp(aa\ T)$, $INAS_{cont}(T) = bb\ exp(aa\ (T-4))$

$INAS_{dep}(SSi) = dd\ exp(cc\ SSi)$

Processes：　Advection, Diffusion, Precip. Scavenging（cloud water; Brownian and turbulent diffusion, phoretic effects, others; Brownian diffusion, interception and impaction）**,Nucleation Scavenging, Ice Nucleation（Homo. Freezing, Immersion/Condensation Freezing, Contact Freezing, Deposition Nucleation）, Aerosol Re-generation during hydrometeors' evaporation/sublimation, Aerosol transportation associated with interaction among hydrometeors**

Aerosol Initial Conditions(Idealized experiment) : Vertical Profiles

Aerosol Initial/Boundary Conditions: Global Aerosol Model Output (e.g. SPRINTARS)

Various Seeding Methods are available

Initial and Boundary conditions for Aerosols（1）
（SPRINTARS > CReSS−4ICE−AEROSOL）

SPRINTARS

Sea Salt Particles

SD: Sectional (4 bins, mass, 0.1 – 10 μm)

ρa = 2.2 g cm^{-3}, κ = 1.16 ,

Mineral Dust Particles

SD: Sectional (6 bins, mass, 0.1 – 10 μm)

ρa = 2.6 g cm^{-3}, κ = 0.14 ,

CReSS-4ICE-AEROSOL

Sea Salt Particles

SD: Log-normal_μ (mass, number, mode radius , σ=2.0)

ρa = 2.2 g cm^{-3}, κ = 1.2,

INAS_aa = 0.0e0, INAS_bb = 0.0e0, INAS_cc = 0.0e0, INAS_dd = 0.0e0

SD: Log-normal_sub-μ (mass, number, mode radius , σ=2.0)

ρa = 2.2 g cm^{-3}, κ = 1.2,

INAS_aa = 0.0e0, INAS_bb = 0.0e0, INAS_cc = 0.0e0, INAS_dd = 0.0e0

Mineral Dust Particles

SD: Log-normal_μ (mass, number, mode radius , σ=2.0)

ρa = 2.6 g cm^{-3}, κ = 0.03,

INAS_aa = -0.517e0, INAS_bb = 7.86e3, INAS_cc = 0.52e0, INAS_dd = 1.813e3

SD: Log-normal_sub-μ (mass, number, mode radius , σ=2.0)

ρa = 2.6 g cm^{-3}, κ = 0,03,

INAS_aa = -0.517e0, INAS_bb = 7.86e3, INAS_cc = 0.52e0, INAS_dd = 1.813e3

$INAS_{imm/cond}(T) = bb \exp(aa\, T)$, $INAS_{cont}(T) = bb \exp(aa\, (T-4))$

$INAS_{dep}(SSi) = dd \exp(cc\, SSi)$

Initial and Boundary conditions for Aerosols（2）
（SPRINTARS ＞ CReSS-4ICE-AEROSOL）

SPRINTARS

Sulfate Particles

SD: Log-normal (mass, mode radius = 0.0695 μm, σ=2.0)
ρa= 1.769 g cm^{-3}, κ= 0.51,

Organic Carbone (OC) Particles

SD: Log-normal_ex (mass, mode radius= 0.1 μm , σ=2.0)
ρa = 1.8 g cm^{-3}, κ = 0.14,
SD: Log-normal_in (mass, mode radius= 0.1 μm , σ=2.0)
ρa = 1.8 g cm^{-3}, κ = 0.14,

Black Carbone (BC) Particles

SD: Log-normal_ex (mass, mode radius = 0.1 μm , σ=2.0)
ρa = 2.3 g cm^{-3}, κ = $5x10^{-7}$,
SD: Log-normal_in (mass, mode radius = 0.1 μm , σ=2.0)
ρa = 2.3 g cm^{-3}, κ = $5x10^{-7}$,

OCs of human activity and forest fire origin are all internally mixed with BC.
For BC, all forest fire origins are internally mixed with OC, while human activity origins are half external and half internal.
Plant-origin secondary OC is an external mixture.

CReSS-4ICE-AEROSOL

Sulfate Particles

SD: Log-normal (mass, number, mode radius_ini = 0.0695 μm, mode radius , σ=2.0)
ρa = 1.8 g cm^{-3}, κ = 0.68,
INAS_aa = 0.0e0, INAS_bb = 0.0e0, INAS_cc = 0.0e0, INAS_dd = 0.0e0

Organic Carbone (OC) Particles

SD: Log-normal (mass, number, mode radius_ini = 0.1 μm , mode radius , σ=2.0)
ρa = 1.3 g cm^{-3}, κ = 0.1,
INAS_aa = 0.0e0, INAS_bb = 0.0e0, INAS_cc = 0.0e0, INAS_dd = 0.0e0

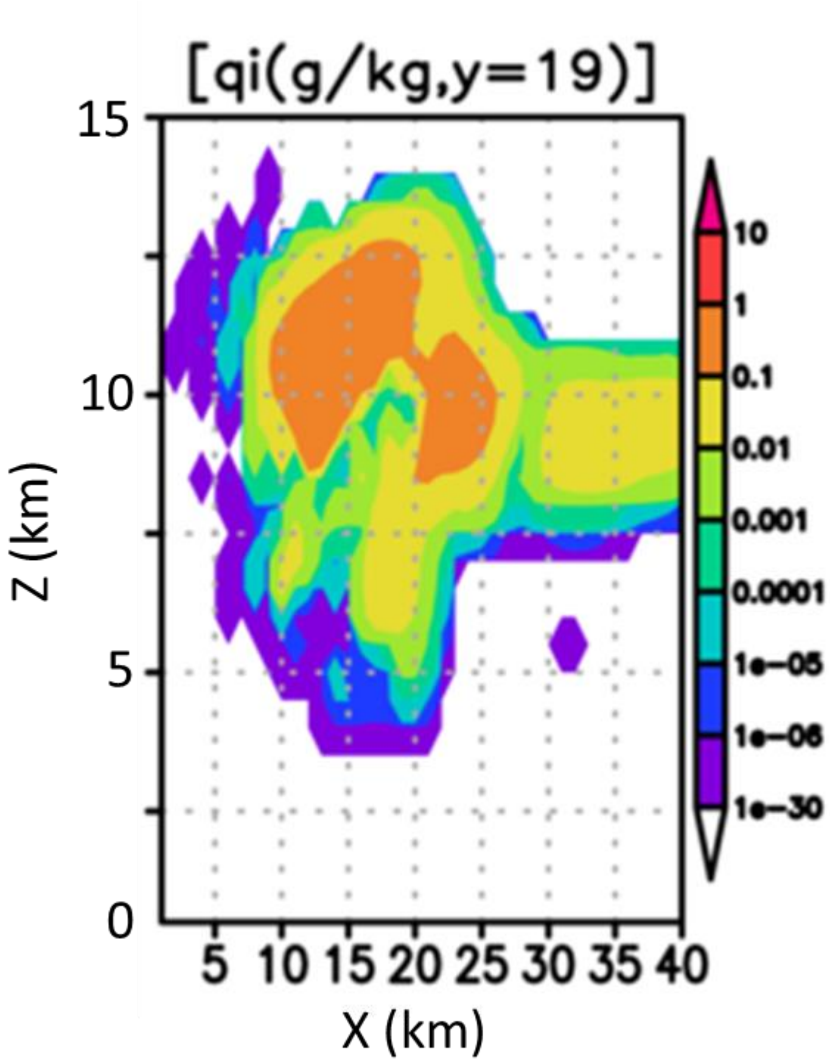
Black Carbone (BC) Particles

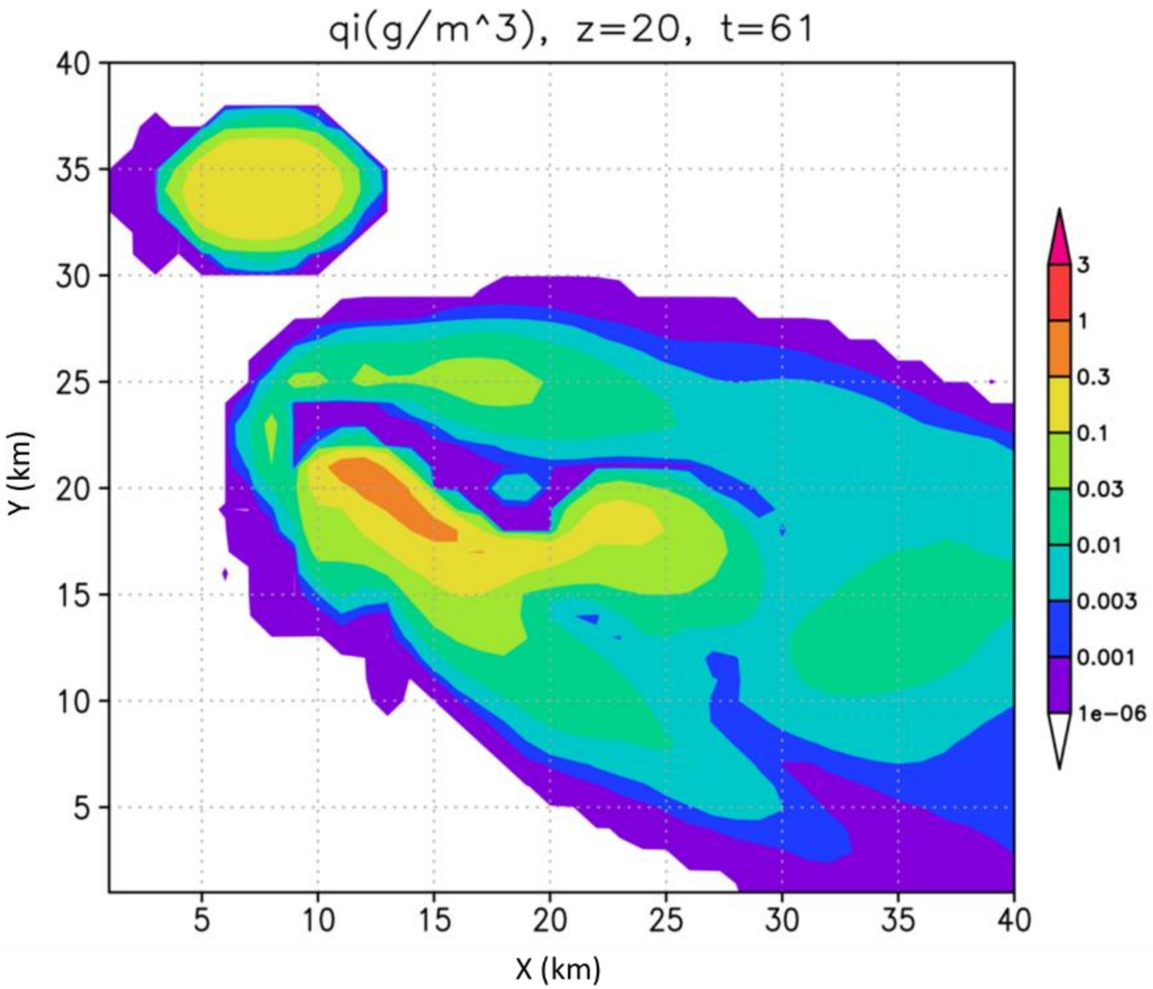
SD: Log-normal (mass, number, mode radius_ini = 0.1 μm , mode radius , σ=2.0)
ρa = 0.3 g cm^{-3}, κ = 0.01,
INAS_aa = -0.517e0, INAS_bb = 7.86e3, INAS_cc = 0.52e0, INAS_dd = 1.813e3

Internal Mixture of OC & BC

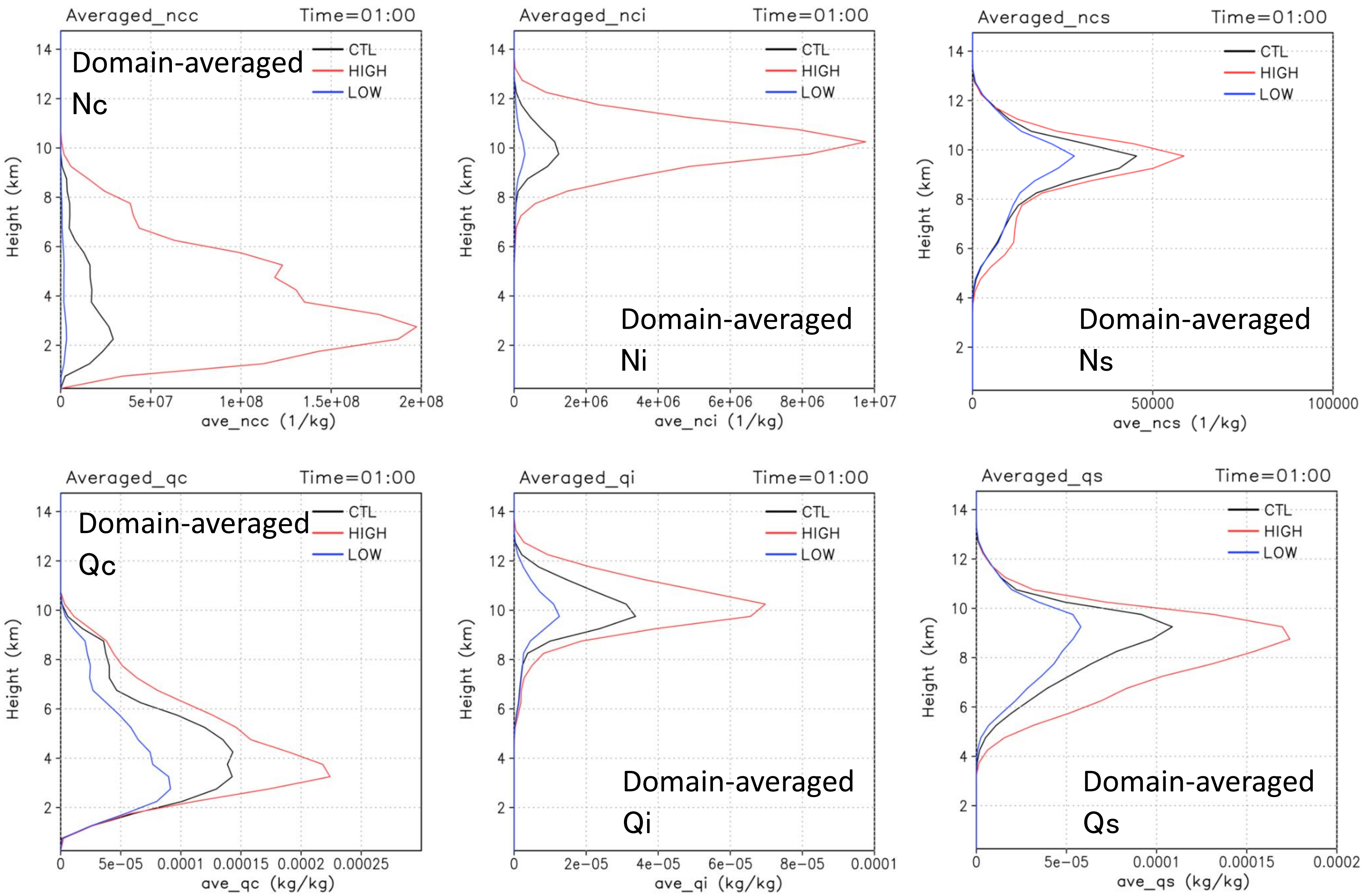
SD: Log-normal (mass, number, mode radius_ini = 0.1 μm , mode radius , σ=2.0)
ρa = 1.3 g cm^{-3}, κ = 0.1,
INAS_aa = -0.517e0, INAS_bb = 7.86e3, INAS_cc = 0.52e0, INAS_dd = 1.813e3

Qi in anvil cloud associated with Supercell (Idealized Sensitivity Experiments, CTL)



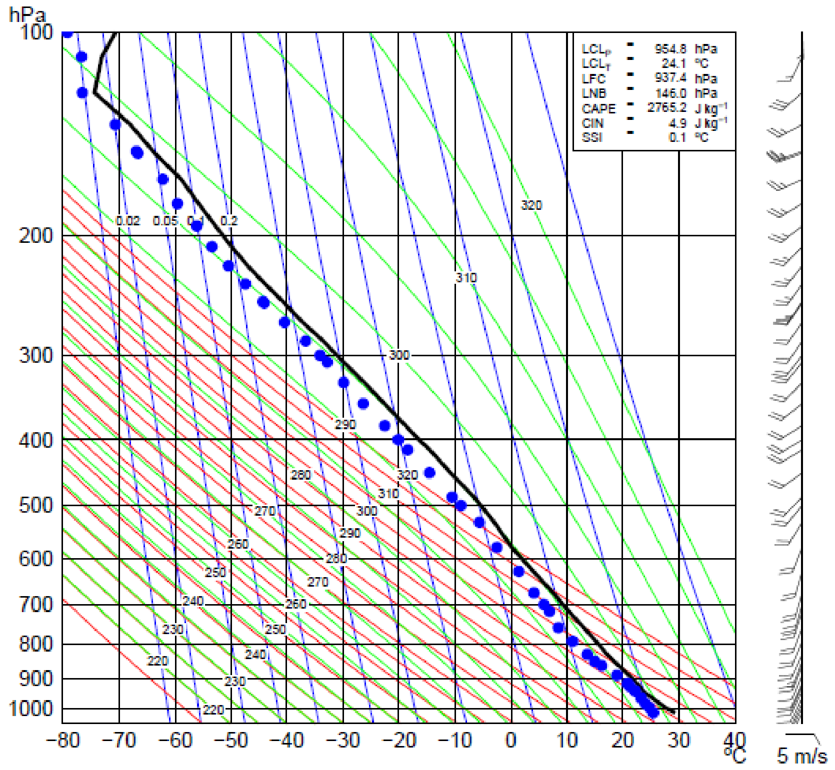


Aerosol effects on HIWC in anvil cloud associated with Supercell
(Idealized Sensitivity Experiments)



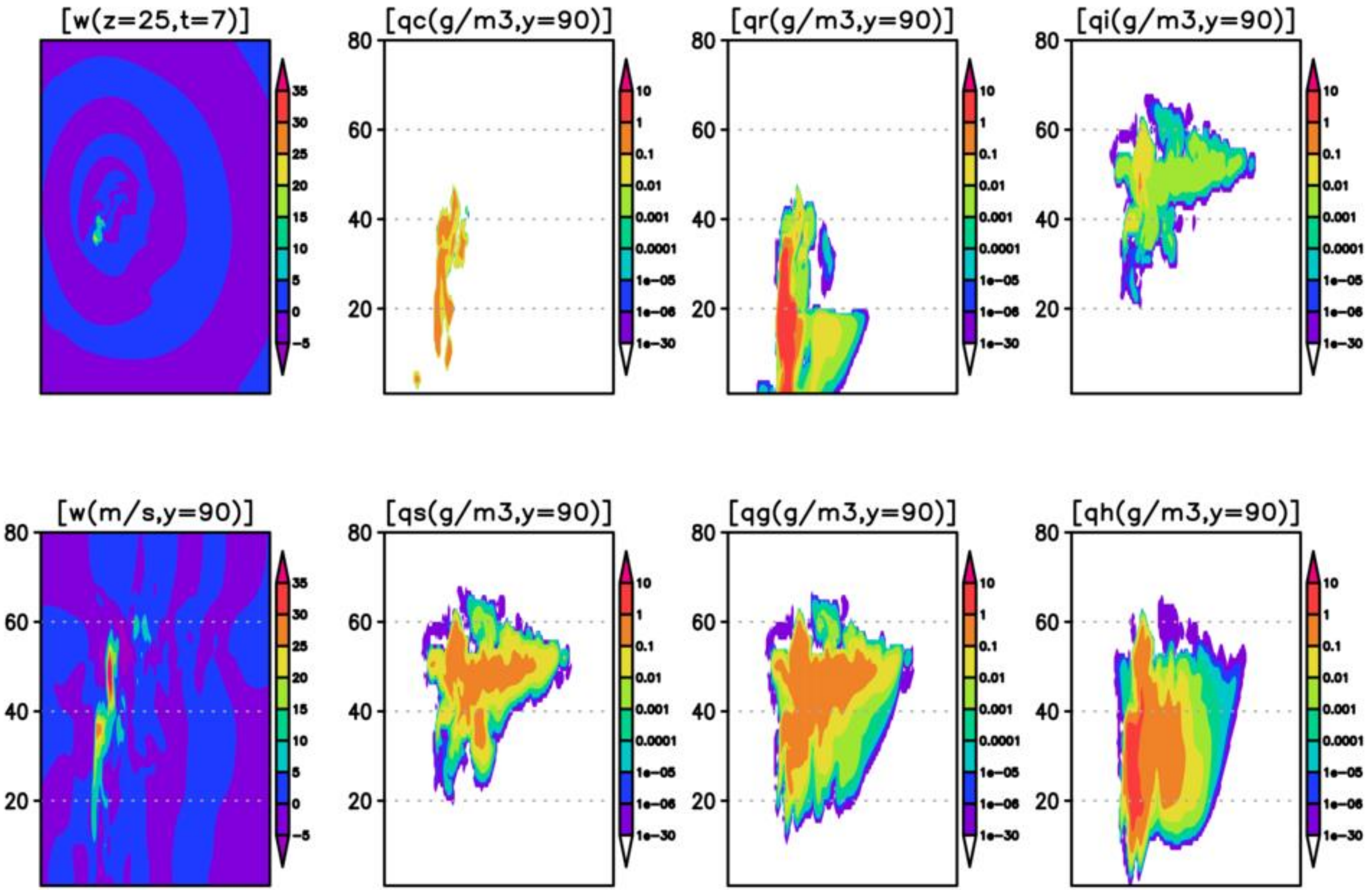
Setup for Sensitivity Experiments

Model : CReSS-4ICE-AEROSOL
Domain : 50km x 50km 20km
Resolution : 250m x 250m x 250m
Integration Time : 2 hours
Sounding: Typical for summertime MCS formation environment off the East Coast of U.S.
Aerosol sounding : Typical for summertime environment off the East Coast of U.S.

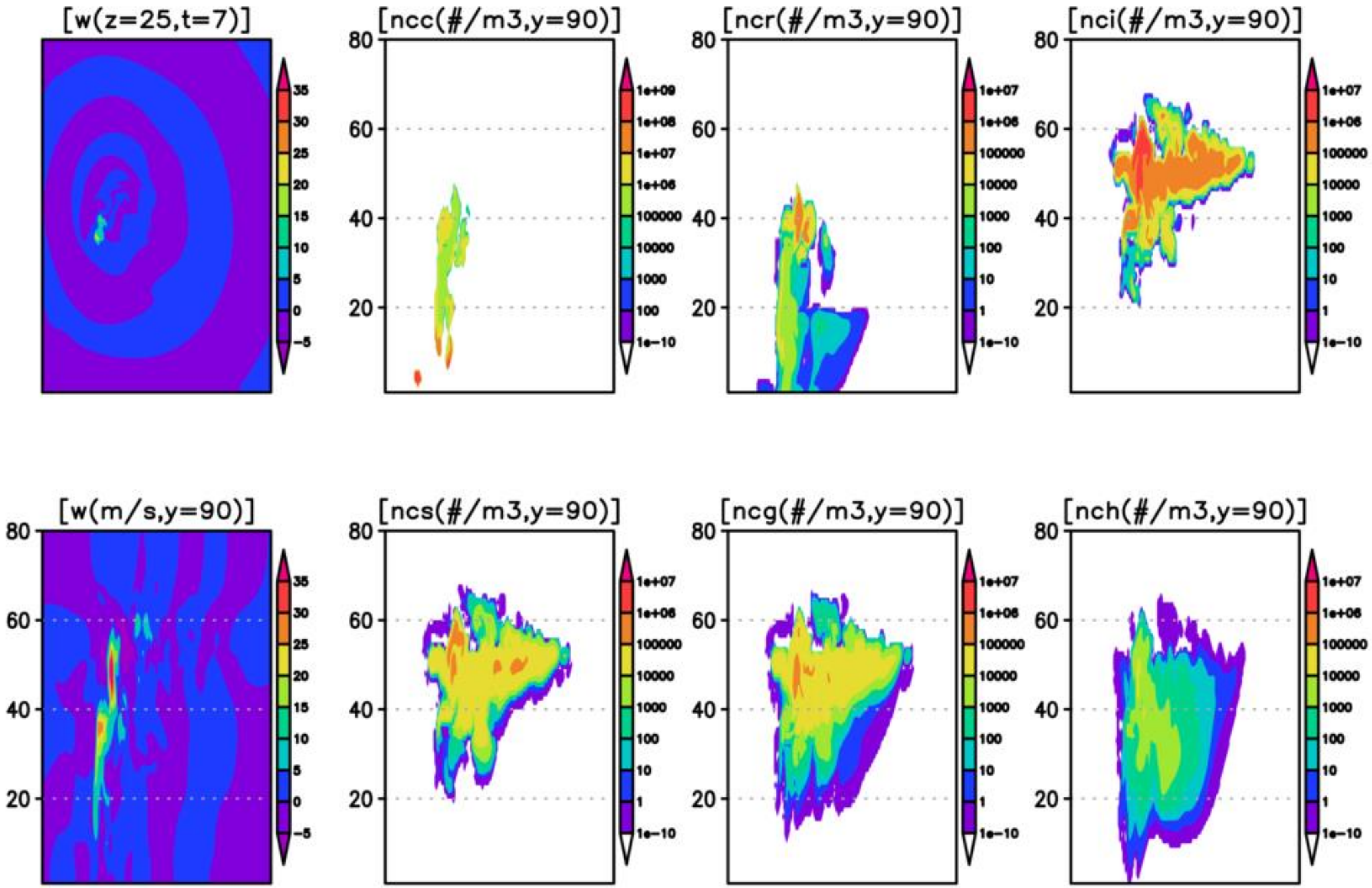


	CTL	hiCAPE	loCAPE	hiTcb	loTcb	hi/loRH	hi/loSHR
LCL_P (hPa)	954.8	954.8	954.8	954.4	955.2	At 530 hPa	
LCL_T (C)	24.1	24.1	24.1	26.0	22.1	RHctl * 1.2	Uctl*1.5
LFCP (hPa)	937.4	938.1	938.1	932.0	940.5	RHctl*0.78	Uctl*0.5
LNB (hPa)	146.0	145.9	145.9	147.1	147.4		
CAPE	2765.2	3037.8	2497.3	2953.9	2609.5		
CIN	4.9	4.9	4.9	5.1	4.8		

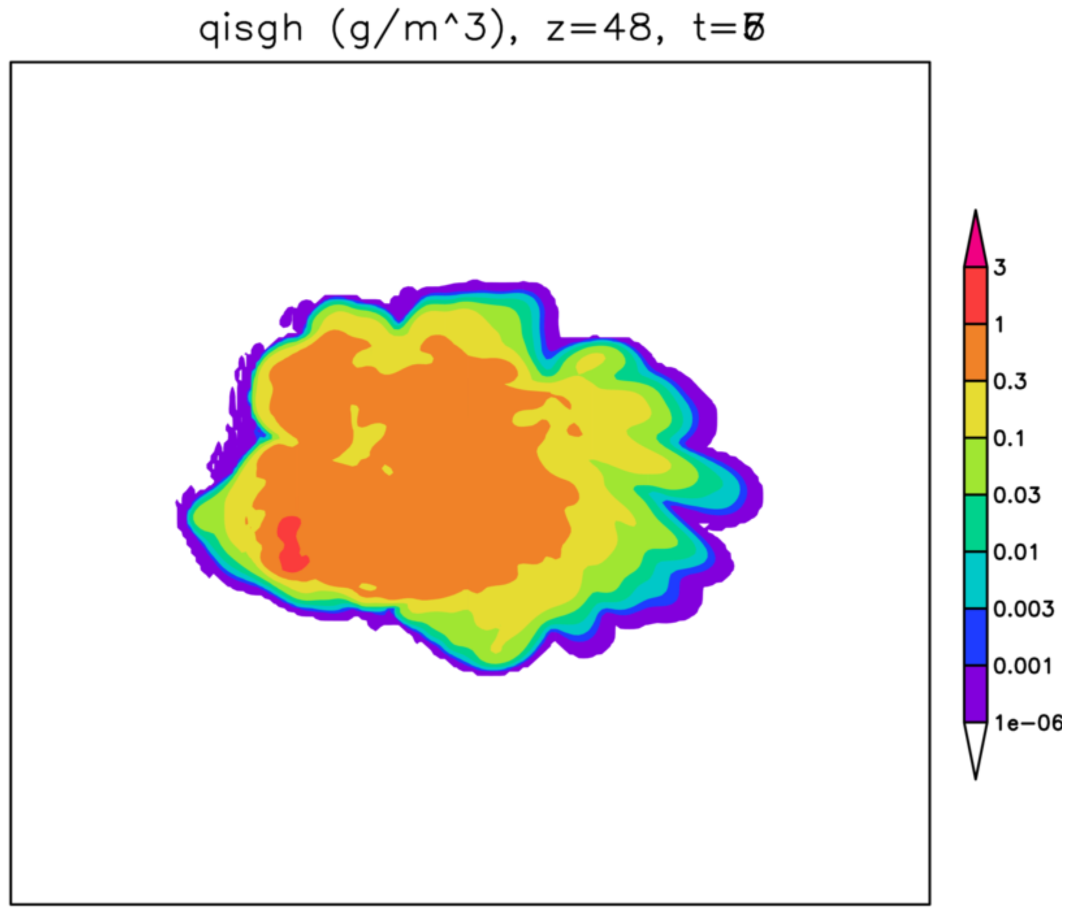
Qx in anvil cloud associated with MCSs
（Idealized Sensitivity Experiments, CTL, 60 min）

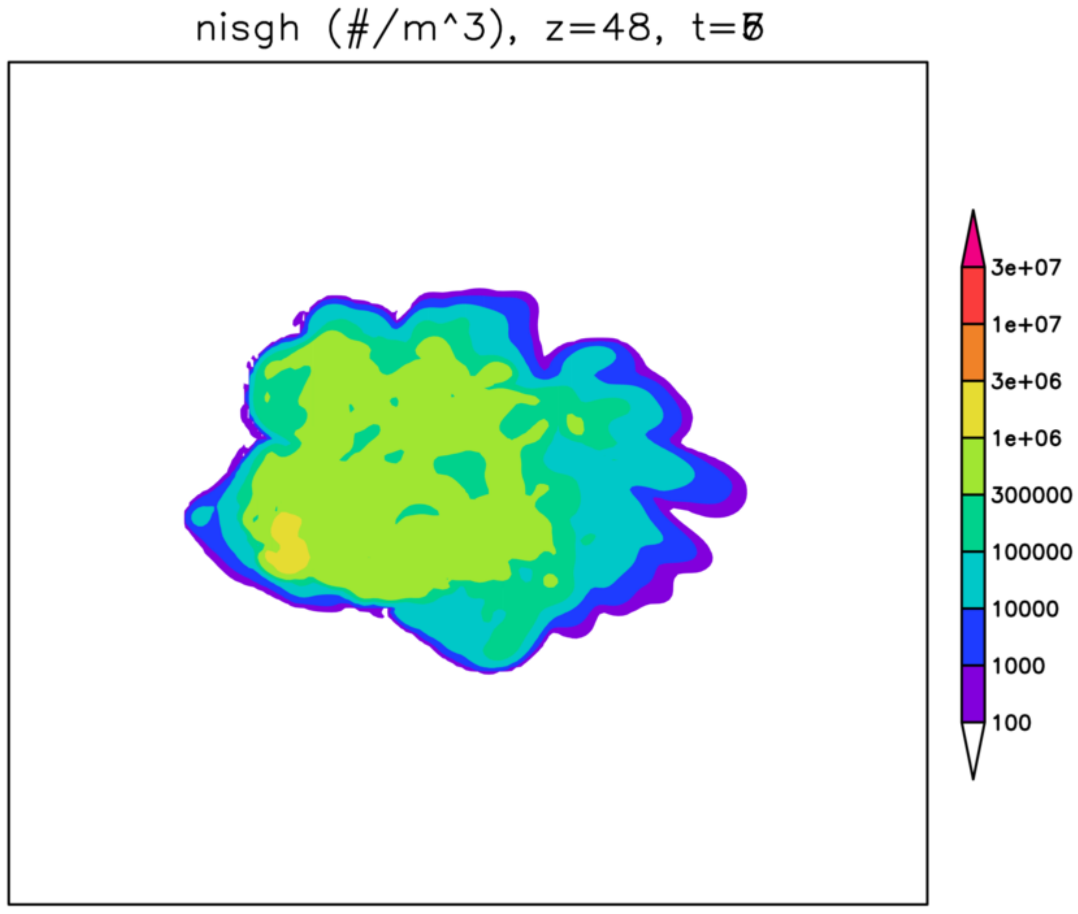


Nx in anvil cloud associated with MCSs
(Idealized Sensitivity Experiments, CTL, 60 min)

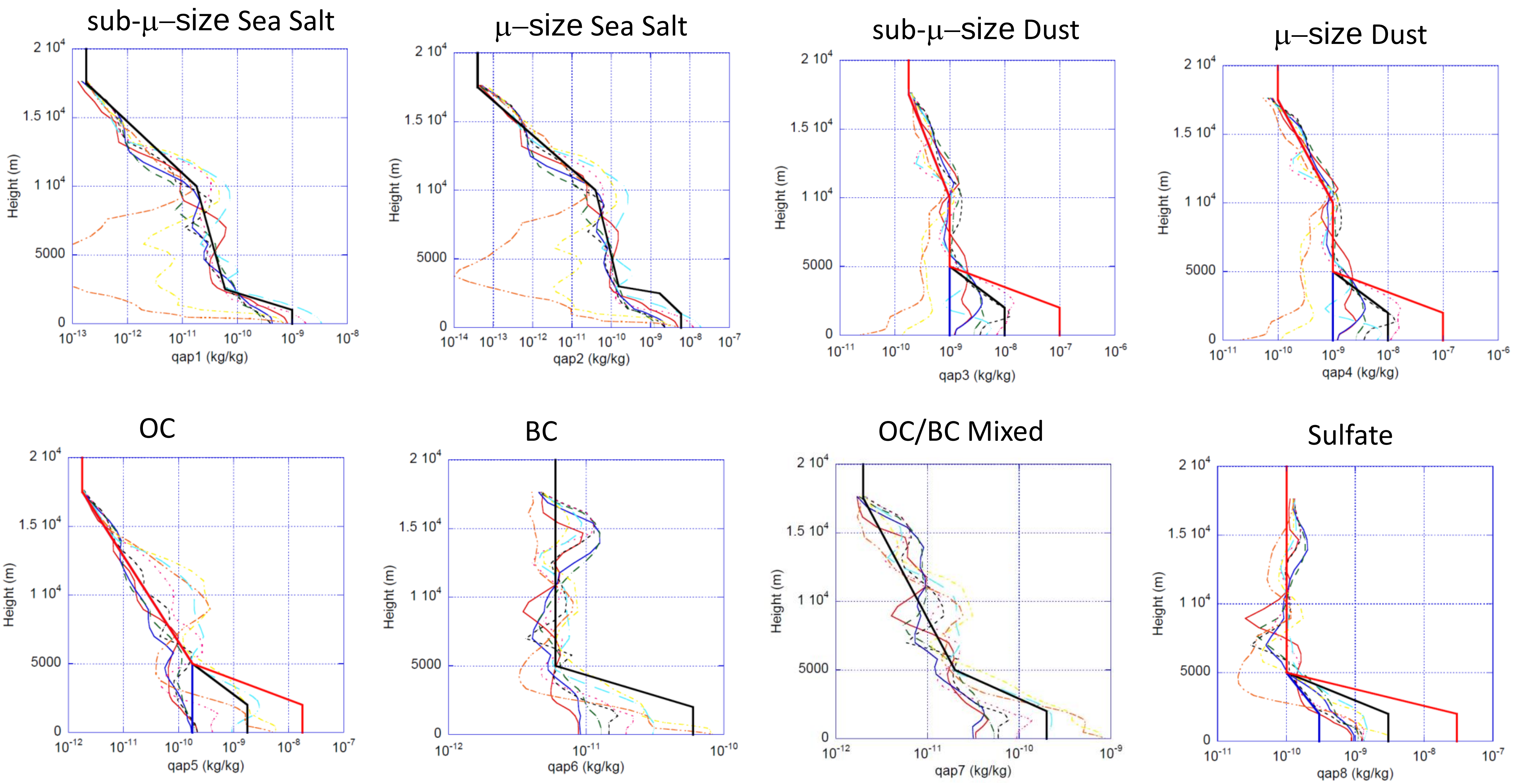


IWC and Nice in anvil cloud associated with MCSs
(Idealized Sensitivity Experiments, CTL, 60 min, 11.6 km)

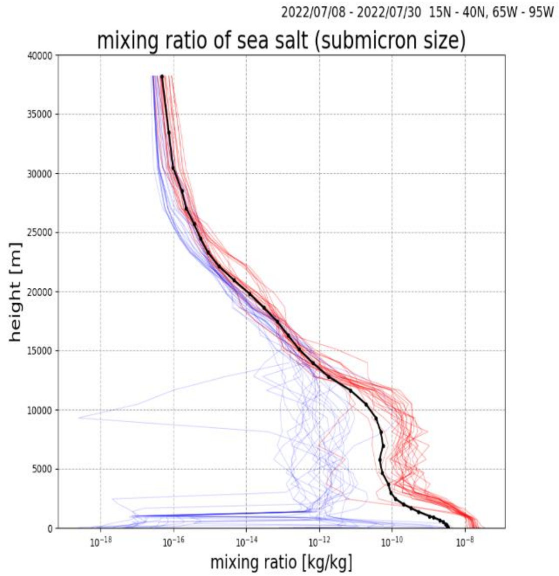


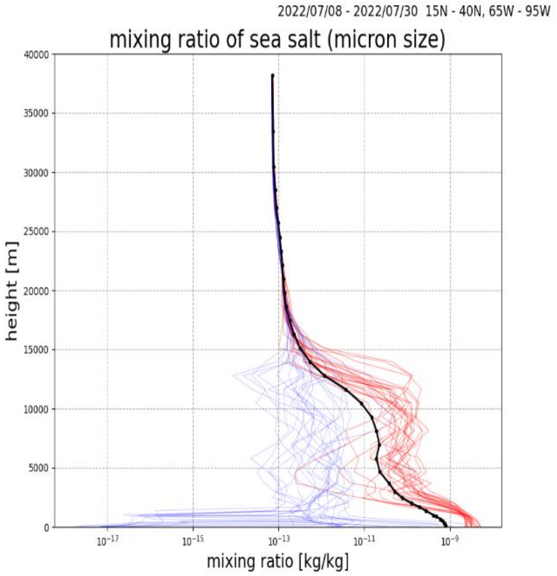


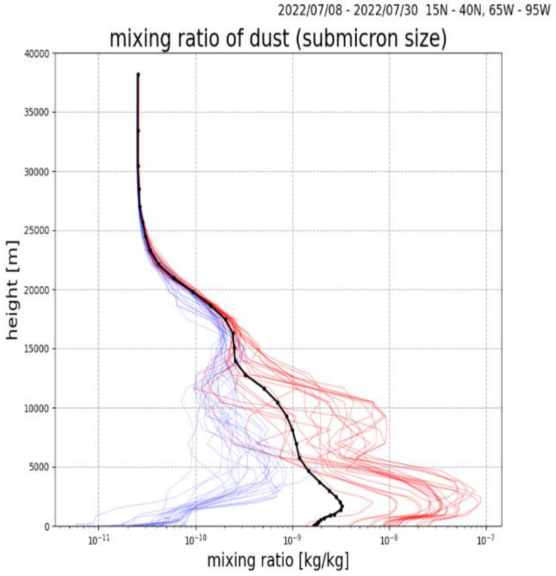
Vertical Profiles of Aerosol Mass Mixing Ratio (Initial Condition)

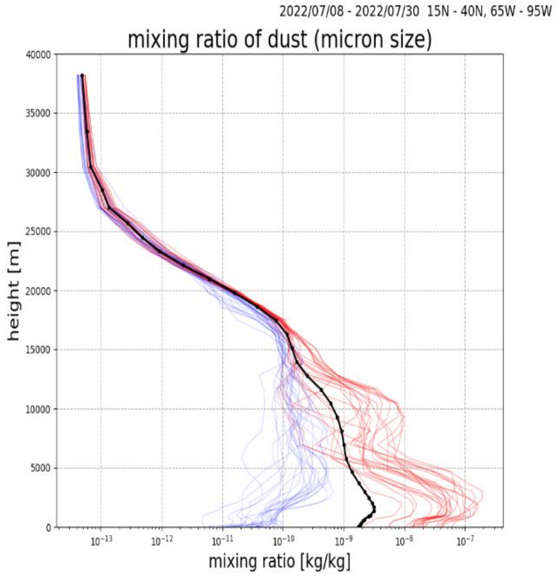


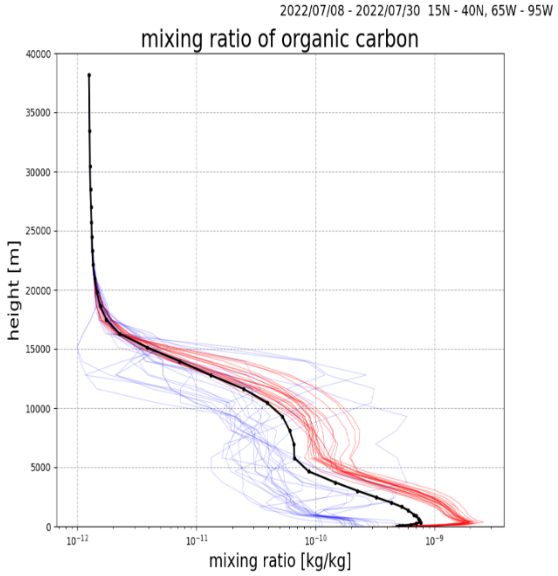
Daily Max- & Min- Profiles of Aerosols in the Observation Area

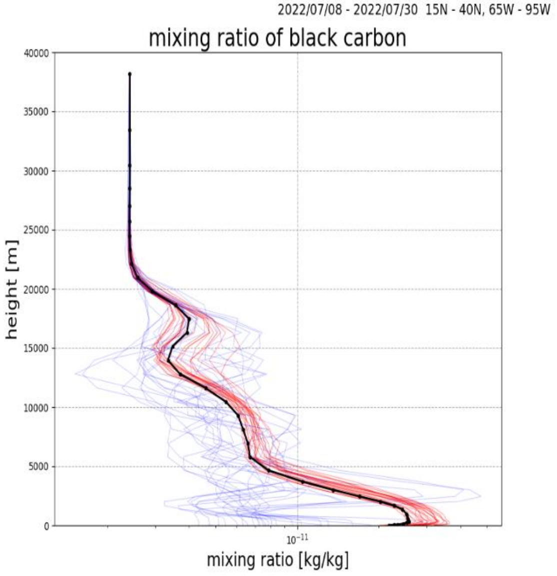


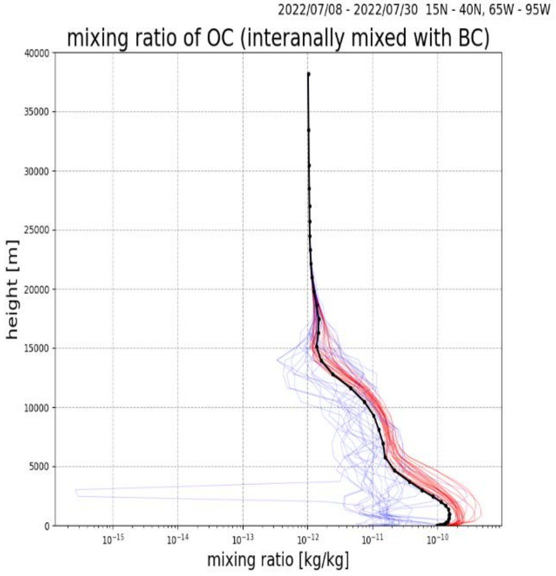


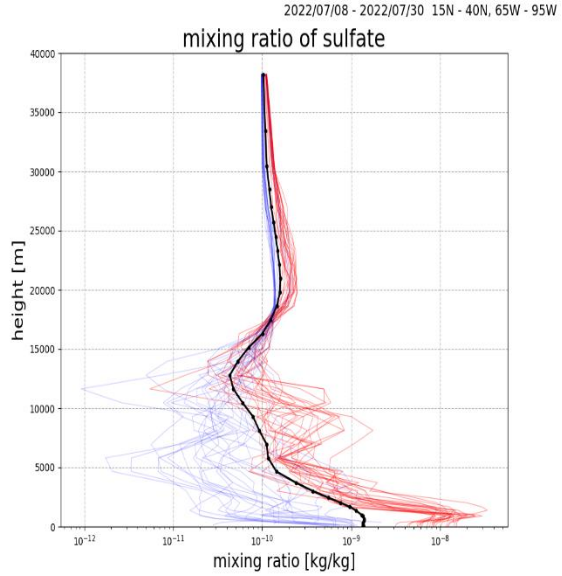






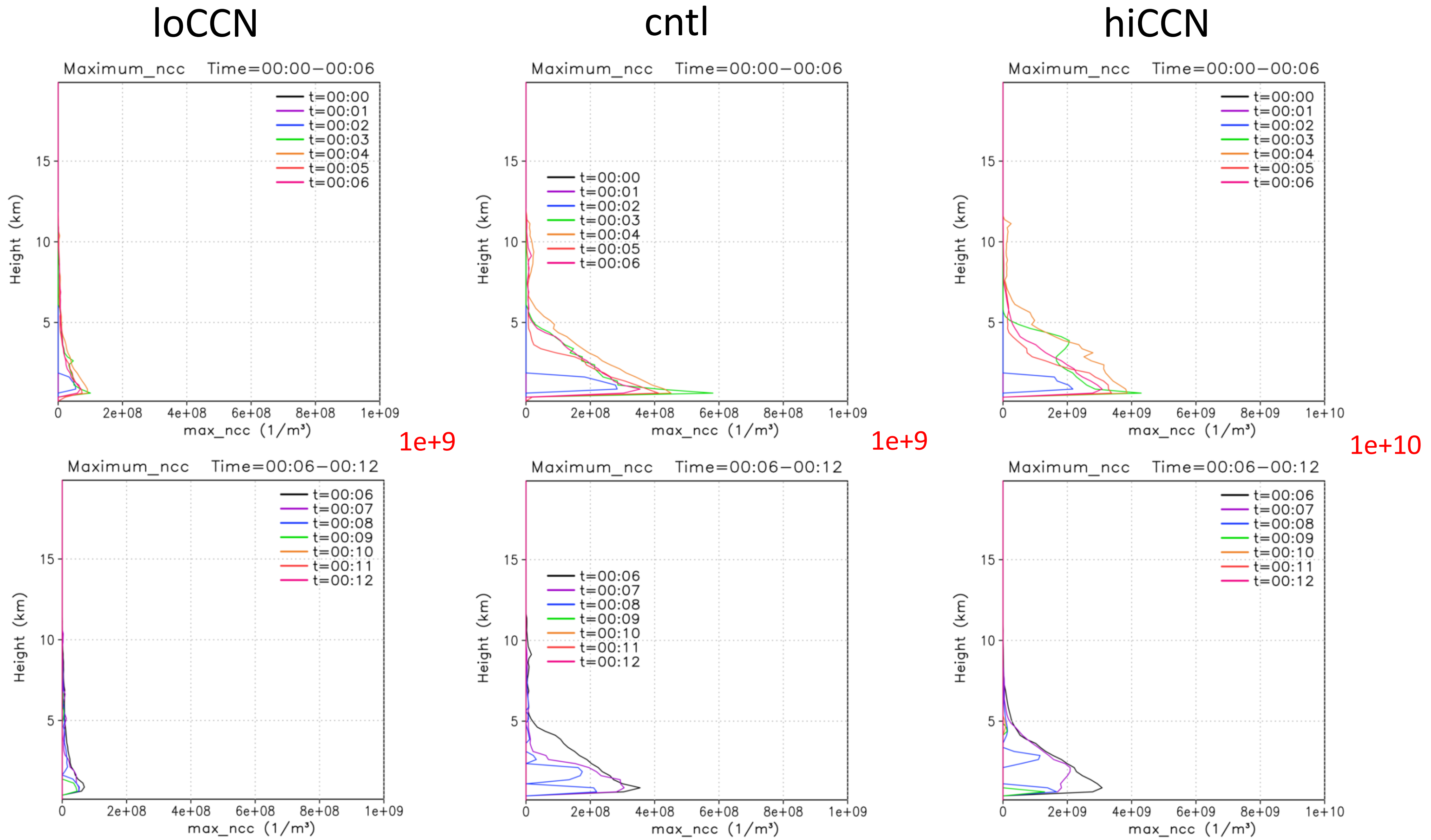






Aerosol effects on HIWC in anvil cloud associated with MCSs

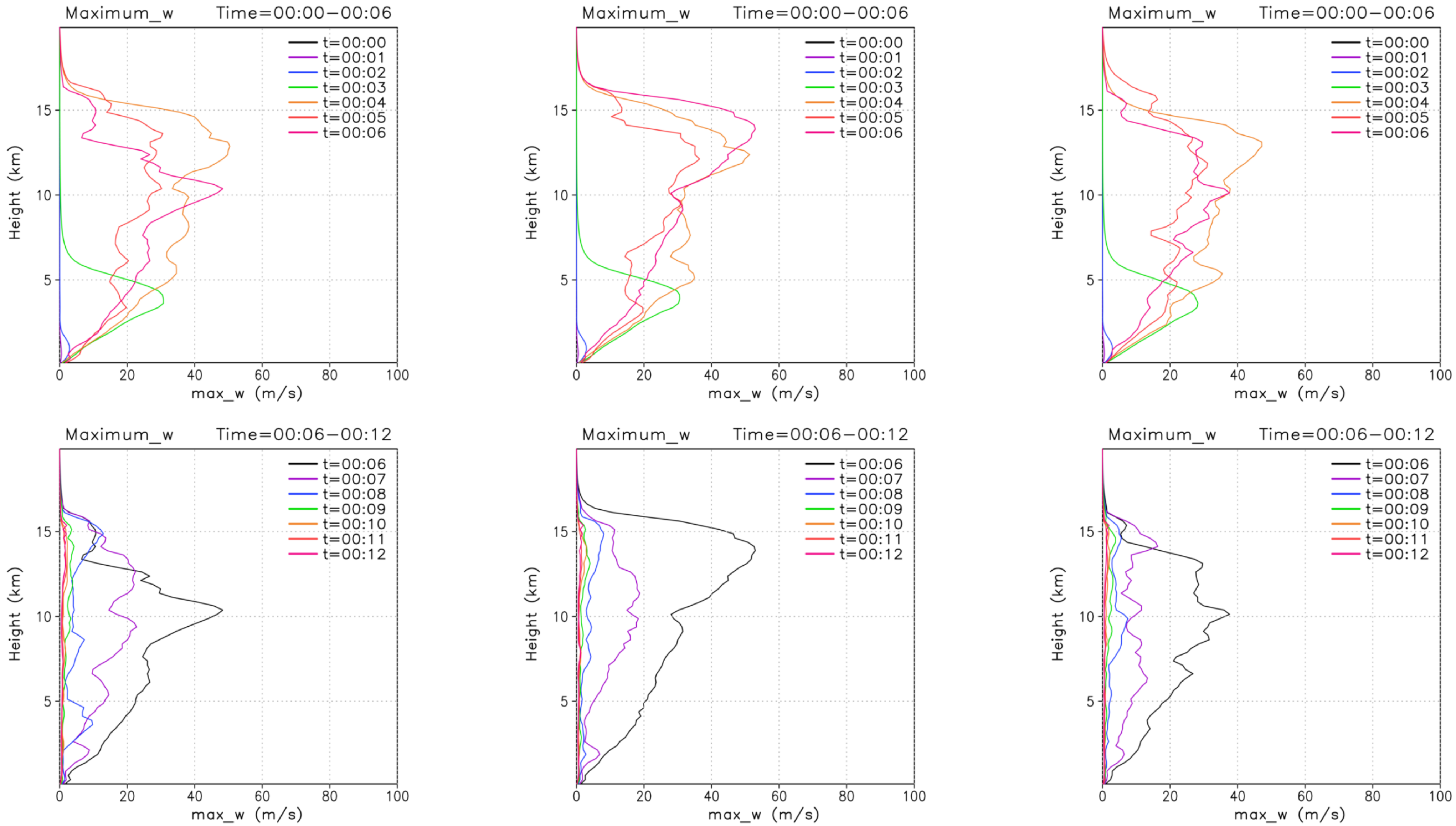
(Domain-maximum Nc; Idealized Sensitivity Experiments)



Aerosol effects on HIWC in anvil cloud associated with MCSs

(Domain-maximum W; Idealized Sensitivity Experiments)

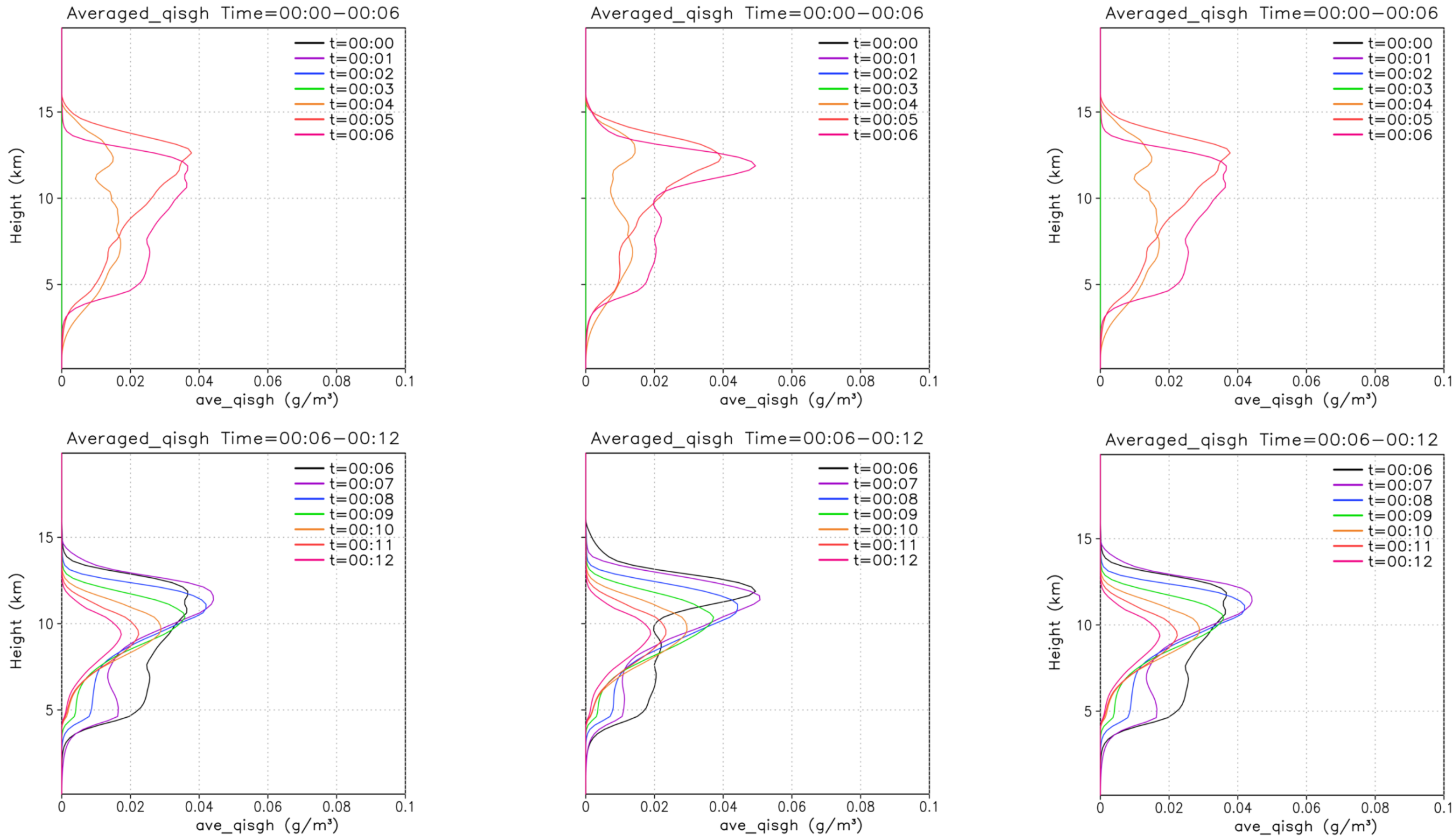
loCCN **cntl** **hiCCN**



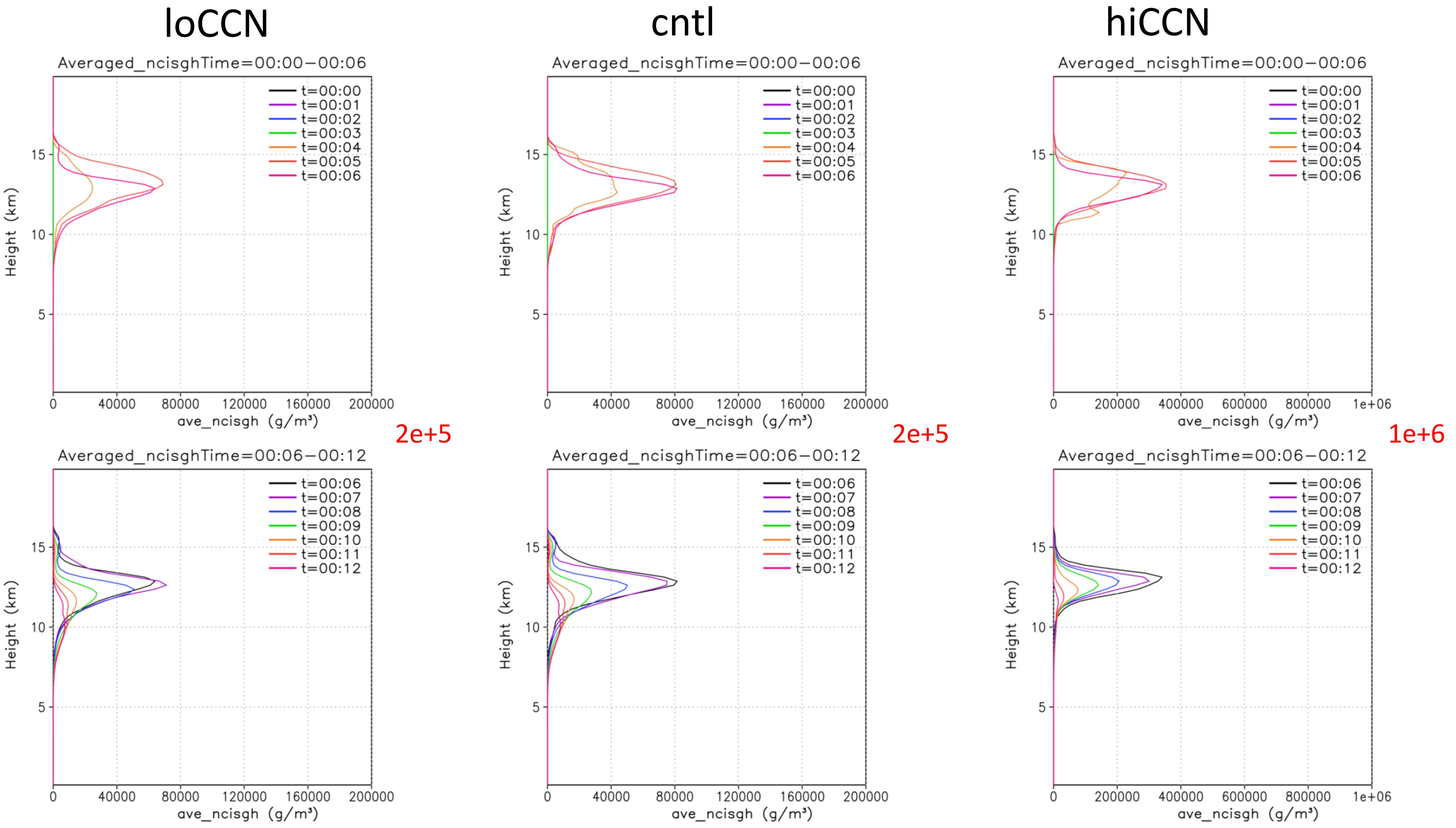
Aerosol effects on HIWC in anvil cloud associated with MCSs

（Domain-averaged IWC; Idealized Sensitivity Experiments）

loCCN **cntl** **hiCCN**

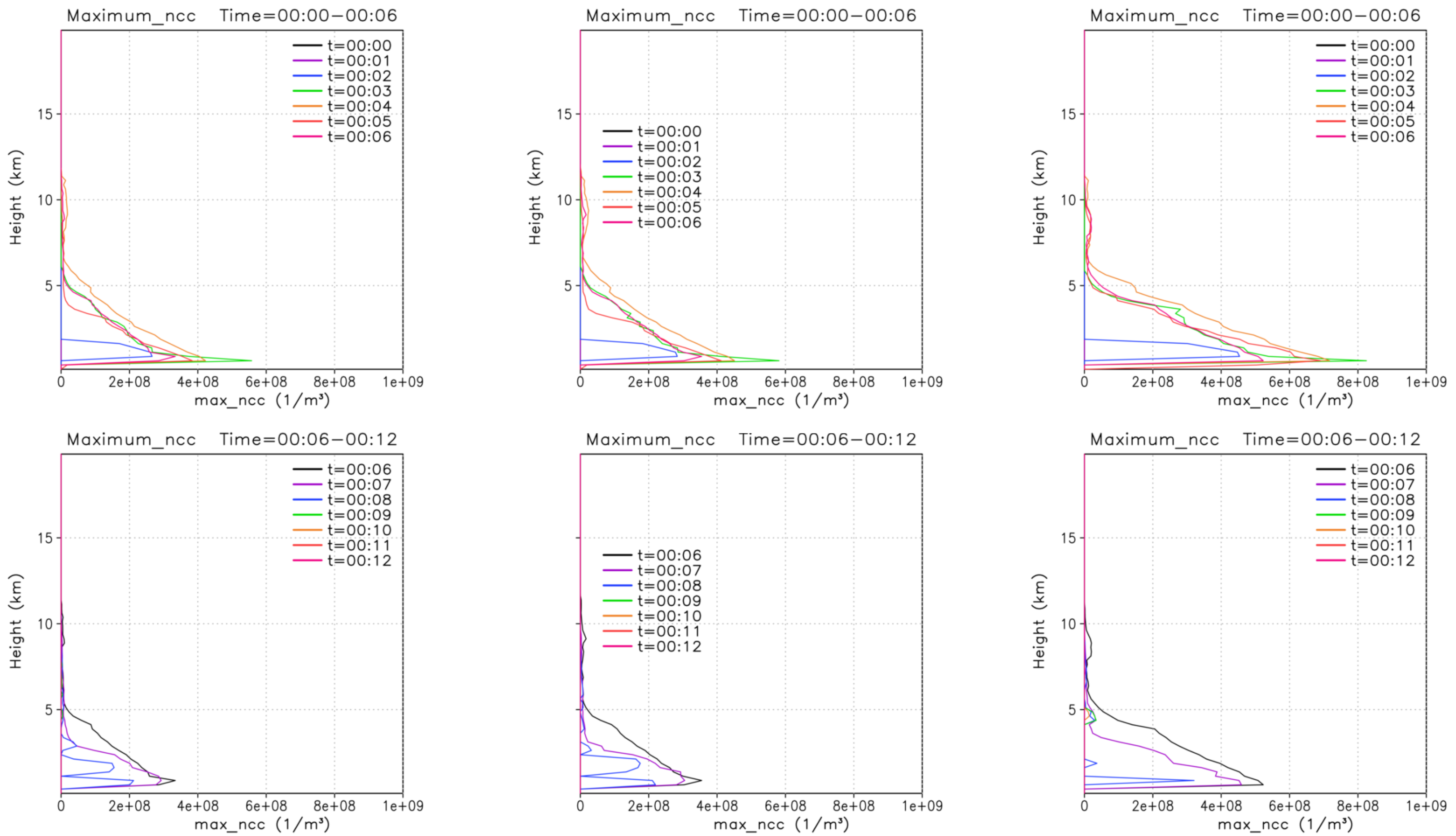


Aerosol effects on HIWC in anvil cloud associated with MCSs
(Domain-averaged Nice; Idealized Sensitivity Experiments)



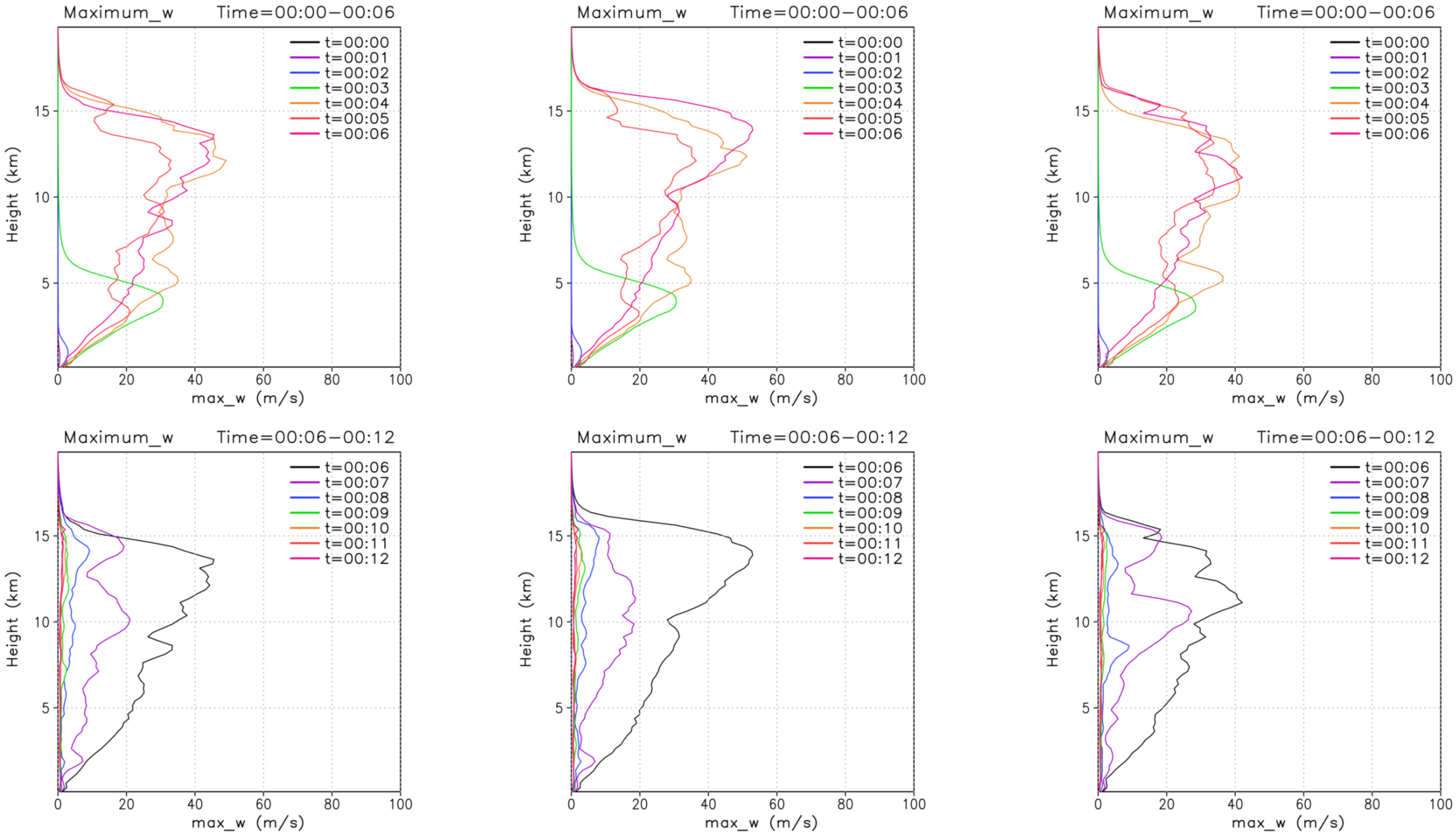
Aerosol effects on HIWC in anvil cloud associated with MCSs
（Domain-maximum Nc; Idealized Sensitivity Experiments）

loINP | cntl | hiINP

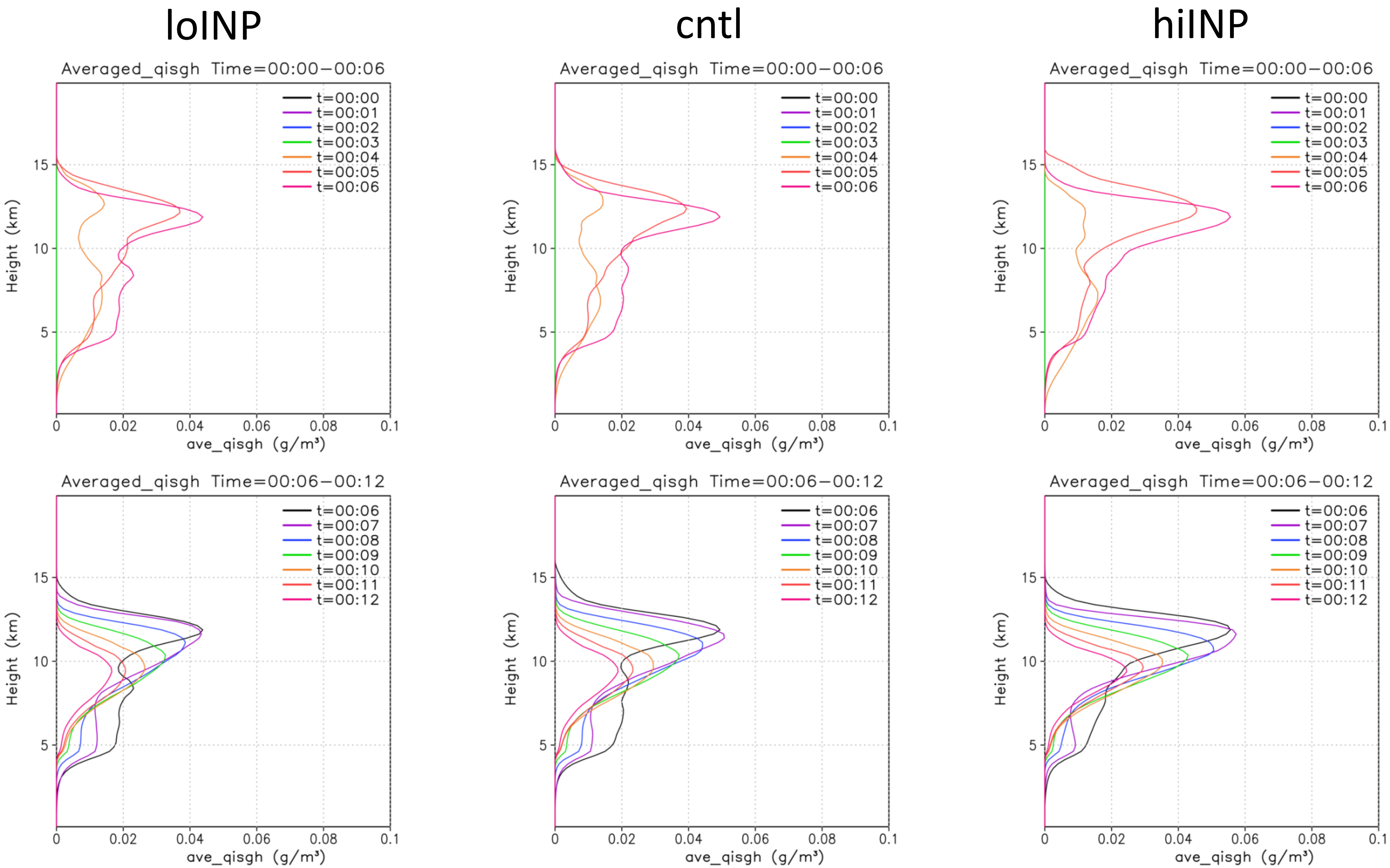


Aerosol effects on HIWC in anvil cloud associated with MCSs
(Domain-maximum W; Idealized Sensitivity Experiments)

loINP **cntl** **hiINP**

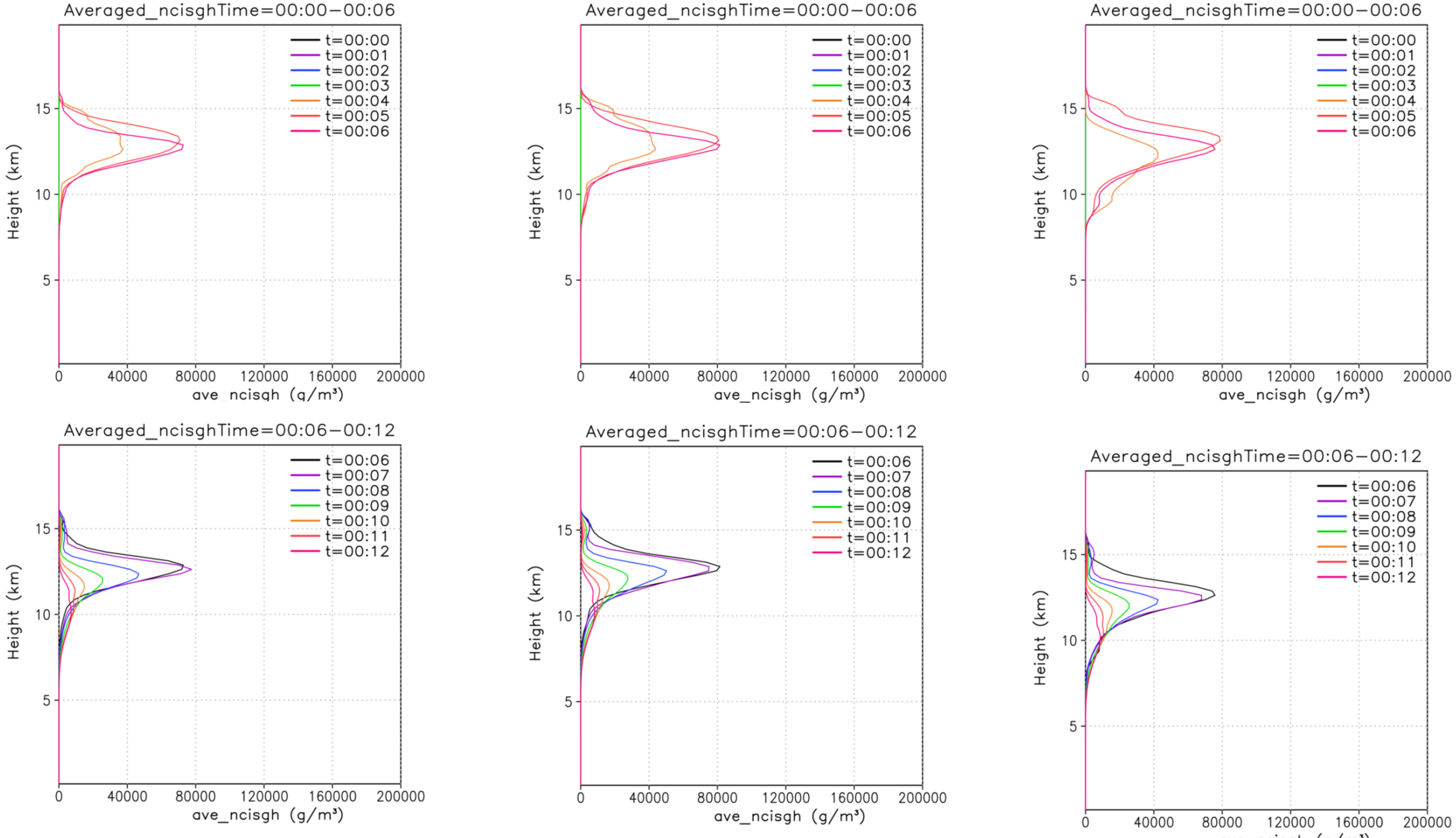


Aerosol effects on HIWC in anvil cloud associated with MCSs
(Domain-averaged IWC; Idealized Sensitivity Experiments)



Aerosol effects on HIWC in anvil cloud associated with MCSs
(Domain-averaged Nice; Idealized Sensitivity Experiments)

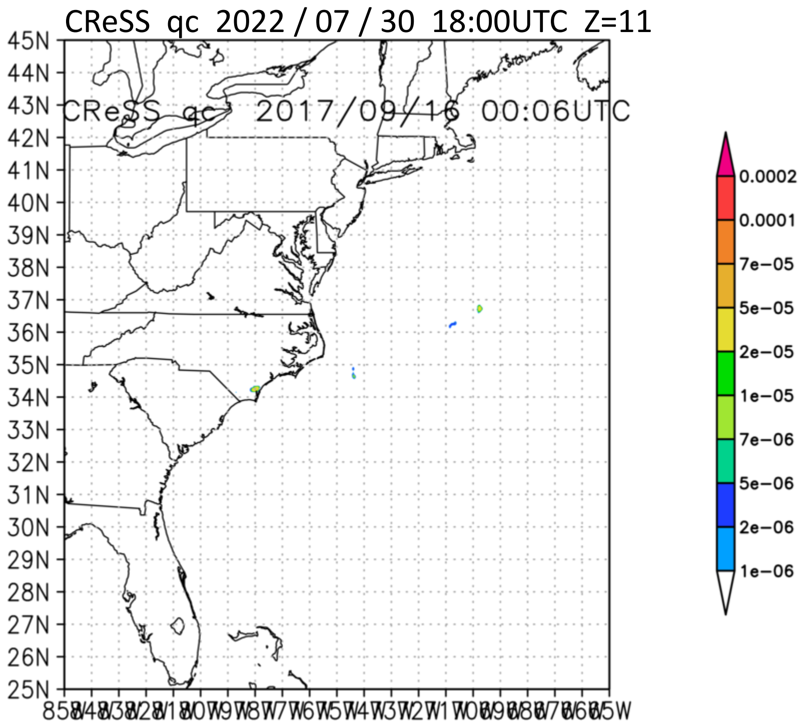
loINP **cntl** **hiINP**



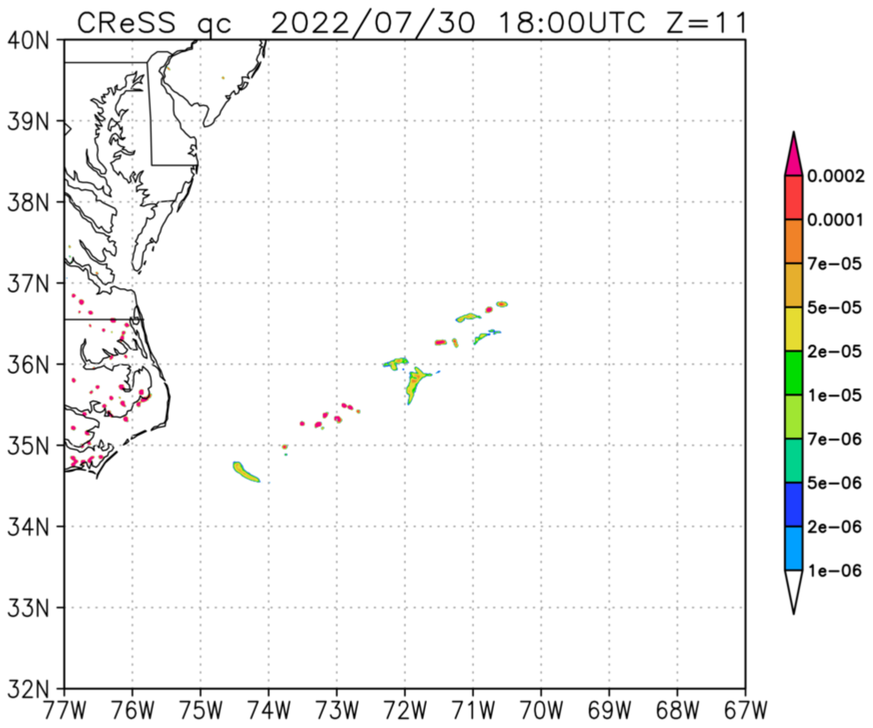
Hindcast Experiment for 30 July 2022 Case (preparation)

- Model configuration
- Selection of Initial Time

GSM>5km_2022073012Zini_FT06



5km>1km_2022073015Zini_FT03



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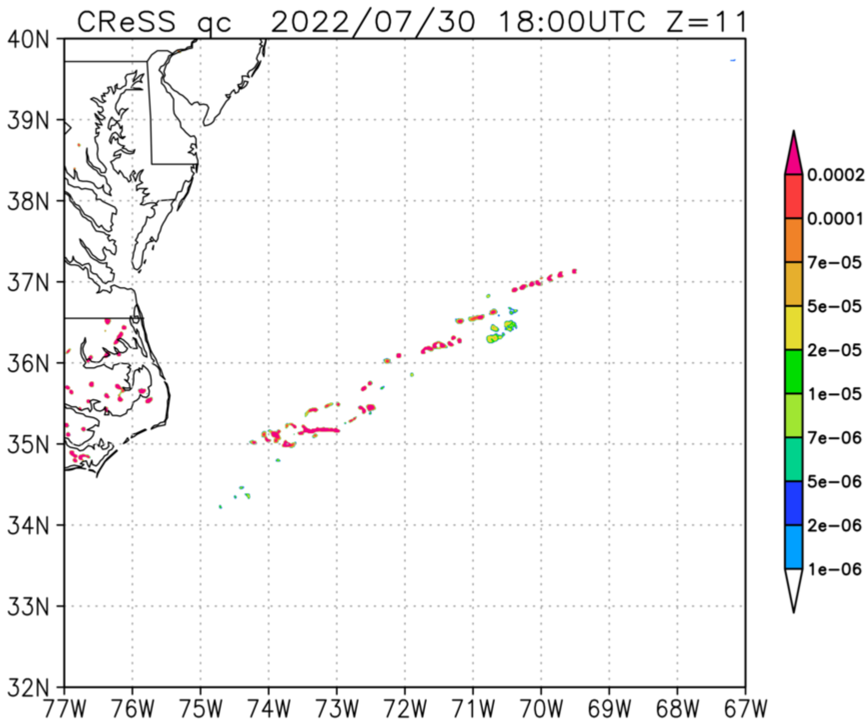

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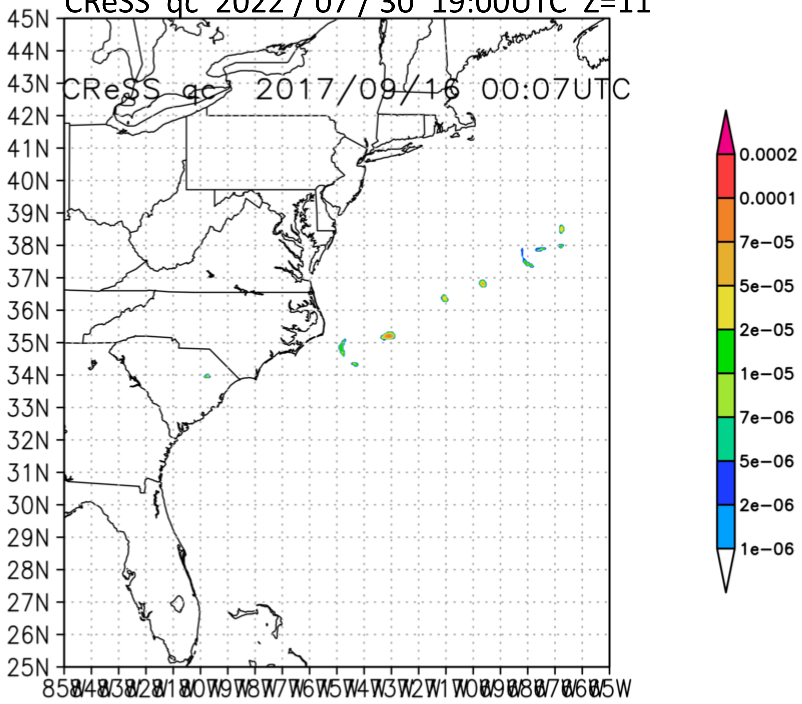

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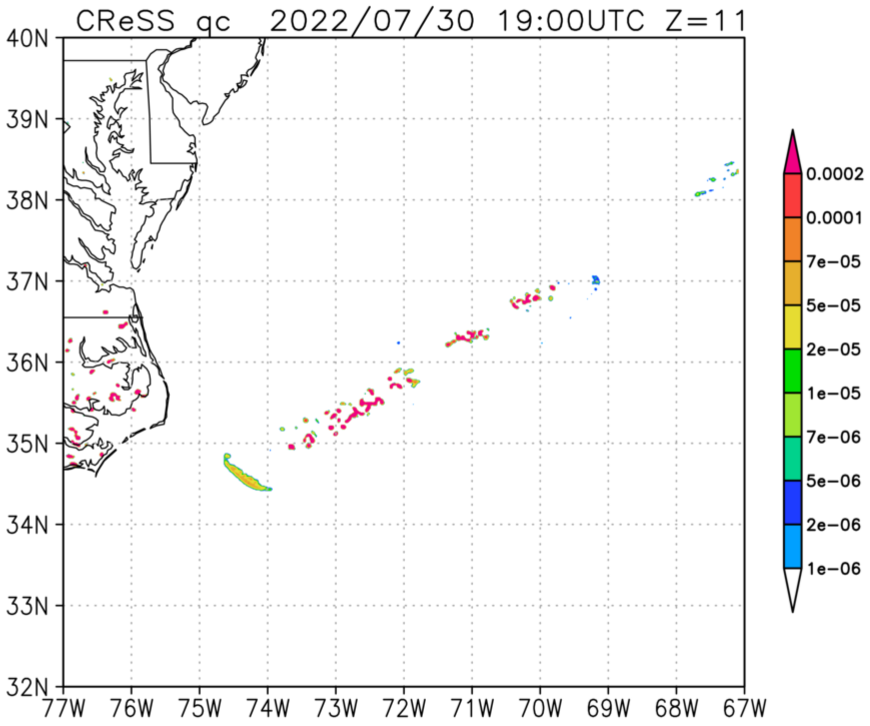

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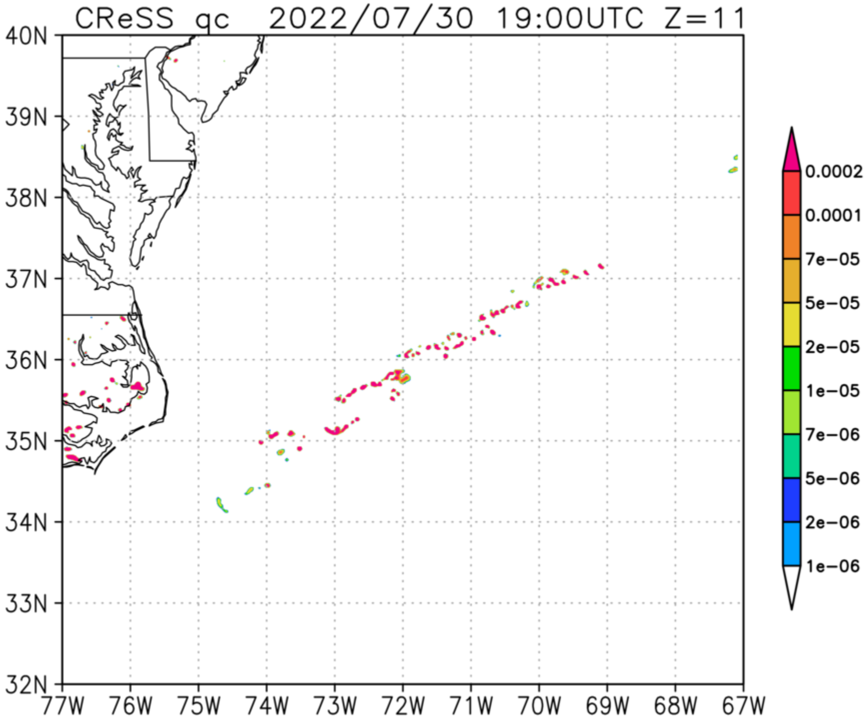

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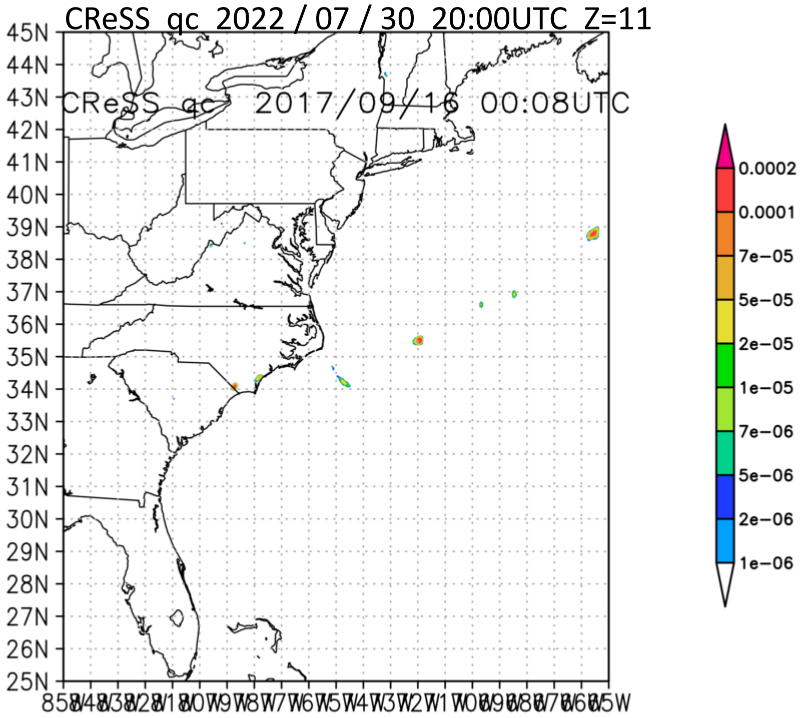

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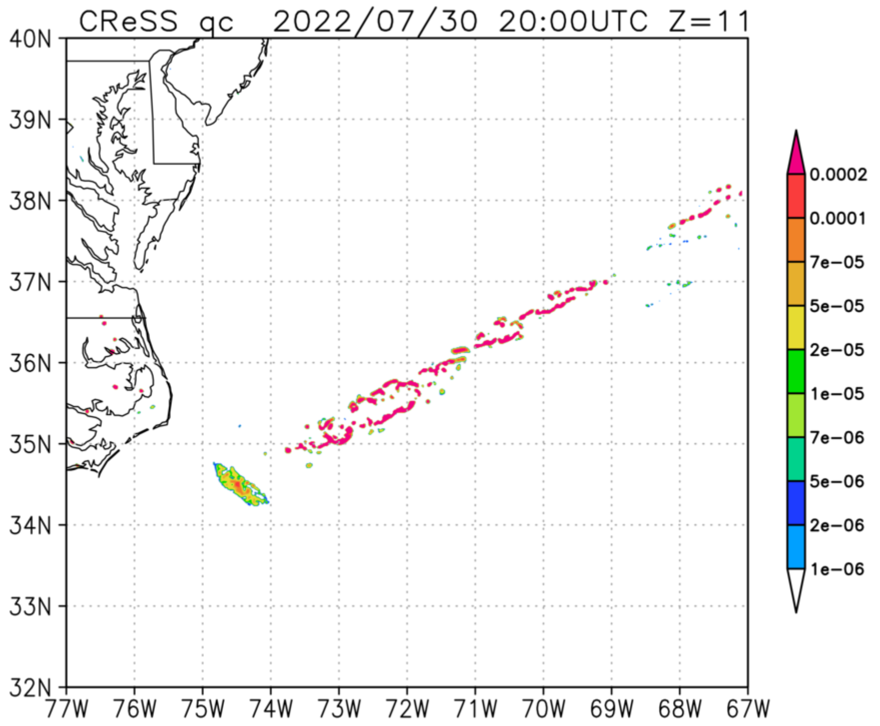

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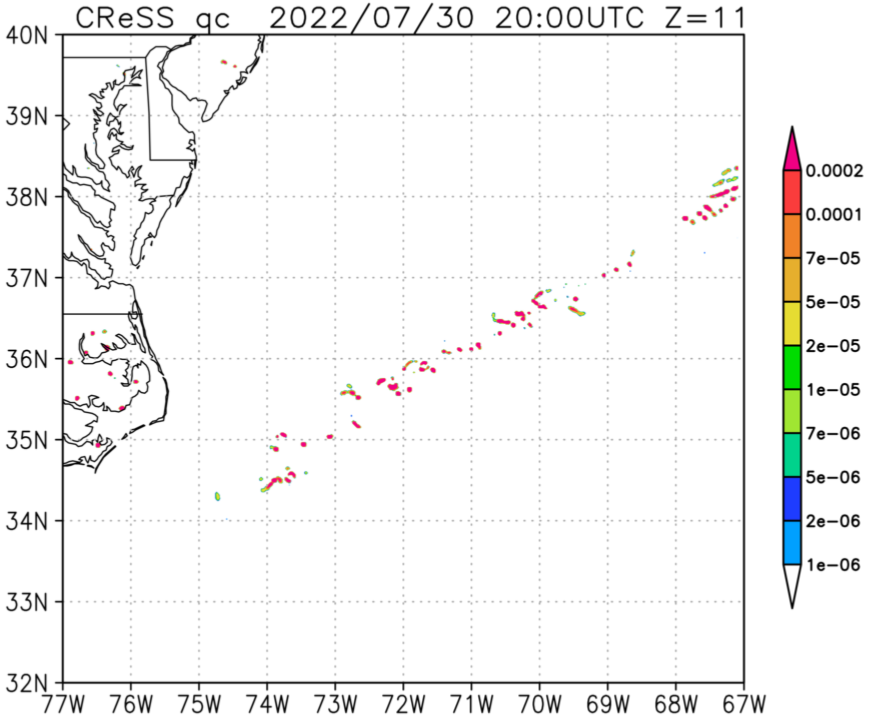

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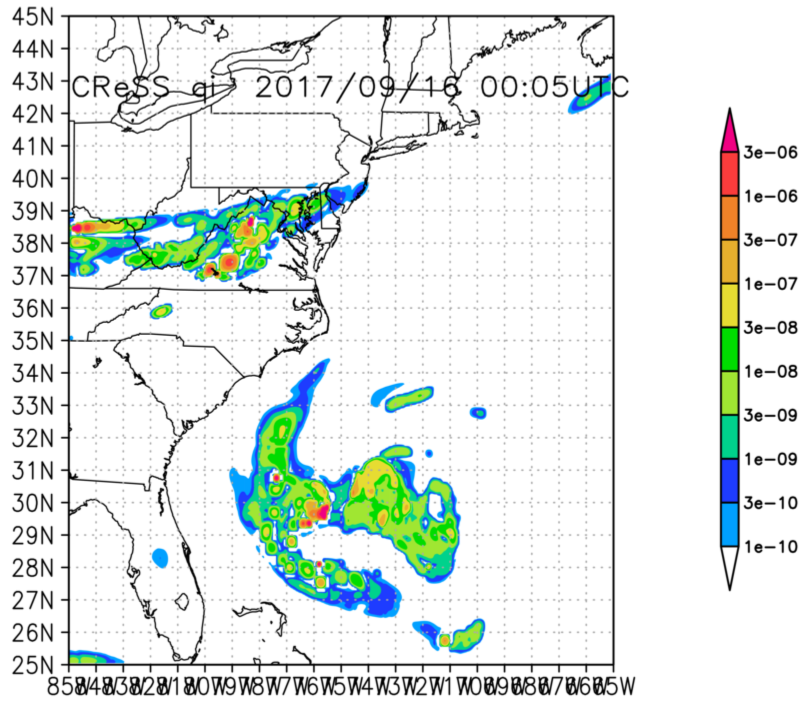

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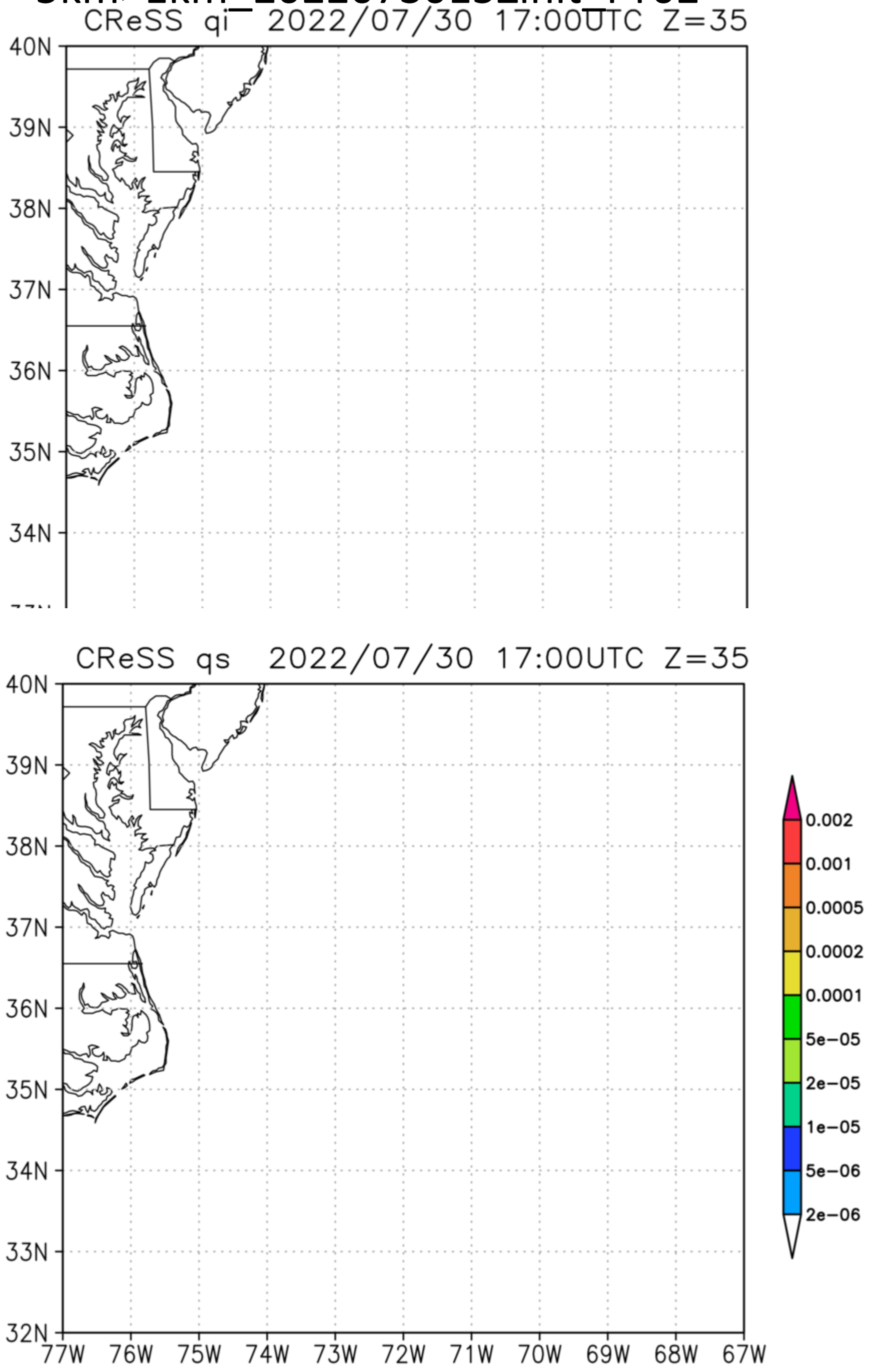

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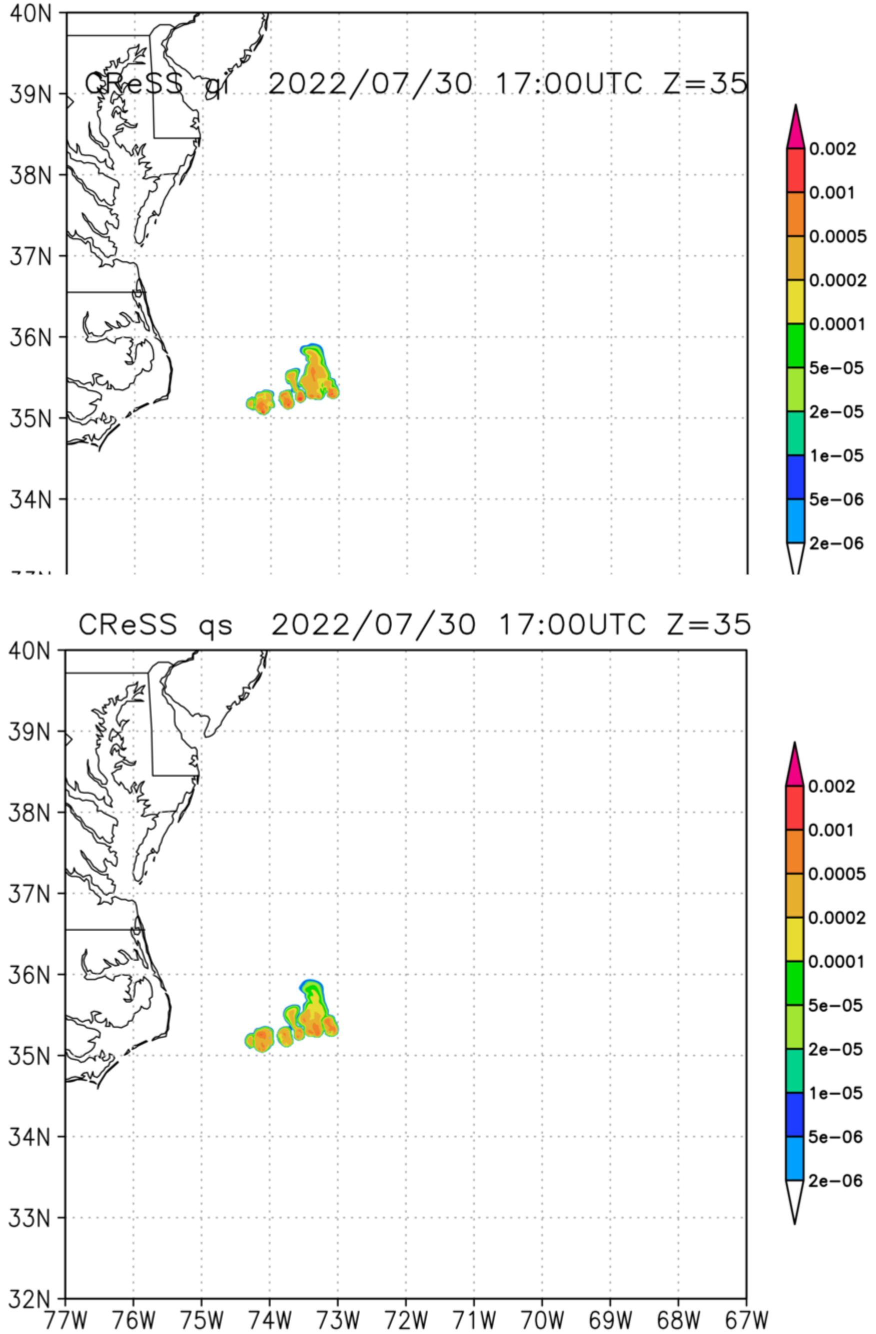

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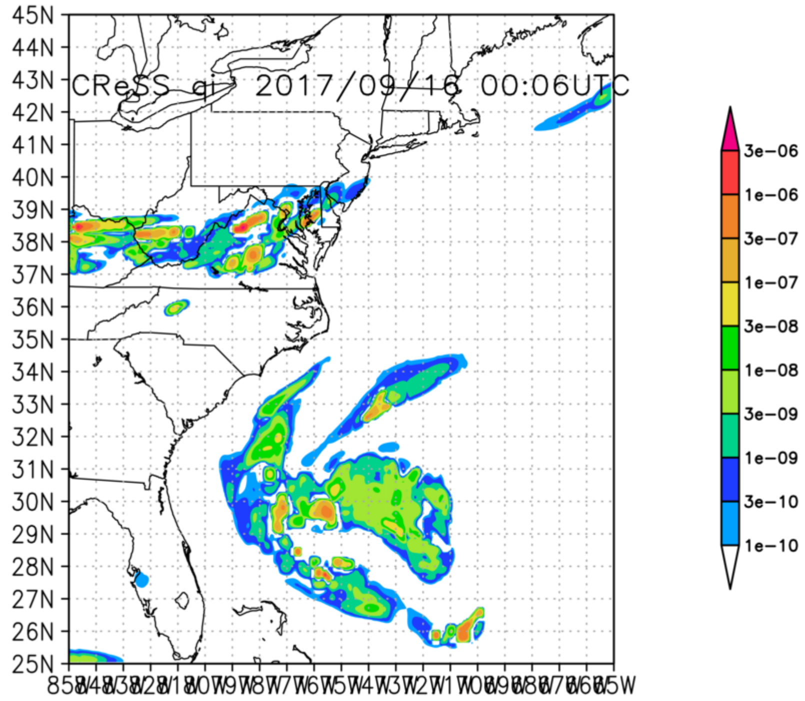

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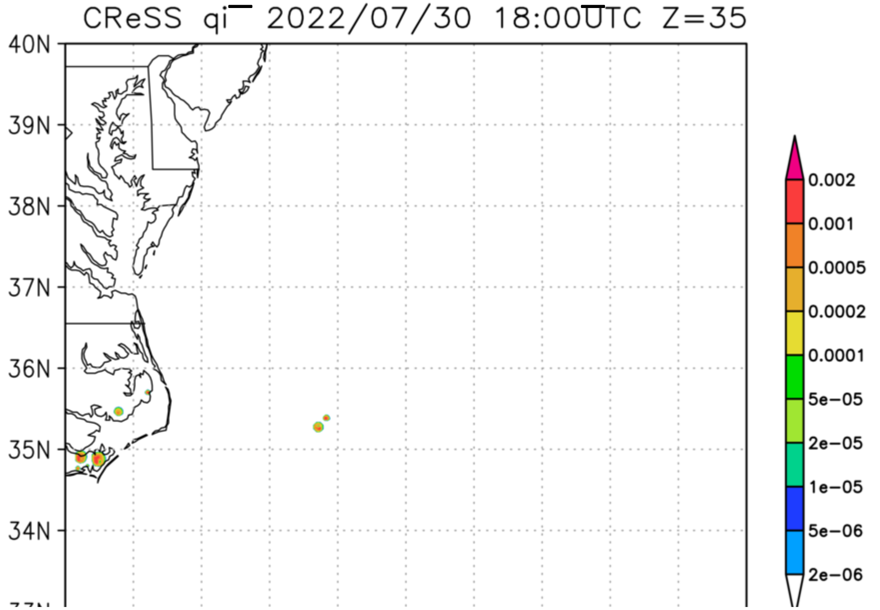

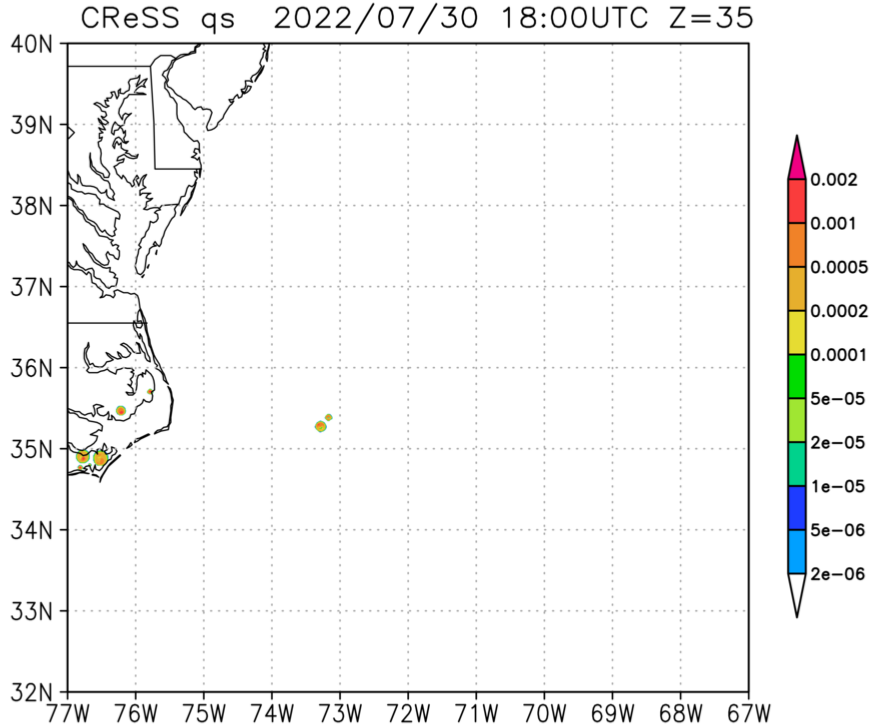

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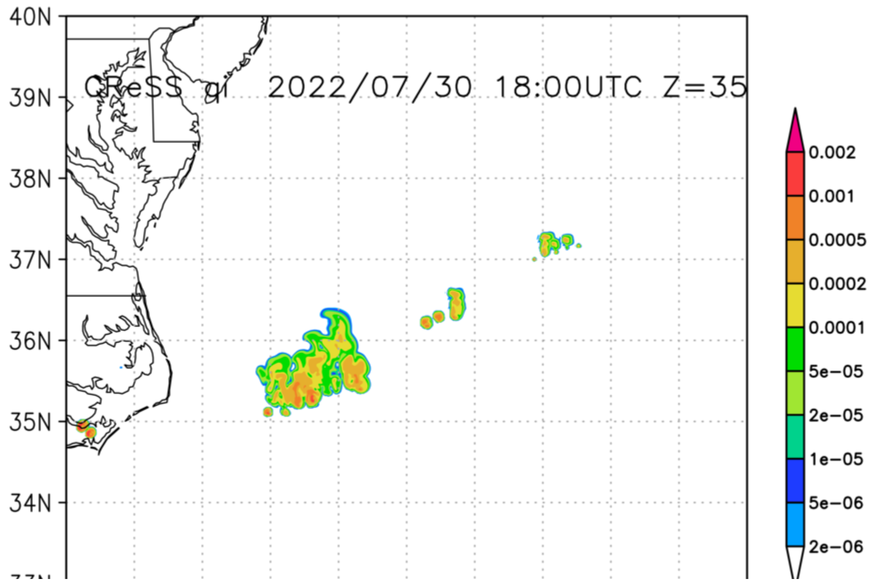

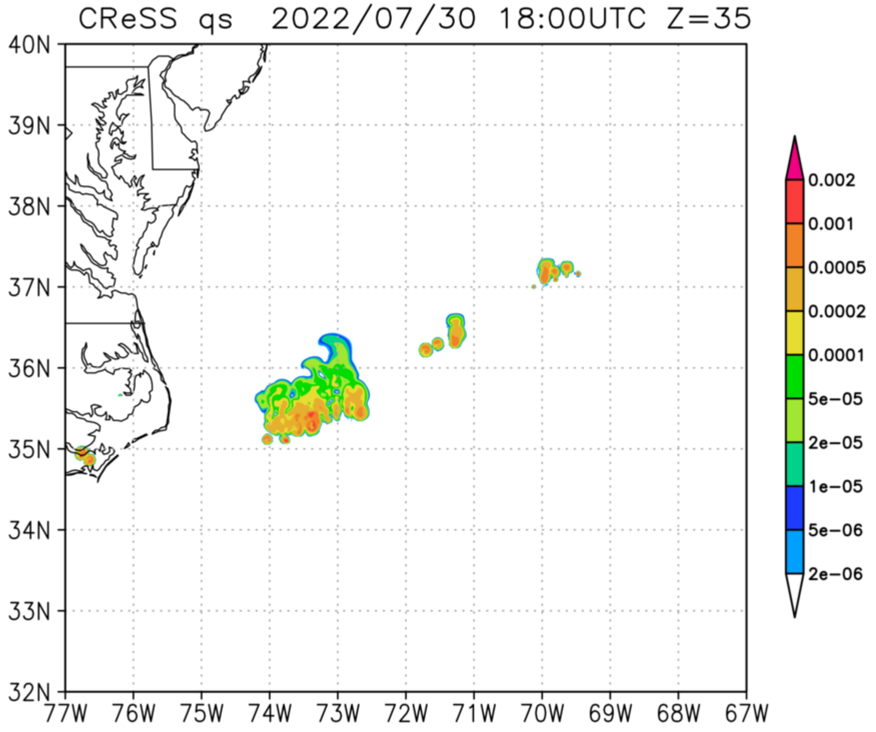

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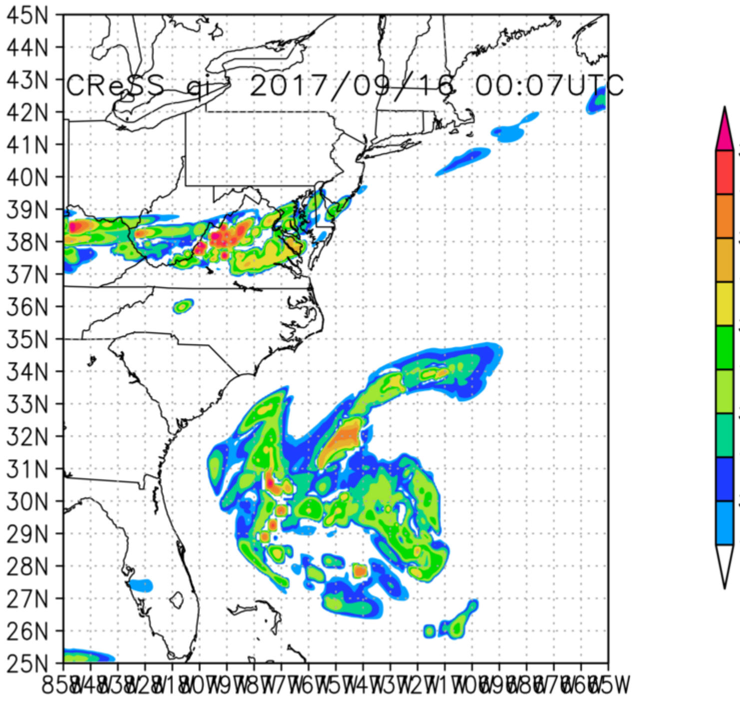

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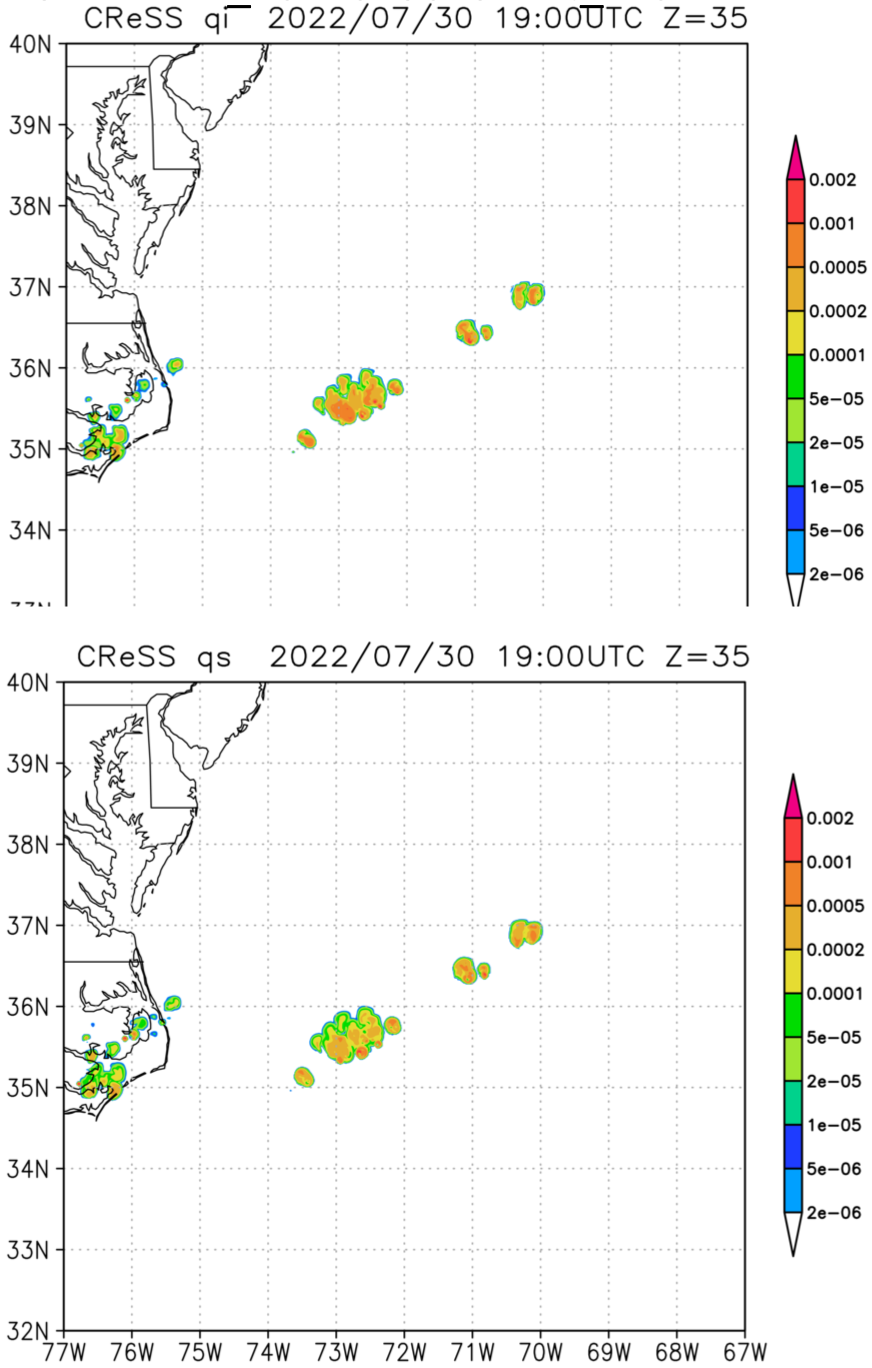

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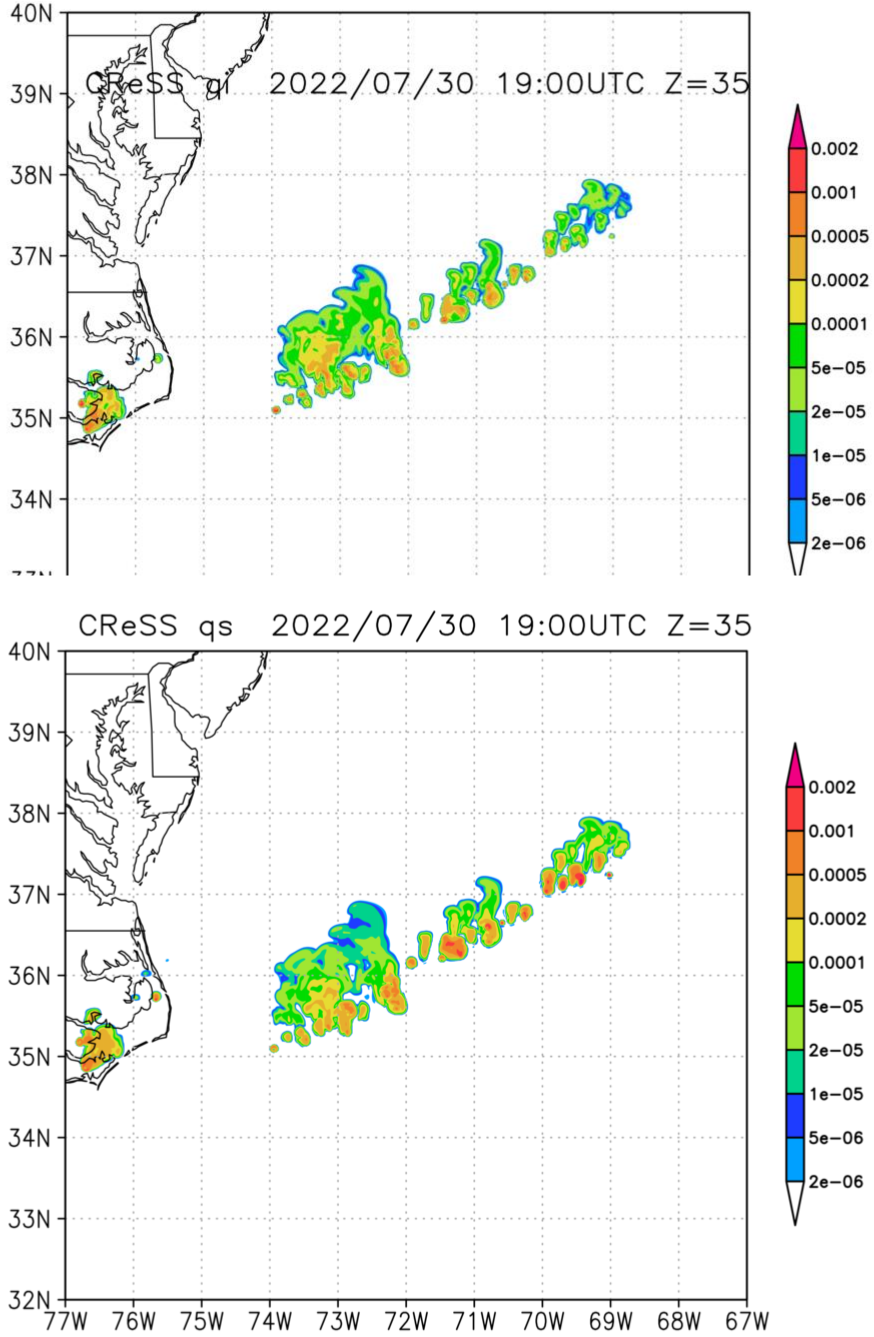

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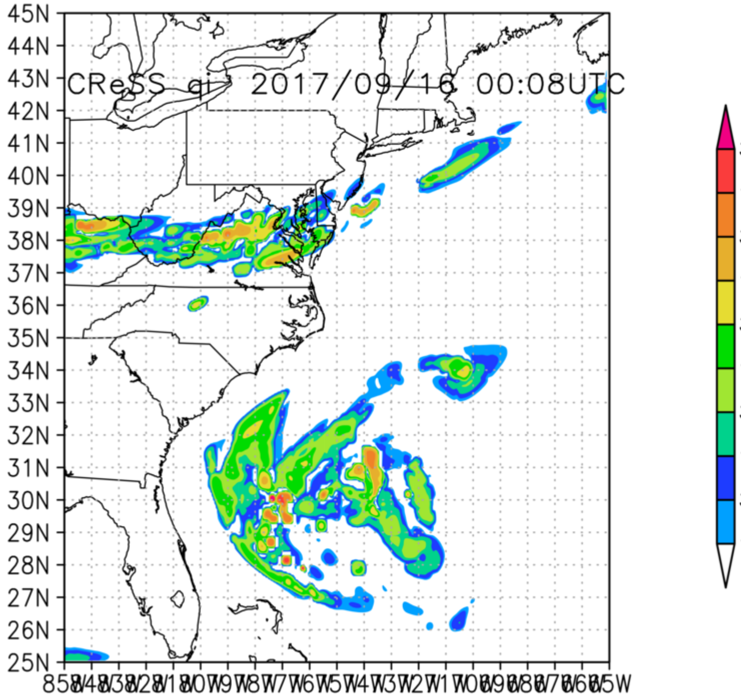

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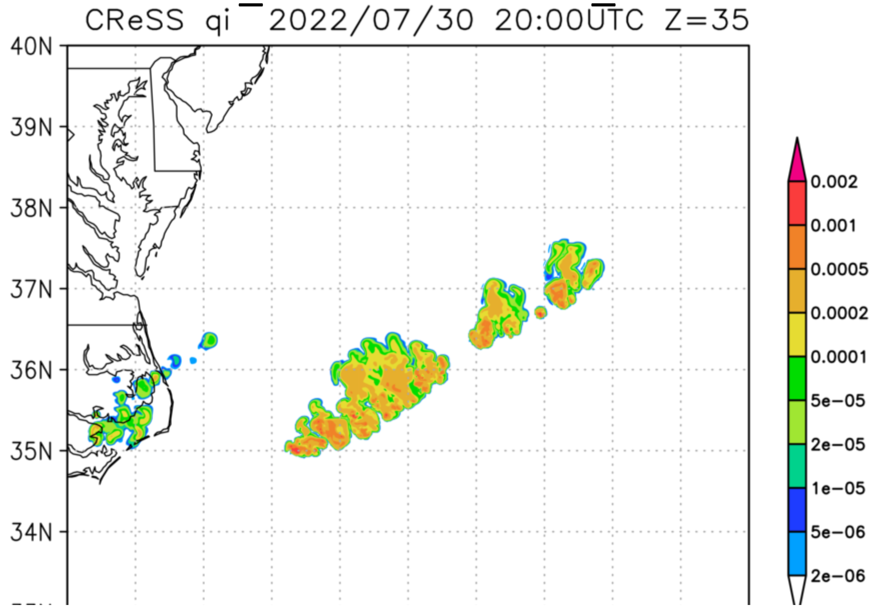

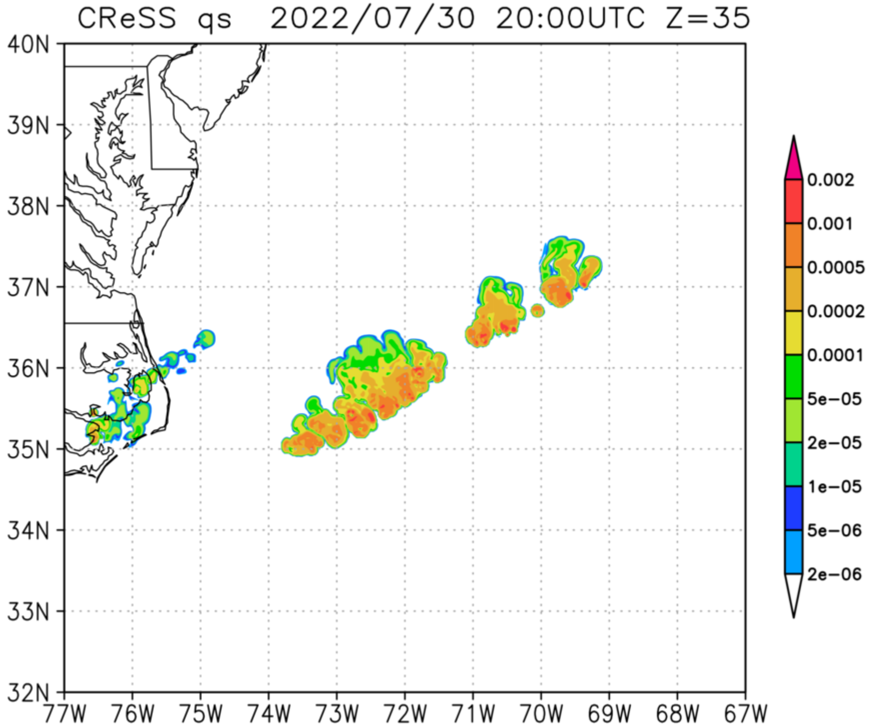

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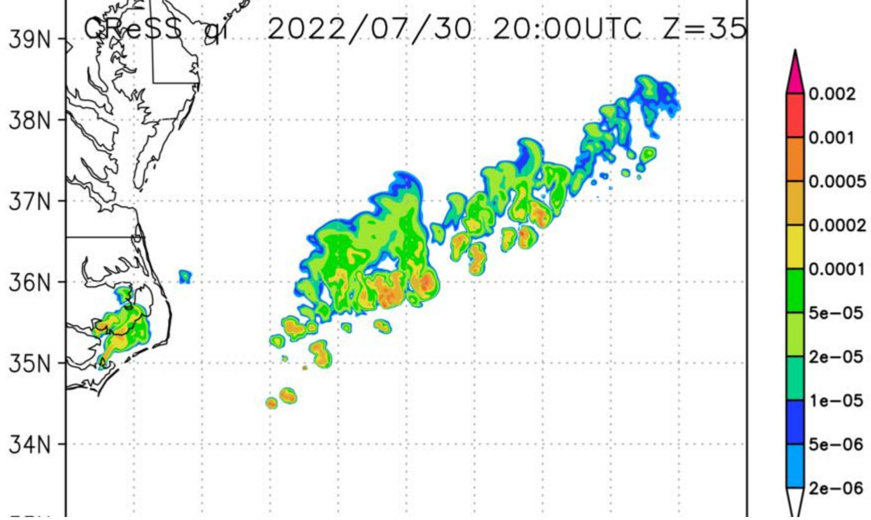

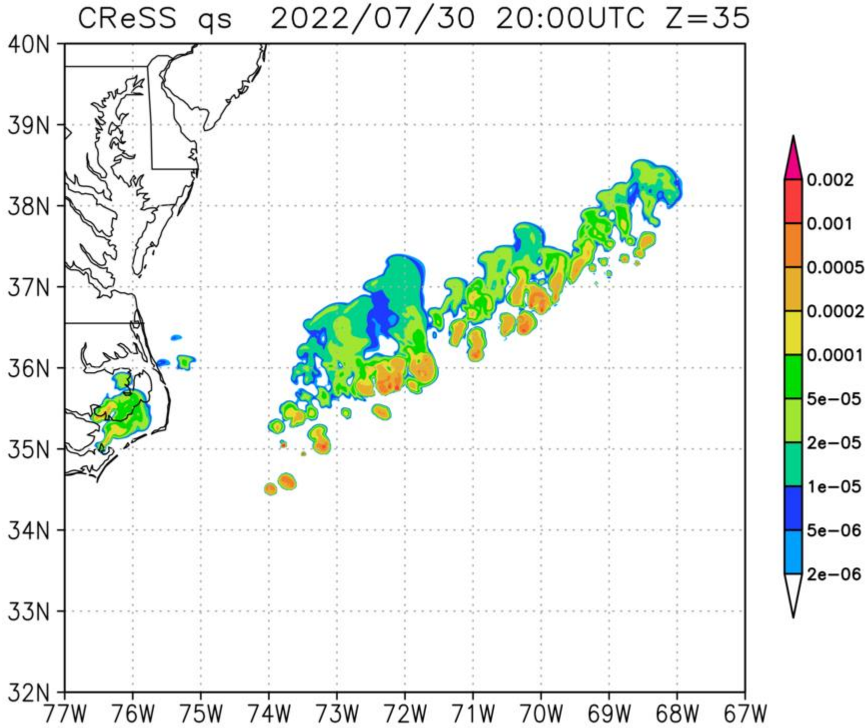

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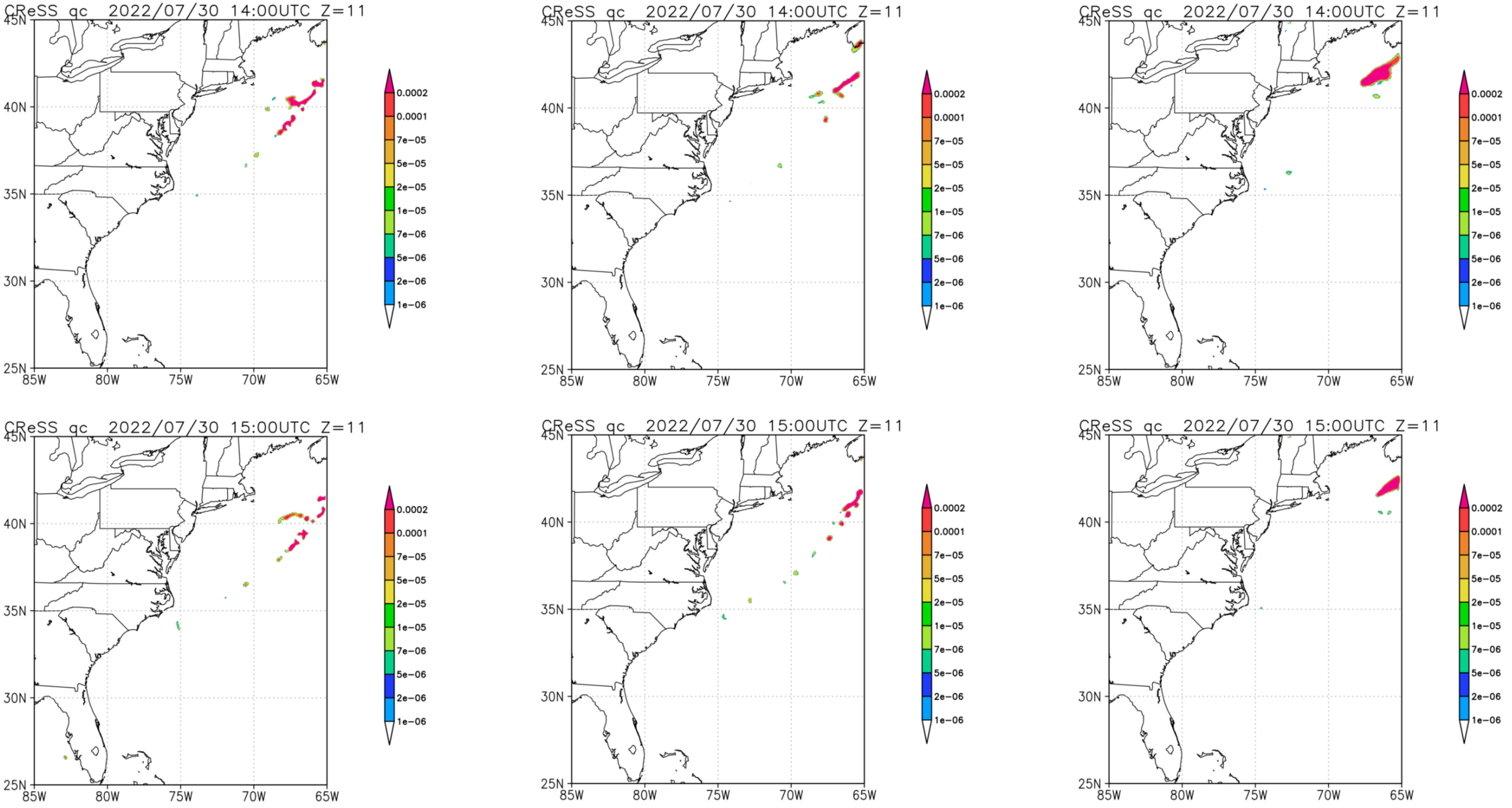

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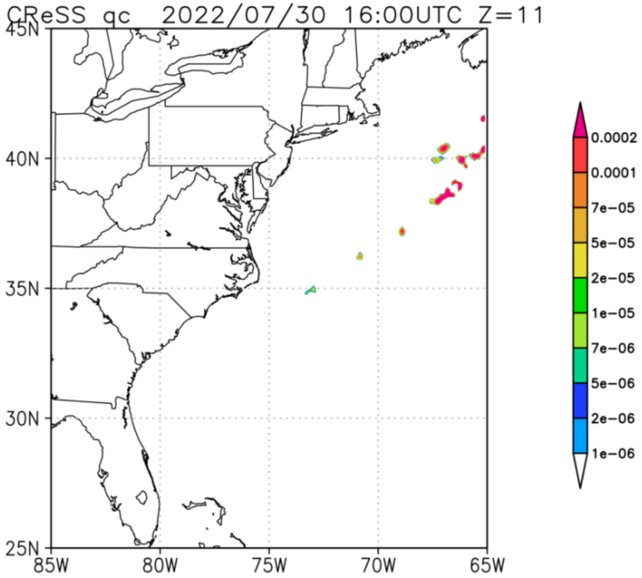

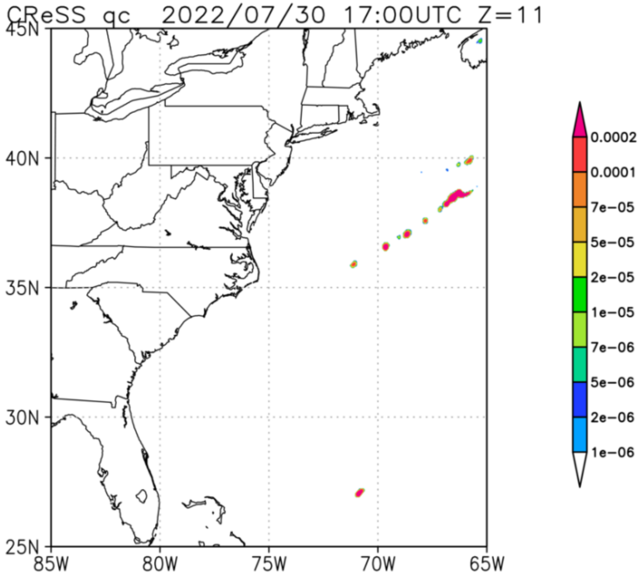

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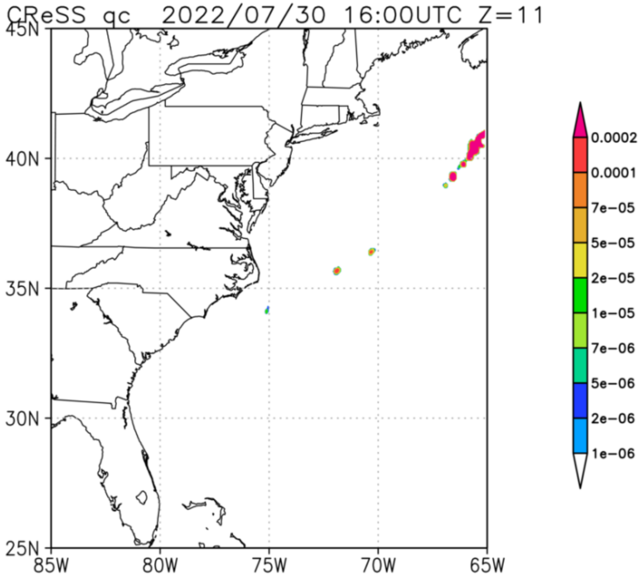

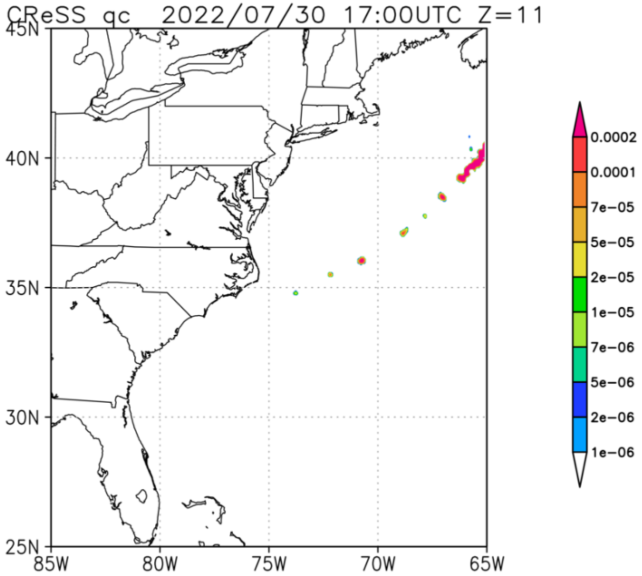

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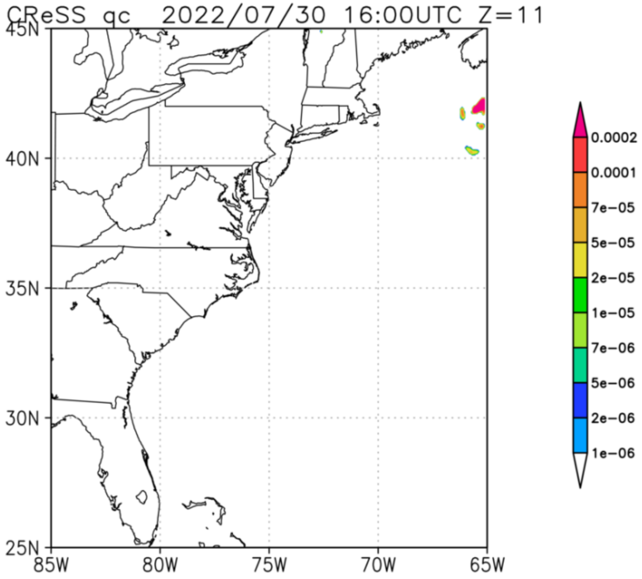

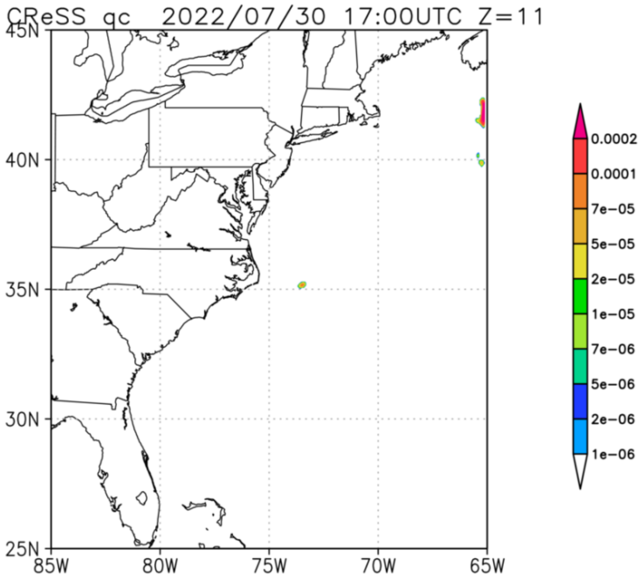

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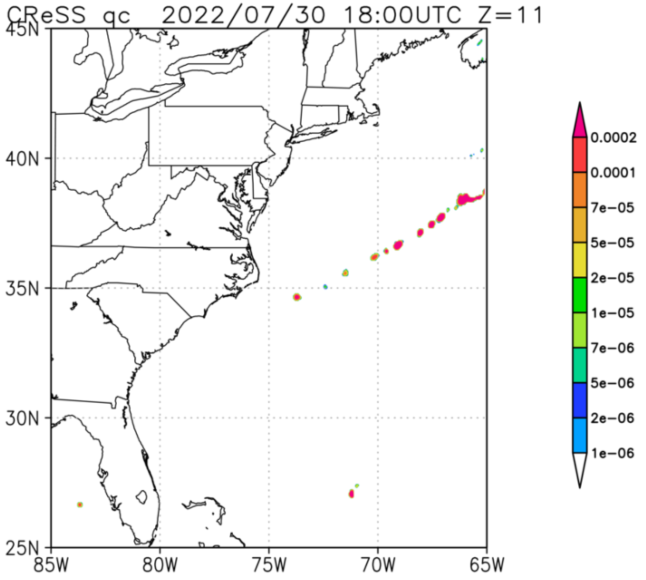

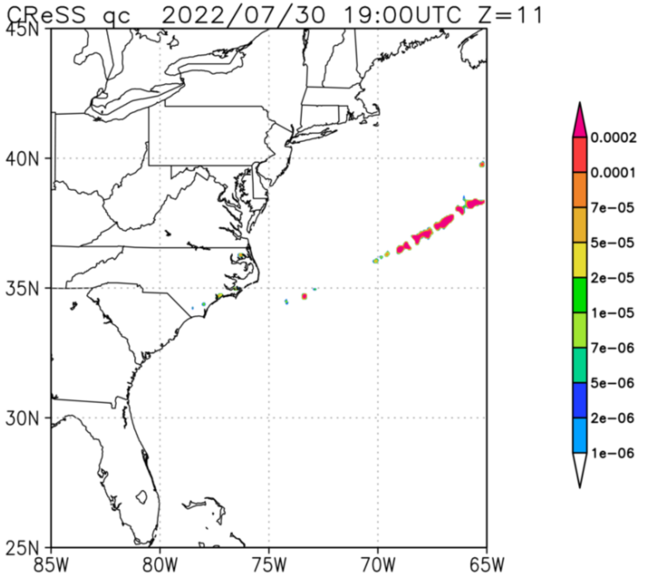

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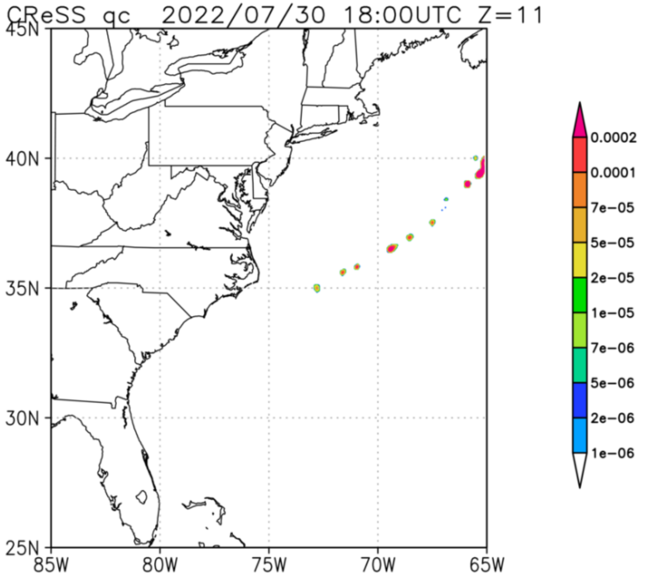

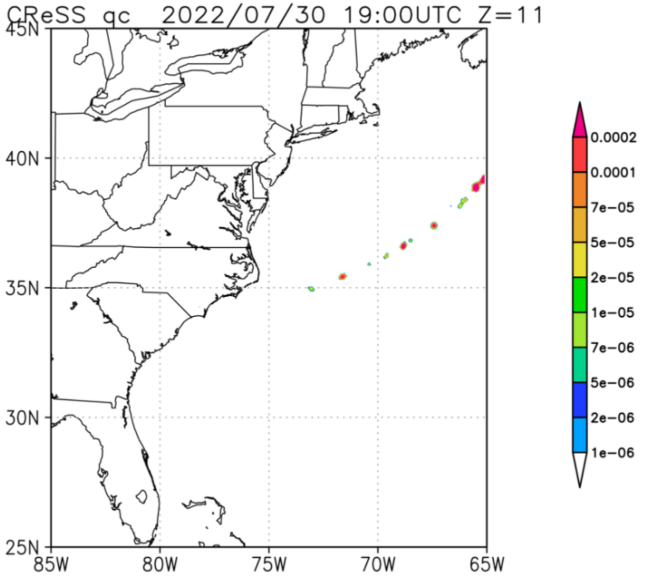

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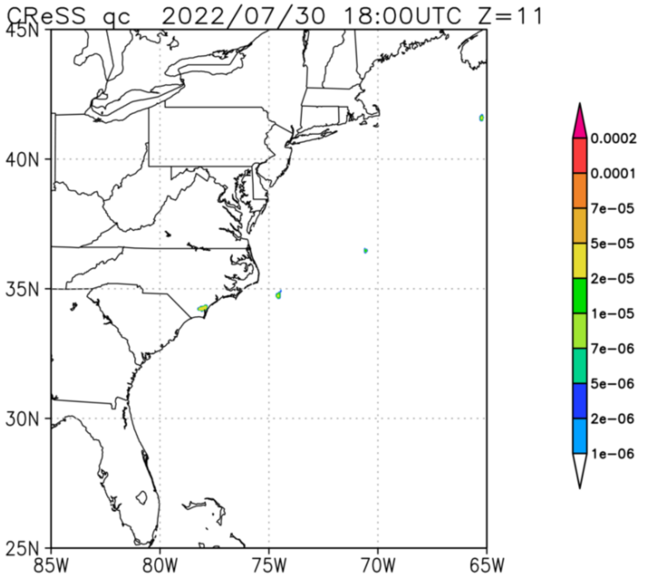

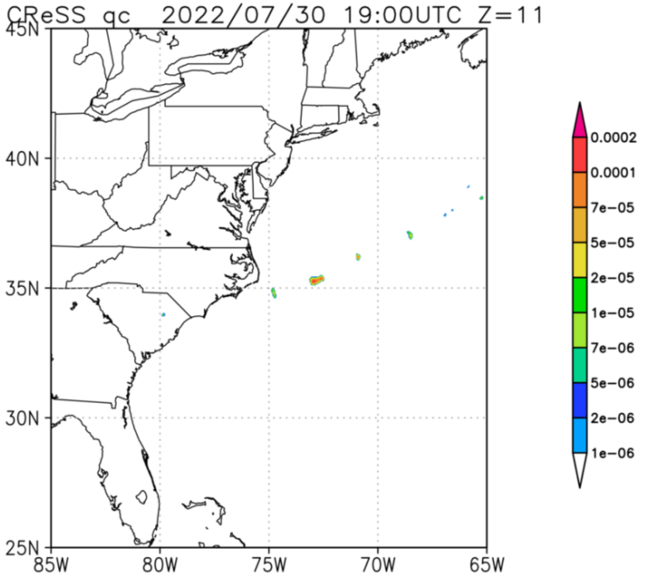

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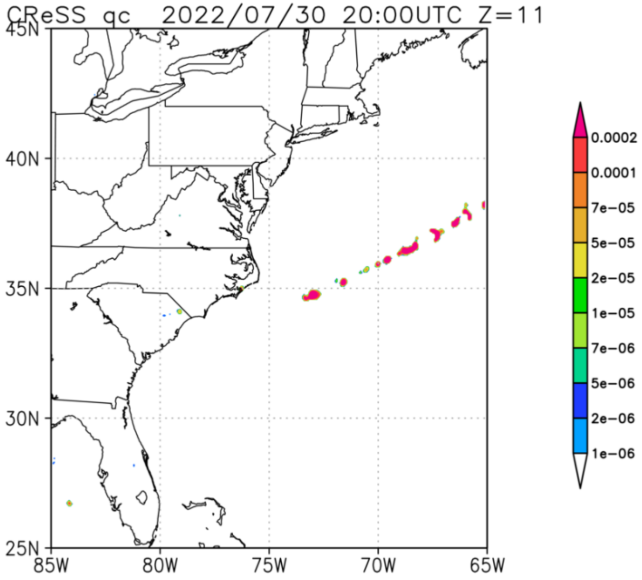
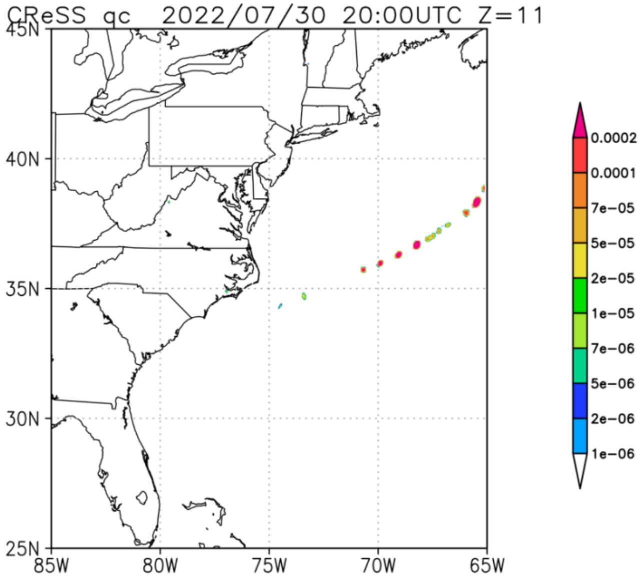
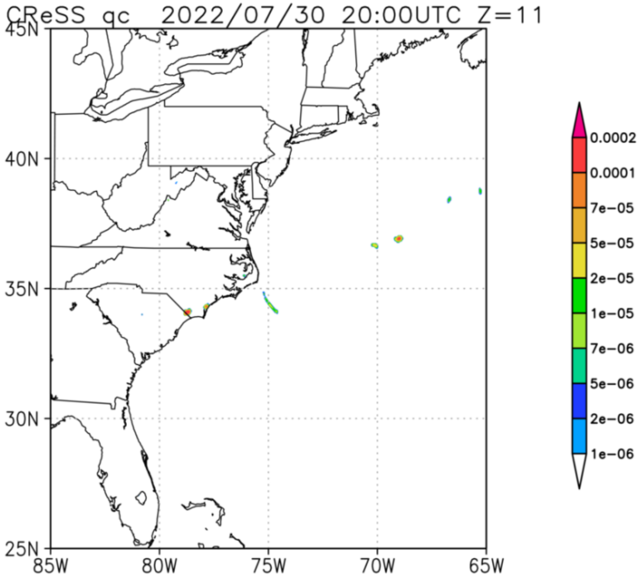
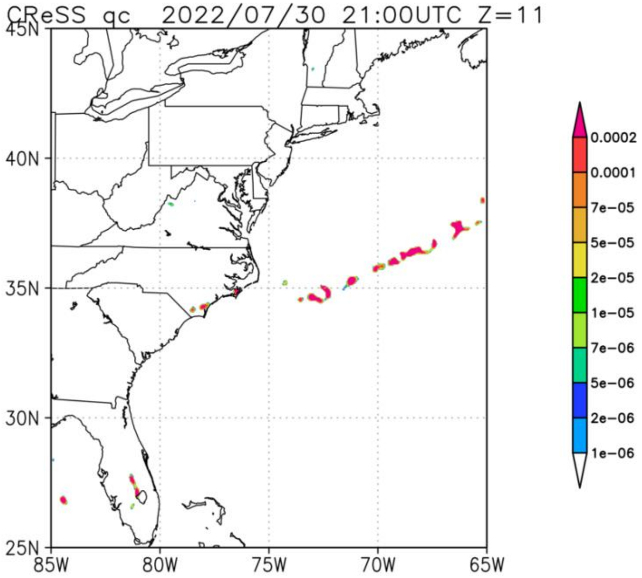
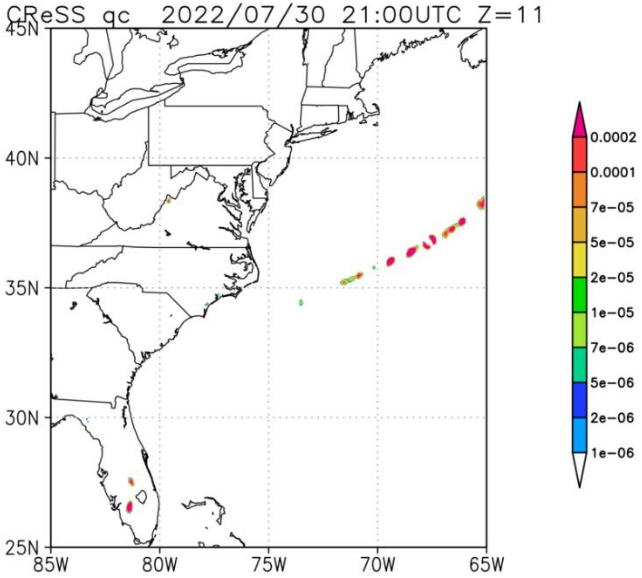
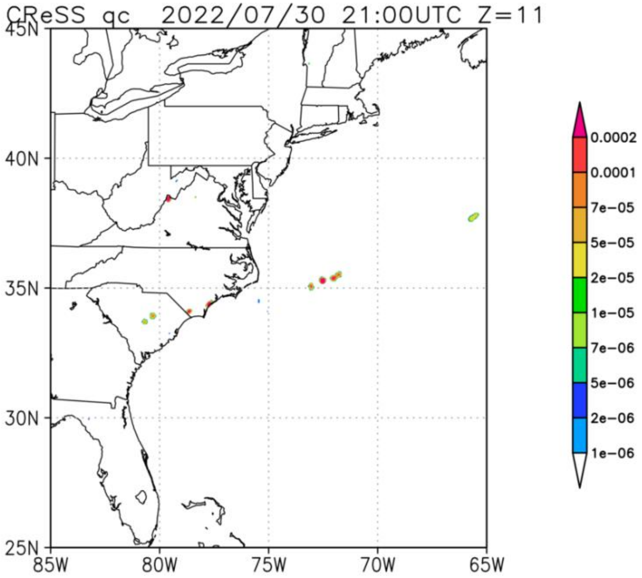






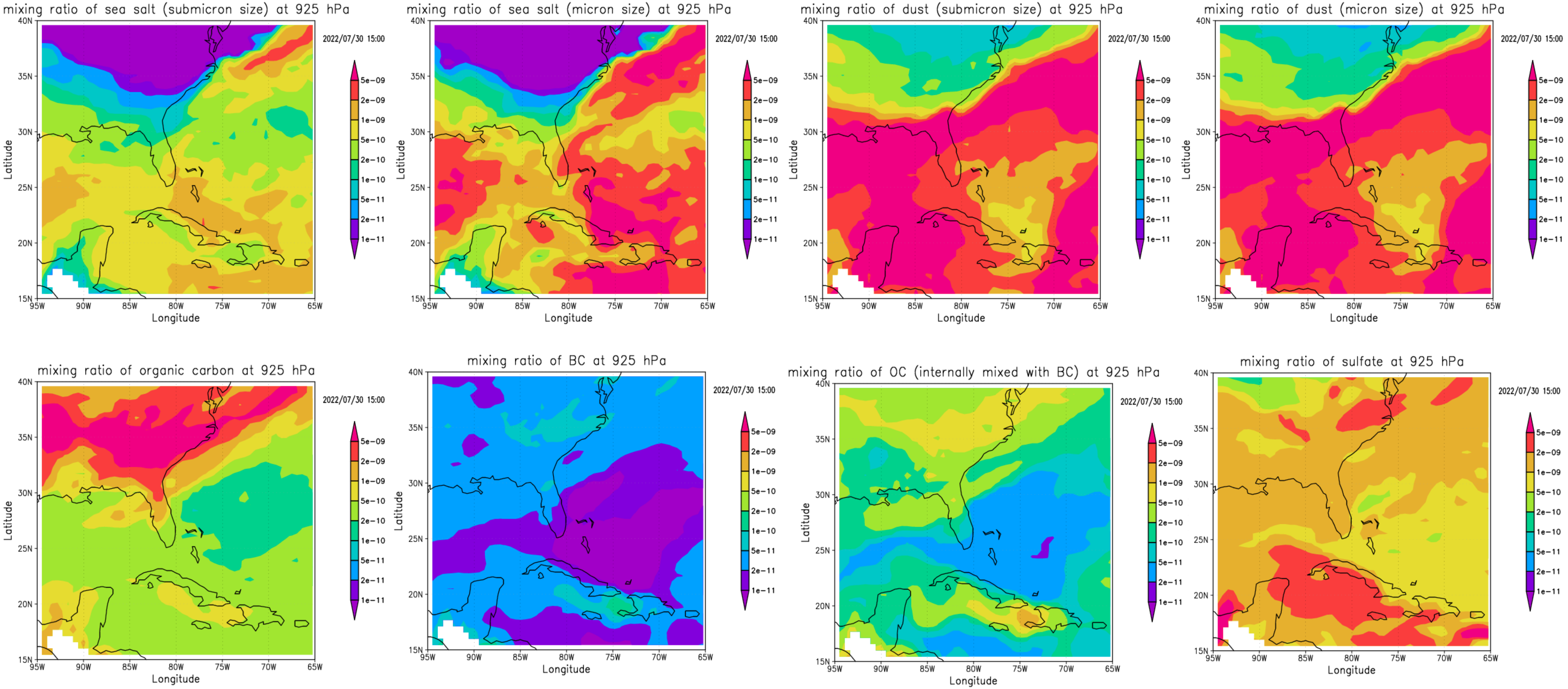






Horizontal Distributions of Aerosols at 925 hPa

(2022. 07. 30. 15UTC, from SPRINTARS)



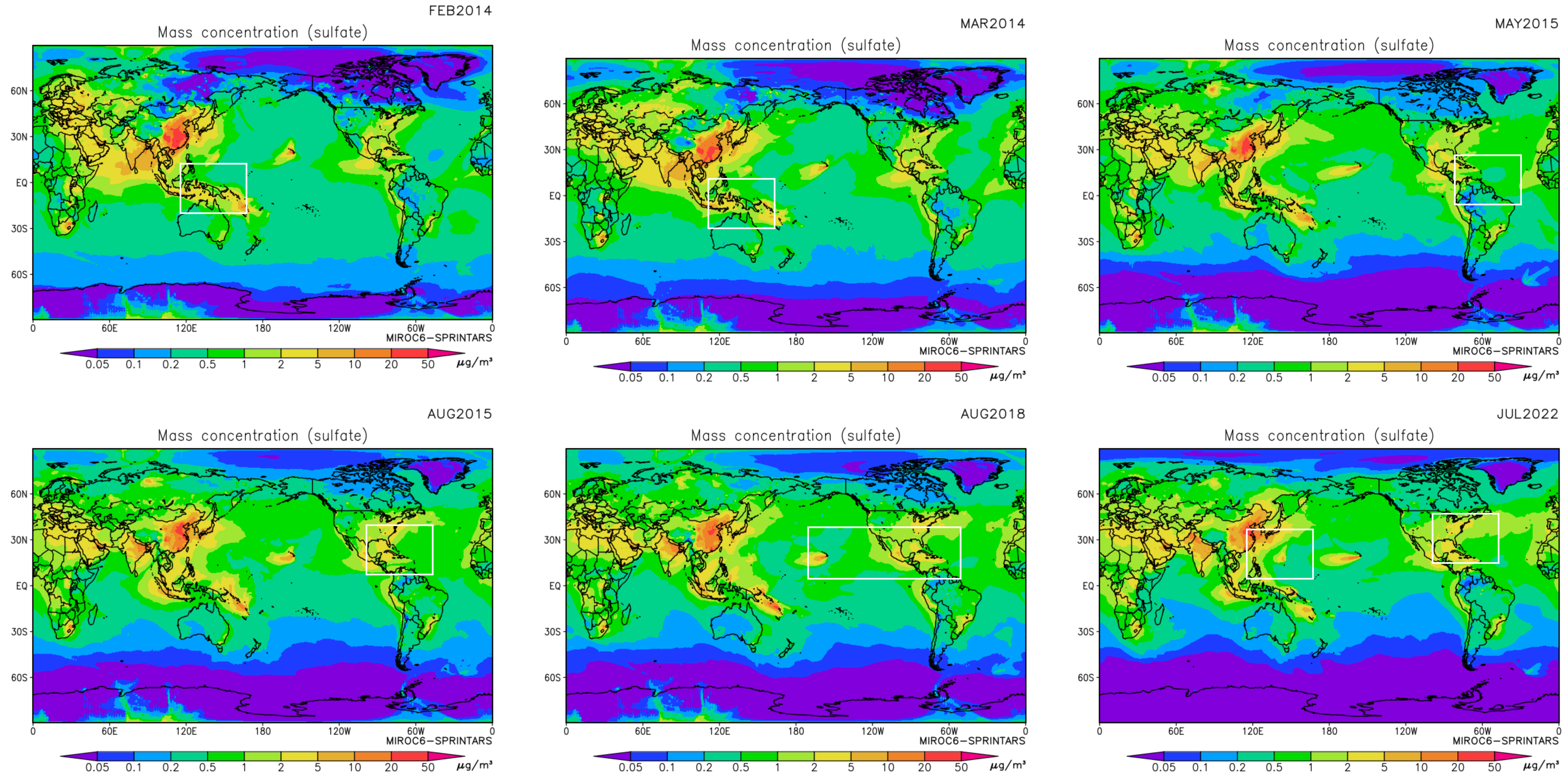
Summary

- The effect of anthropogenic aerosols acting as CCN on HIWC was not significant, probably due to high concentration of BG dust aerosol concentration, unlike for the supercell case.
- The effect of INP (mineral dust aerosol) concentration on ice water content was not significant, probably due to high concentration of BG dust aerosol concentration.
- The effect of aerosol concentration acting as CCN/INP on HIWC becomes more obvious as the updraft velocity increases.
- The effects of CAPE, RH, and SHR on HIWC are clear, but the effects of Tcb are unclear.

Future works

- Hindcast using CReSS-4ICE-AEROSOL for 30 July 2022 case.
- Compare with aircraft/satellite/NEXRAD observation data.
- Hindcast using CReSS-4ICE-AEROSOL for cases of MCSs over North American Continent and polluted East Asia, also a case of MCSs from CPEX-CV project.

Monthly Average of Sulfate (from SPRINTARS)



Monthly Average of Dust (from SPRINTARS)

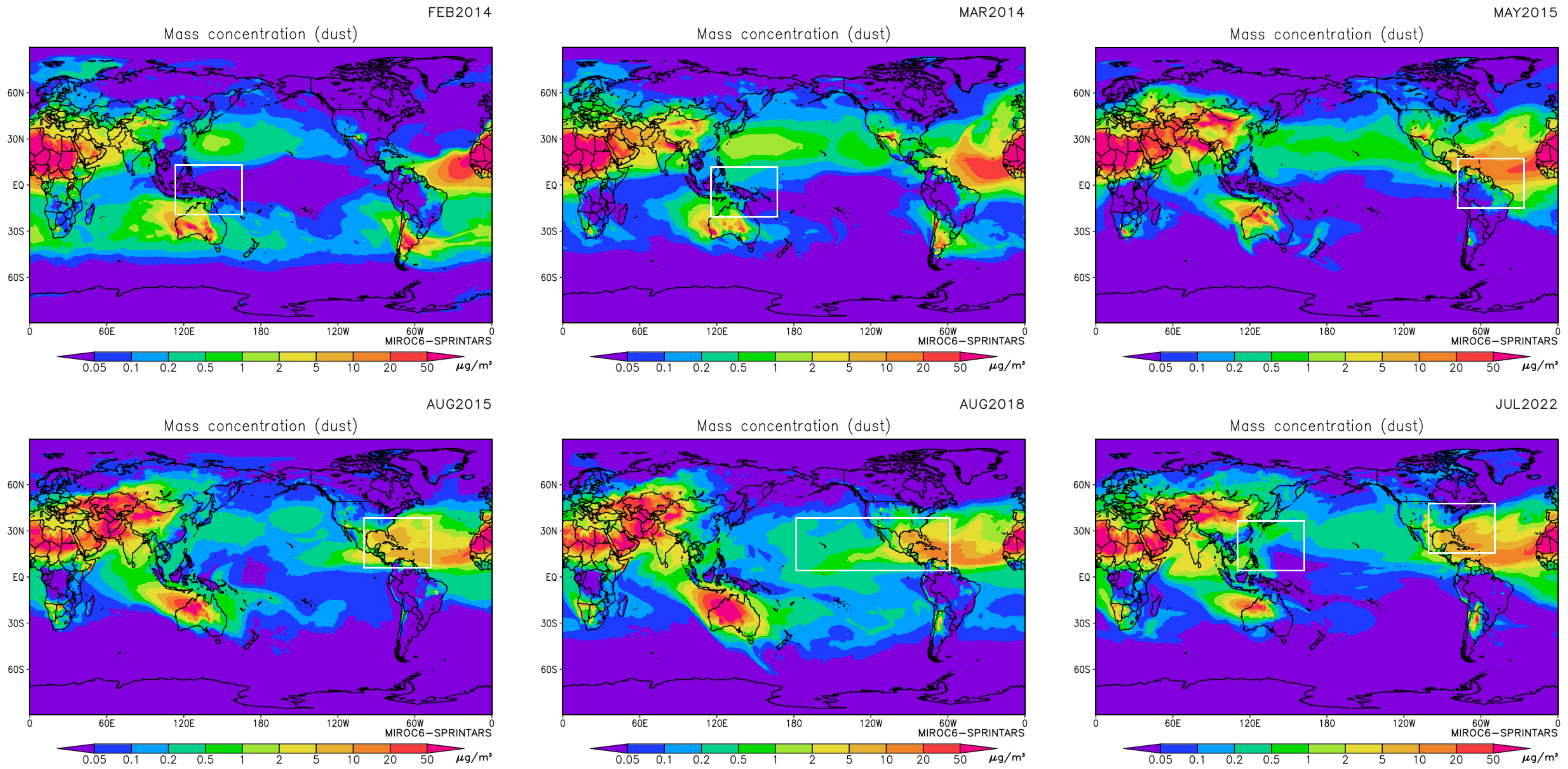


Figure adapted from: Bravin, Strapp, doi:10.4271/2019-01-1964. Reprinted with permission. © 2019 SAE International

Results of Idealized Sensitivity Experiments

(Domain-maximum values)

	CTL	hiCCN	loCCN	hiINP	loINP	hiRH	loRH	hiCAPE	loCAPE	hiTcb	loTcb	hiSHR	loSHR
W (m/s)	19.7	29.8	20.3	20.6	19.7	38.9	12.0	36.9	12.1	21.9	25.0	10.8	31.0
qc (kg/kg)	3.3e-3	8.1e-3	1.3e-3	4.3e-3	3.2e-3	3.5e-3	2.3e-3	3.5e-3	2.7e-3	3.5e-3	3.1e-3	2.3e-3	3.7e-3
ncc (#/kg)	2.2e8	2.0e9	3.9e7	3.6e8	2.1e8	2.5e8	2.1e8	2.5e8	2.1e8	2.2e8	2.2e8	2.1e8	2.4e8
qi (kg/kg)	2.3e-4	3.9e-4	2.2e-4	2.6e-4	2.3e-4	4.1e-4	3.6e-5	3.5e-4	1.5e-4	2.5e-4	3.1e-4	-	3.6e-4
nci (#/kg)	3.4e6	5.2e6	3.8e6	3.5e6	3.4e6	5.3e6	7.2e5	5.5e6	1.9e6	2.7e6	4.4e6	-	6.1e6
qs (kg/kg)	7.2e-4	9.7e-4	7.7e-4	7.5e-4	7.2e-4	8.3e-4	6.9e-5	8.9e-4	5.2e-4	7.3e-4	7.6e-4	-	1.0e-3
ncs (#/kg)	4.4e5	5.6e5	4.7e5	4.4e5	4.4e5	5.4e5	3.3e4	5.8e5	2.6e5	4.2e5	5.0e5	-	6.7e5

Sensitivity to Spatial Resolution

(Domain-maximum values, CCN3000)

	dx, dy=1 km	dx, dy=500 m	dx, dy=250 m
W (m/s)	26.9	35.2	42.0
qc (kg/kg)	5.8e-3	7.1e-3	8.5e-3
ncc (#/kg)	1.5e9	1.7e9	1.9e9
qi (kg/kg)	7.7e-4	7.3e-4	8.0e-4
nci (#/kg)	8.9e6	5.3e7	5.8e7
qs (kg/kg)	1.1e-3	1.3e-3	1.7e-3
ncs (#/kg)	7.7e5	4.9e5	8.9e5