Idealized Marine Cold-Air Outbreak Simulations

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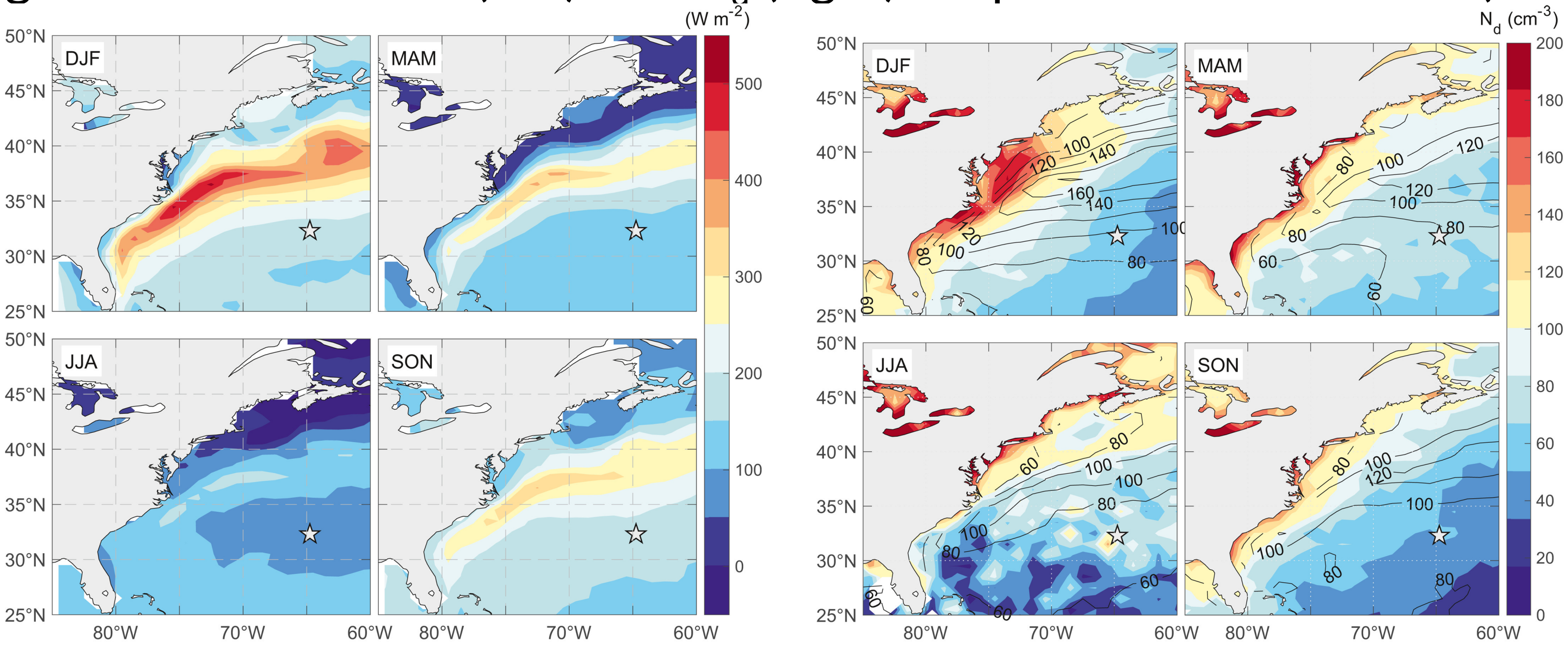
Motivation

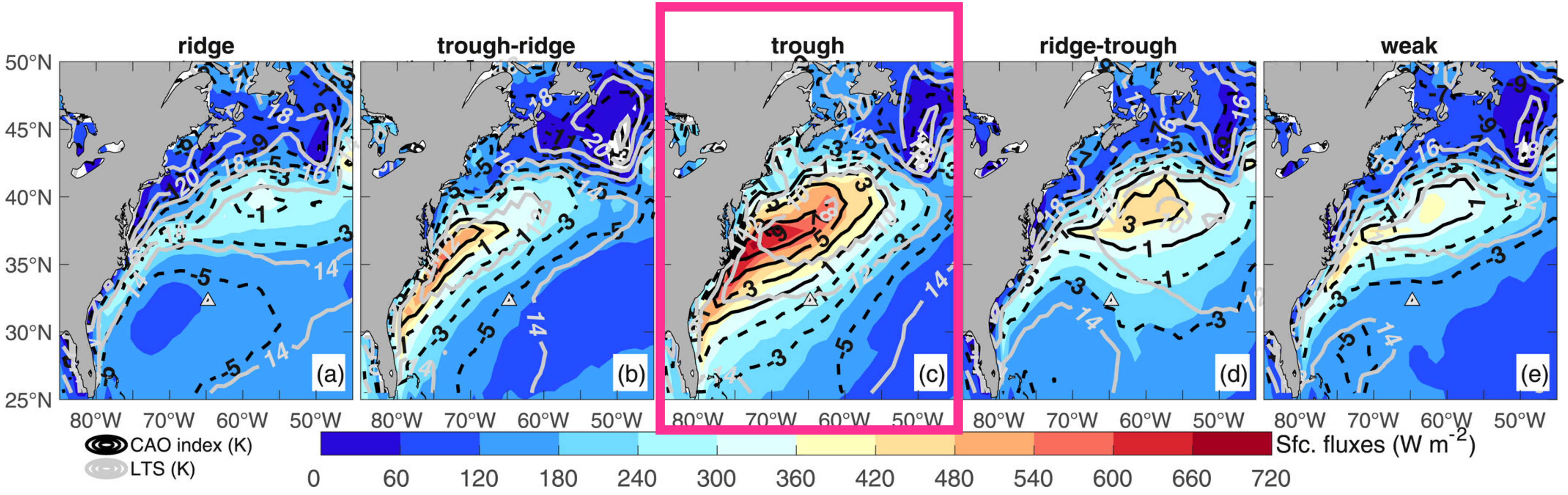
- Wintertime WNAO presents the highest occurrence of low clouds, often linked to Marine Cold-Air Outbreaks (MCAO)
- Highest surface fluxes (left) and N_d (right) despite the lowest AOD (Corral et al., 2021)



Painemal et al. (2021)

MCAO modeling study	Dates	Model, Δx, boundary layer Δz
Tornow et al. (2022)	March 17–19, 2008	DHARMA, $\Delta x = 150$m; $\Delta z = 20$m
Li et al. (2022, 2023)	Feb 28 & March 1, 2020	WRF, $\Delta x = 300$m; $\Delta z = 33$m
Chen et al. (2022)	March 1, 2020	WRF, $\Delta x = 1$km; $\Delta z = 46$m

Synoptic conditions associated with MCAO



Painemal et al. (2023)

- Among the 15 pattern classifications, Pattern #3 (Trough) is distinguished by the highest surface heat fluxes
- A total of **17 dates** between 2018 and 2020 correspond to Pattern #3, including March 1, 2020

Research Goal

Objective

- To investigate the individual and synergistic impacts of aerosol concentration and sea surface fluxes on the properties of boundary layer clouds during marine cold-air outbreaks (MCAO)

Approach

- A suite of high-resolution ($\Delta x = \Delta y =$100m, $\Delta z = 25$m, $\Delta t = 1$s), idealized cloud-resolving modeling simulations

1) CCN concentration
2) SST
3) Wind speed

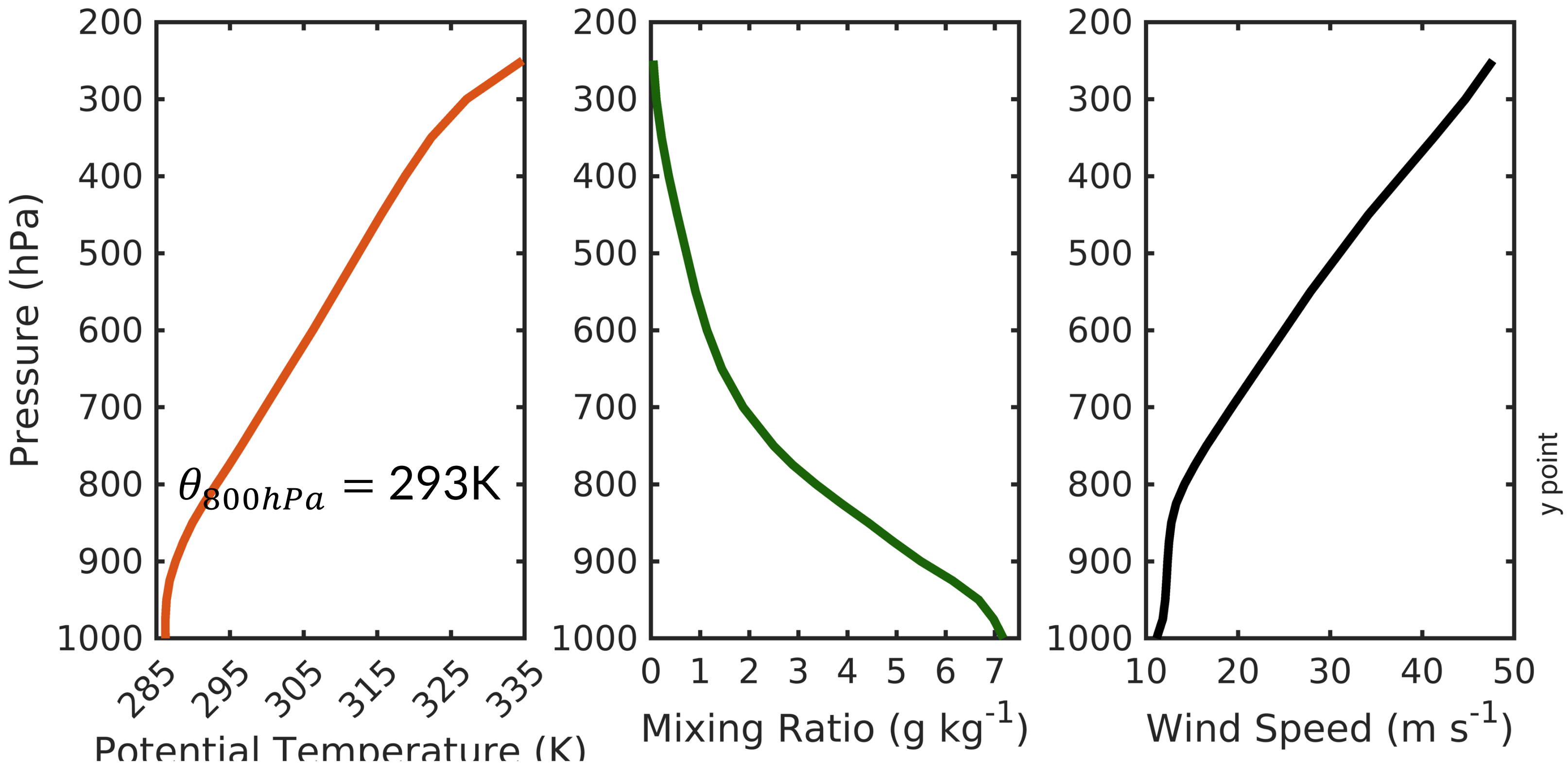
Idealized MCAO Simulations

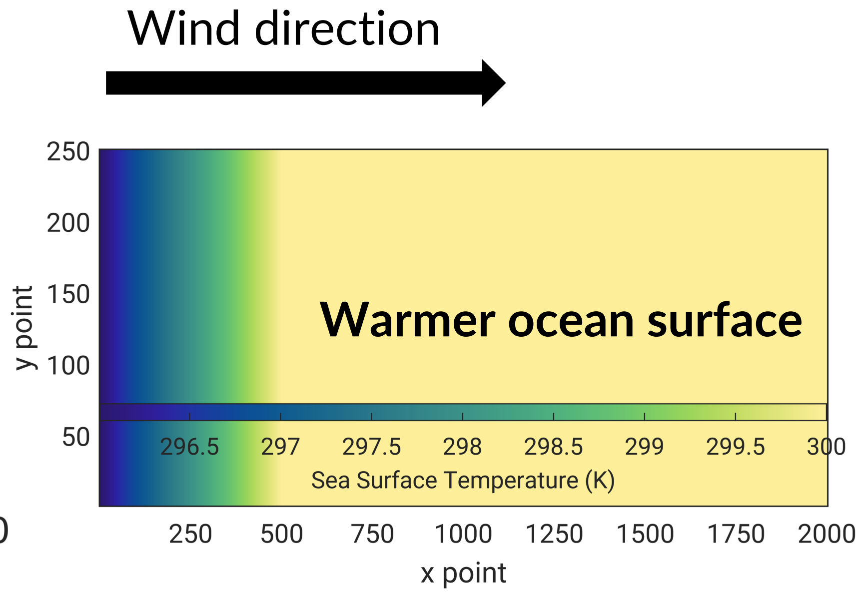
- Regional Atmospheric Modeling System (RAMS) version 6.3.04
- Domain: 200 km × 25 km × 7 km (2000 × 250 points across 280 levels)
- Boundary condition: open radiative, constant inflow in x, and cyclic in y direction
- Resolution: $\Delta x = \Delta y =$100m, $\Delta z =$25m
- Time: Starts at 0900 UTC for a 15-hour duration with a time step of $\Delta t = 1$s

Model Physics	Setting
Radiation	Harrington two-stream, updated every 5s
Turbulence	Deardorff TKE
Microphysics	Full microphysics, double-moment bin emulating bulk
Aerosol	Accumulation mode ammonium sulfate Exponentially decreasing with height, 200 mg^{-1} at the surface (CONTROL) Sources and sinks, dry and wet deposition

Initial sounding for simulations
:an average of 17 Trough days

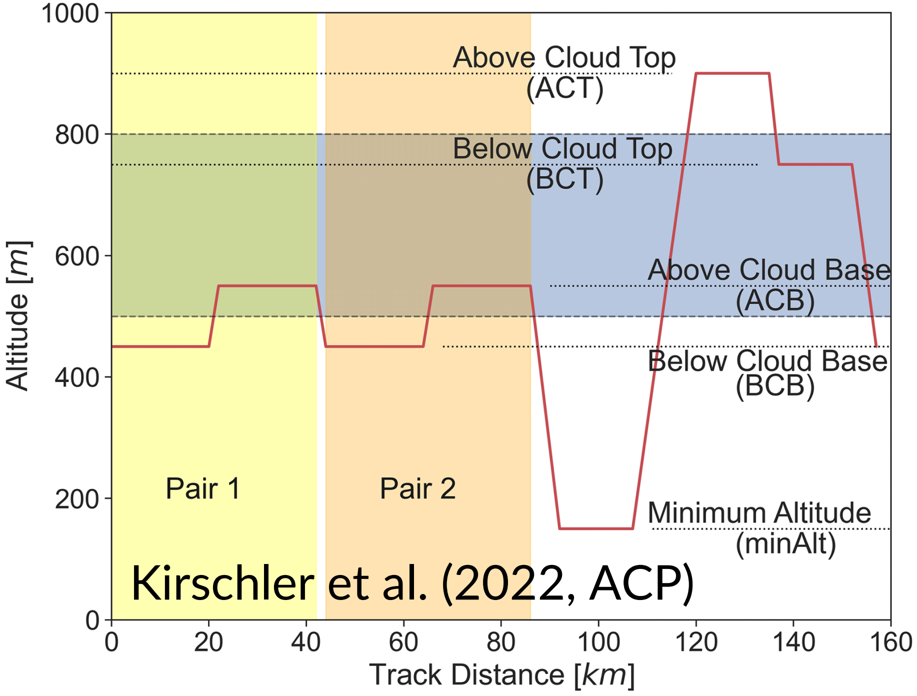
ERA-5 at 9 UTC for Ocean-Only Regions (25–40°N, 60–80°W)





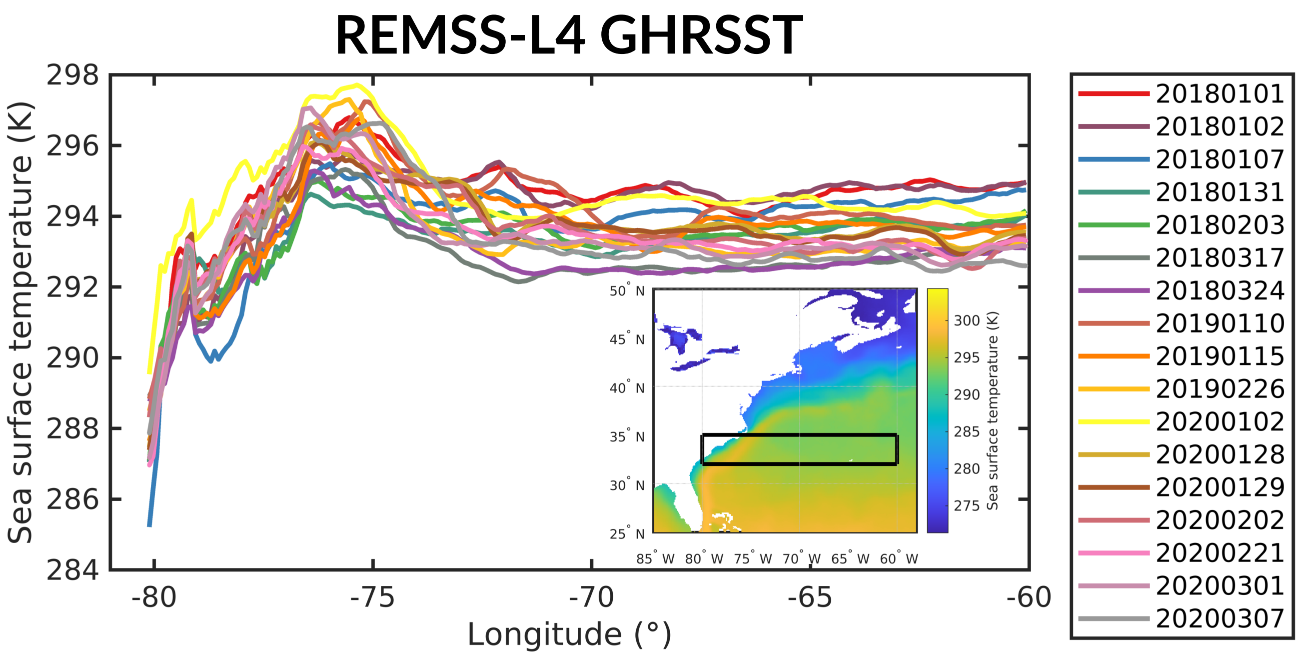
MCAO index = $\theta_{800hPa} - \boldsymbol{\theta_{SST}}$

Sensitivity Experiments
Factor 1. CCN

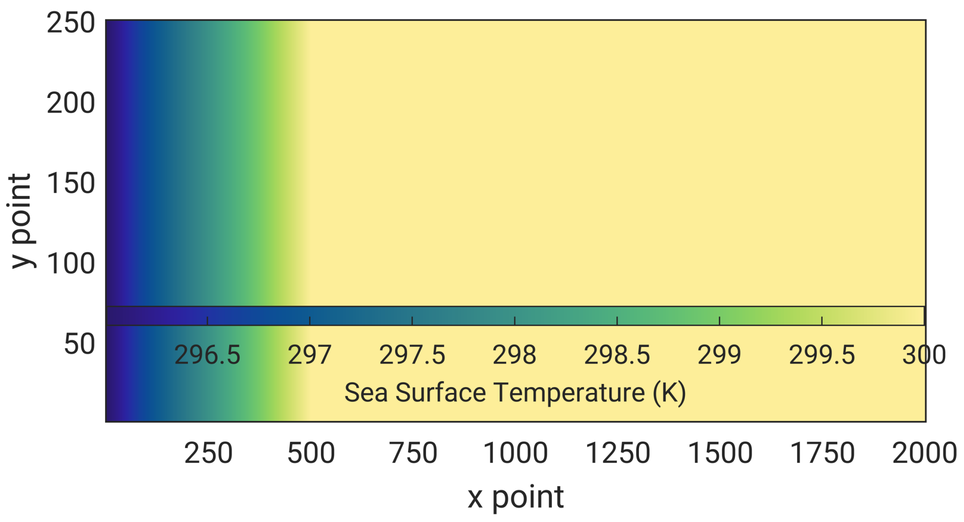


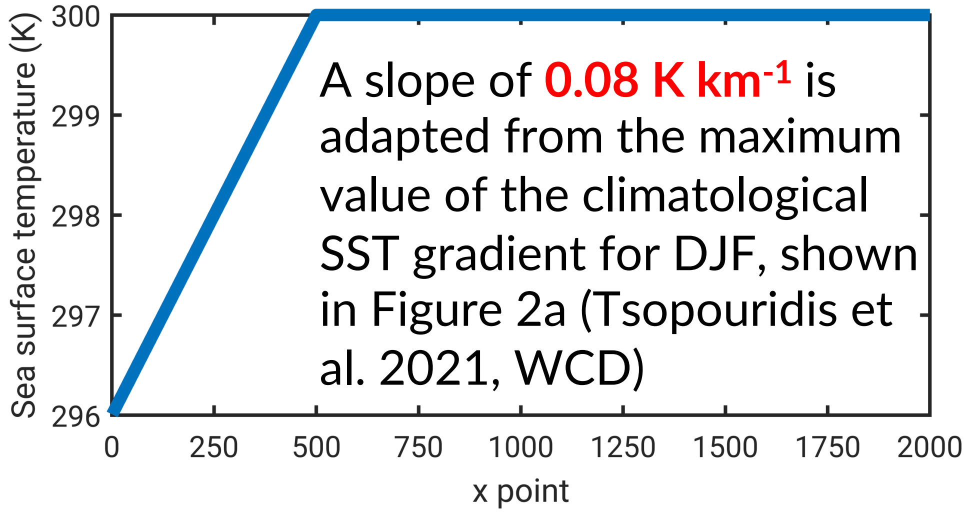
Flight	Date	$t_{initial}$ [UTC]	CCN-100 mode (Supersat [%])	D_{max} [km]	In-cloud [s]	$N_{CCN_{0.43\%}}$ [cm^{-3}]	w [m s^{-1}]	N_C [cm^{-3}]	h_{ACB} [m]
RF01	14 Feb 2020	17:21:32	Scan (0.17–0.70)	37.2	19	647 (± 35)	0.83 (± 0.56)	298 (± 173)	127 (± 4)
RF01	14 Feb 2020	17:30:17	Scan* (0.17–0.70)	35.3	28	664 (± 50)	1.67 (± 0.70)	593 (± 492)	136 (± 14)
RF01	14 Feb 2020	17:58:43	Scan (0.16–0.69)	28.3	51	582 (± 46)	1.74 (± 1.21)	723 (± 344)	103 (± 5)
RF01	14 Feb 2020	18:05:17	Scan* (0.16–0.68)	35.6	44	582 (± 36)	2.07 (± 1.26)	570 (± 308)	111 (± 3)
RF02	15 Feb 2020	17:09:31	Scan (0.17–0.71)	22.9	59	436 (± 37)	0.62 (± 0.48)	389 (± 217)	82 (± 6)
RF02	15 Feb 2020	17:18:16	Scan (0.17–0.71)	19.8	58	630 (± 36)	0.63 (± 0.33)	648 (± 279)	73 (± 2)
RF02	15 Feb 2020	18:23:53	Scan (0.16–0.71)	29.4	34	489 (± 34)	0.87 (± 0.52)	297 (± 223)	147 (± 6)
RF02	15 Feb 2020	18:32:38	Scan (0.16–0.71)	38.4	130	440 (± 20)	1.85 (± 0.82)	385 (± 171)	200 (± 3)
RF03	17 Feb 2020	17:41:11	Scan* (0.17–0.71)	40.0	74	1564 (± 65)	0.25 (± 0.29)	930 (± 663)	93 (± 3)
RF09	27 Feb 2020	18:47:10	Scan* (0.16–0.72)	32.7	62	659 (± 39)	0.72 (± 0.53)	671 (± 357)	98 (± 5)
RF09	27 Feb 2020	18:55:55	Scan (0.17–0.72)	29.7	36	575 (± 46)	0.64 (± 0.53)	336 (± 218)	125 (± 6)
RF09	27 Feb 2020	19:28:43	Scan (0.16–0.71)	37.5	41	582 (± 29)	0.73 (± 0.54)	467 (± 250)	145 (± 5)
RF09	27 Feb 2020	19:39:39	Scan (0.17–0.71)	33.2	48	656 (± 42)	0.91 (± 0.77)	355 (± 224)	189 (± 19)
RF09	27 Feb 2020	20:10:17	Scan (0.16–0.71)	28.7	42	674 (± 29)	1.13 (± 0.94)	716 (± 377)	151 (± 4)
RF09	27 Feb 2020	20:19:02	Scan (0.16–0.71)	31.9	35	650 (± 35)	0.83 (± 0.68)	647 (± 292)	199 (± 4)
RF13	1 Mar 2020	14:10:32	Scan* (0.16–0.71)	28.2	96	1217 (± 93)	1.57 (± 1.28)	1020 (± 556)	113 (± 4)
RF13	1 Mar 2020	15:00:51	Scan (0.16–0.72)	37.2	74	361 (± 19)	1.54 (± 1.63)	372 (± 197)	169 (± 5)
RF13	1 Mar 2020	16:02:06	Scan* (0.17–0.71)	36.7	51	769 (± 41)	1.46 (± 1.30)	818 (± 721)	139 (± 3)
RF16	6 Mar 2020	19:34:26	Scan (0.17–0.71)	32.3	55	991 (± 46)	0.99 (± 0.73)	1367 (± 958)	208 (± 6)
RF16	6 Mar 2020	19:43:11	Scan (0.16–0.72)	28.3	36	1788 (± 109)	1.80 (± 1.06)	1157 (± 912)	100 (± 3)
RF16	6 Mar 2020	20:15:59	Scan (0.17–0.72)	29.9	49	1501 (± 71)	1.84 (± 1.06)	1014 (± 742)	130 (± 6)
RF16	6 Mar 2020	20:24:44	Scan* (0.17–0.72)	34.7	33	945 (± 53)	1.55 (± 1.27)	397 (± 358)	193 (± 5)
RF17	8 Mar 2020	14:34:49	Flow (0.43)	25.0	39	183 (± 28)	1.05 (± 0.88)	434 (± 228)	117 (± 3)
RF17	8 Mar 2020	14:44:29	Flow (0.43)	29.2	17	245 (± 31)	1.35 (± 0.68)	498 (± 214)	135 (± 3)
RF17	8 Mar 2020	15:11:45	Flow (0.43)	28.7	112	164 (± 26)	0.46 (± 0.45)	208 (± 93)	173 (± 4)
RF17	8 Mar 2020	15:23:22	Flow (0.43)	28.3	72	96 (± 18)	0.95 (± 0.98)	218 (± 101)	163 (± 4)
RF17	8 Mar 2020	15:52:58	Flow (0.43)	30.1	56	196 (± 27)	0.83 (± 0.85)	386 (± 212)	91 (± 3)
RF17	8 Mar 2020	16:02:17	Flow (0.43)	19.8	65	225 (± 33)	1.52 (± 1.34)	346 (± 149)	129 (± 4)
RF19	9 Mar 2020	17:27:27	Flow (0.43)	28.6	26	291 (± 34)	0.63 (± 0.48)	208 (± 146)	125 (± 6)
RF19	9 Mar 2020	17:57:47	Flow (0.43)	23.7	20	299 (± 44)	0.61 (± 0.44)	247 (± 125)	121 (± 4)
RF19	9 Mar 2020	18:41:47	Flow (0.43)	17.5	18	335 (± 46)	0.43 (± 0.28)	215 (± 114)	224 (± 2)
RF19	9 Mar 2020	18:50:13	Flow (0.43)	37.4	24	307 (± 36)	0.64 (± 0.56)	285 (± 171)	196 (± 11)
RF20	11 Mar 2020	13:46:55	Flow (0.43)	25.3	22	875 (± 101)	0.45 (± 0.46)	780 (± 430)	62 (± 2)
RF20	11 Mar 2020	14:26:13	Flow (0.43)	23.3	10	986 (± 134)	0.26 (± 0.21)	320 (± 221)	42 (± 3)
RF21	12 Mar 2020	14:43:10	Flow (0.43)	25.2	19	586 (± 84)	1.64 (± 1.07)	675 (± 383)	141 (± 4)
RF21	12 Mar 2020	14:51:22	Flow (0.43)	27.4	30	500 (± 91)	0.77 (± 0.70)	458 (± 275)	140 (± 4)
RF21	12 Mar 2020	15:19:57	Flow (0.43)	21.2	42	587 (± 102)	0.78 (± 0.72)	654 (± 418)	71 (± 2)
RF21	12 Mar 2020	16:06:00	Flow (0.43)	22.3	34	494 (± 58)	0.68 (± 0.48)	559 (± 255)	116 (± 3)
RF21	12 Mar 2020	16:14:01	Flow (0.43)	38.8	25	455 (± 72)	0.69 (± 0.57)	584 (± 261)	124 (± 46)
All RFs	Average			29.3	45	612	1.02	535	130

Sensitivity Experiments
Factor 2. Sea surface temperature

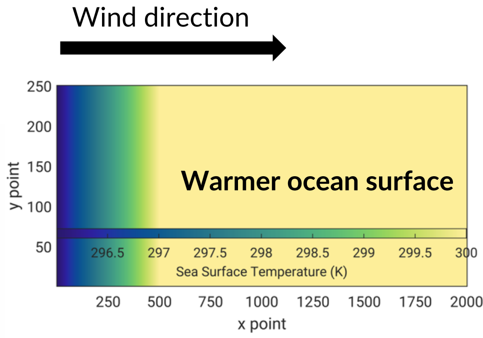


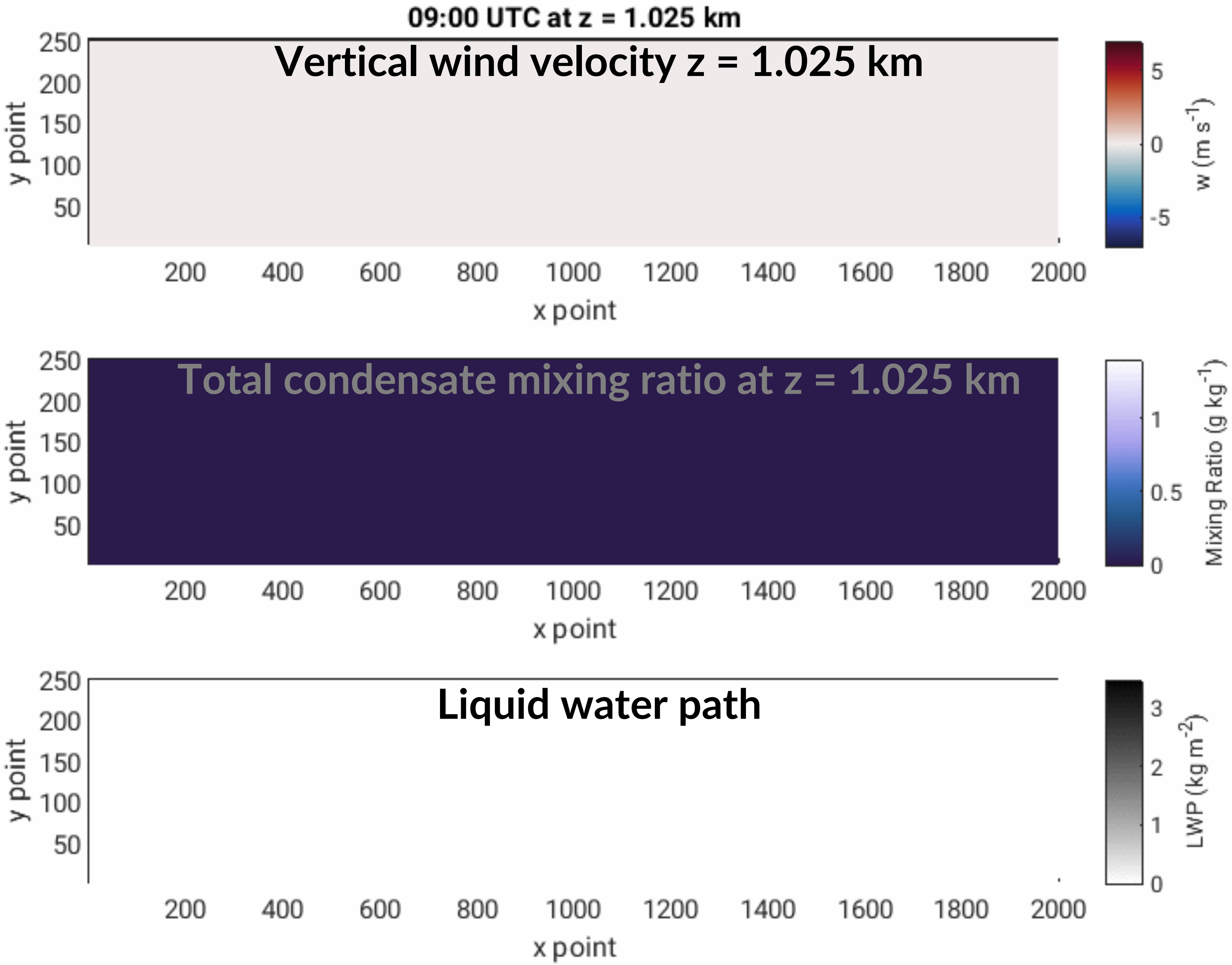
Given that the θ_{800hPa} in the initial sounding is 293K, we selected an SST perturbation range **293—300K** to test scenarios where 0 ≤ MCAO index ≤ 7



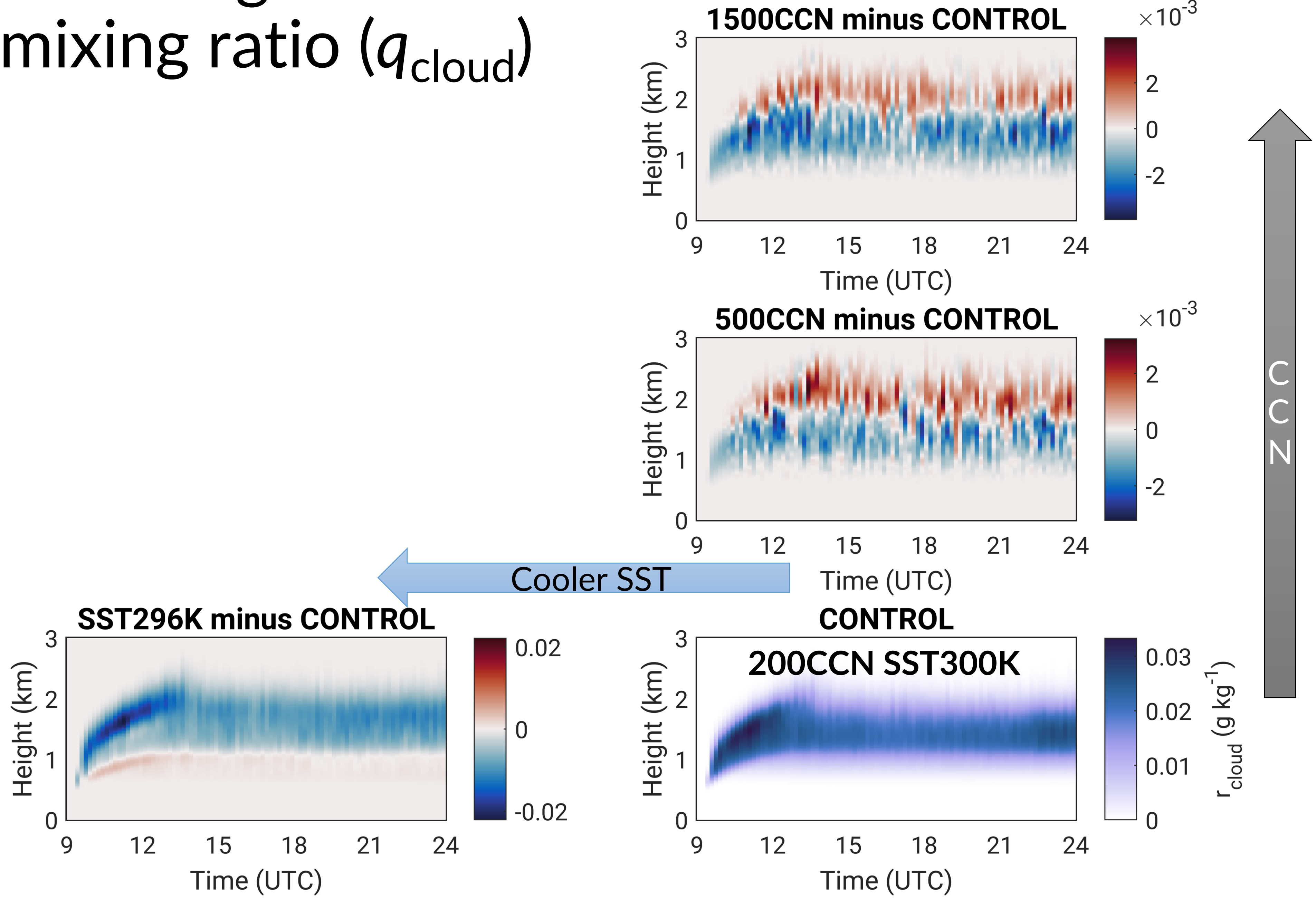


Example Evolution of MCAO Clouds

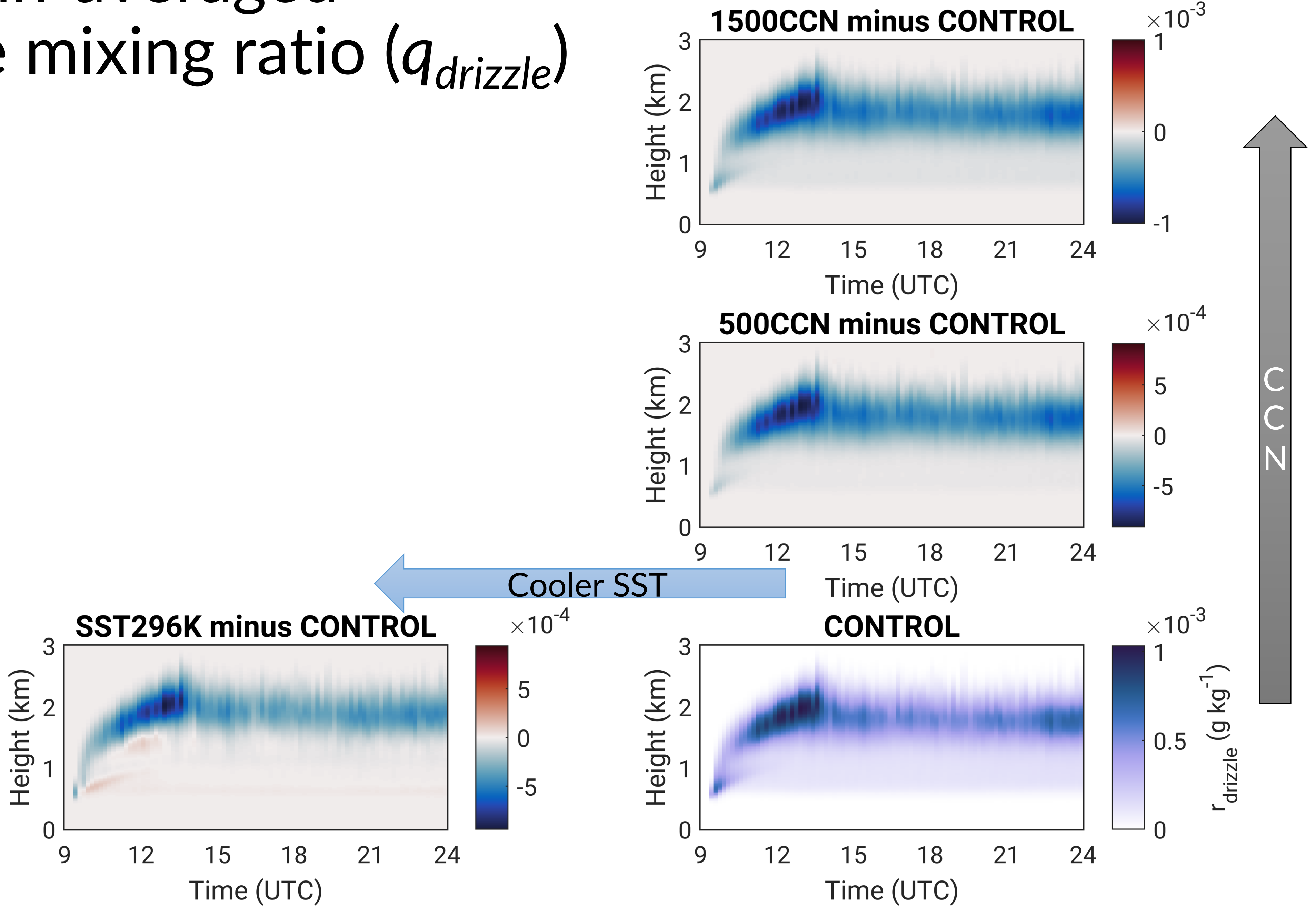




Domain-averaged cloud mixing ratio (q_{cloud})



Domain-averaged drizzle mixing ratio ($q_{drizzle}$)



Next Steps

- While the individual effects of increasing CCN and decreasing SST have been briefly demonstrated, the synergistic impact of these changes will be further assessed.

- Further analysis will include additional details, such as microphysical process rates and turbulent kinetic energy.