Examining Terrain Effects on the Evolution of Precipitation and Vorticity of the Landfalling Tropical Cyclone Fanapi (2010) near Taiwan

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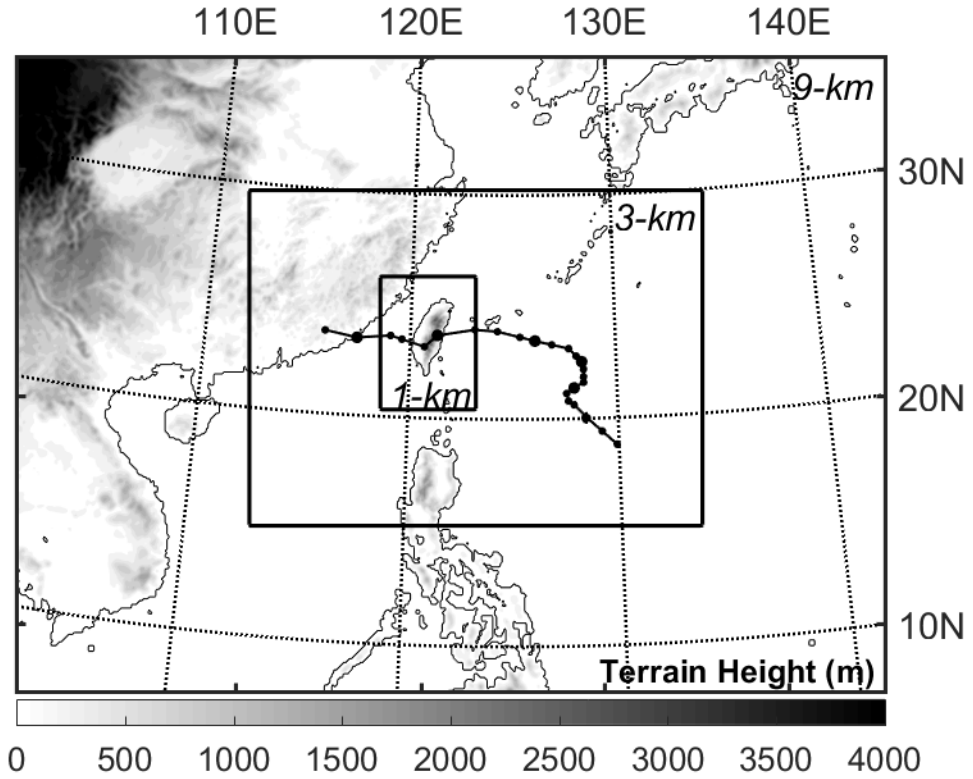
Central Weather Bureau, Taiwan

2020.10.15

Model configuration



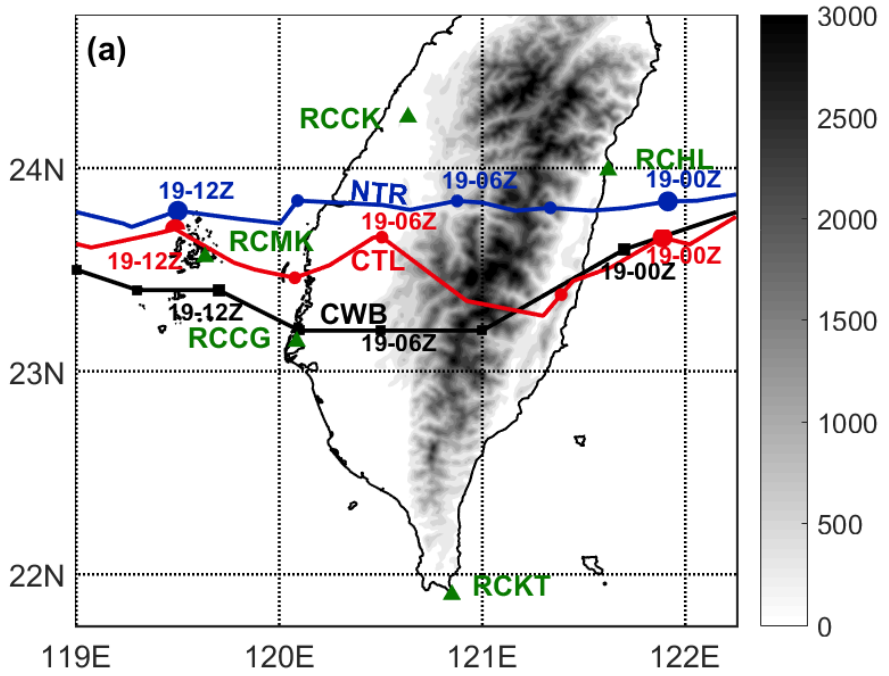
Yang et al. 2018

WRFV3.3.1
2010/09/18 00Z – 2010/09/20 00Z (48-hr)
Grid size: 9/3/1-km with 55 η levels in verticals

Parameterization
CU: Grell-Devenyi ensemble scheme
MP: Morrison 2-moment scheme
PBL: YSU scheme
RA: RRTM (longwave) / Dudhia (shortwave) scheme

CTL: with complex terrain of Taiwan Island

NTR: with flat terrain of Taiwan Island



Convective-Stratiform Separation Algorithm

Evaluate Z_{bg}, ΔZ_{cc} and convective radius R

$$\Delta Z_{cc} = \mathrm{a} \times \cos\left(\frac{1}{b}\frac{\pi Z_{bg}}{2}\right) \qquad Z_{ti} = 42\ dBZ$$

$$R = \begin{cases} 0.5 & \text{km} & Z_{bg} < 20 \\ 0.5 + 3.5\left(\dfrac{Z_{bg} - 20}{15}\right) & \text{km} & 20 \le Z_{bg} < 35 \\ 4 & \text{km} & Z_{bg} \ge 35 \end{cases}$$

Didlake and Houze, 2009

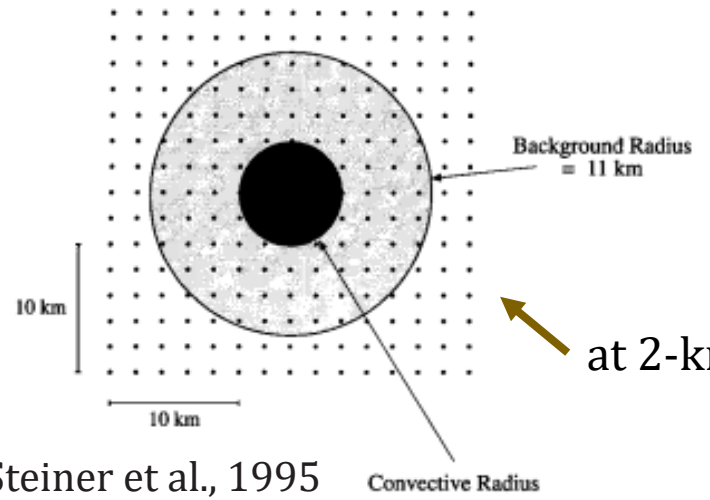
Convective region

DC (Deep Convection):
$Z_{echo\_top} \ge 10$ km
MC (Moderate Convection):
4 km $\le Z_{echo\_top} < 10$ km
SC (Shallow Convection):
$Z_{echo\_top} < 4$ km

Tao and Jiang, 2015; Fritz et al., 2016; Rogers et al., 2020;

None convective region

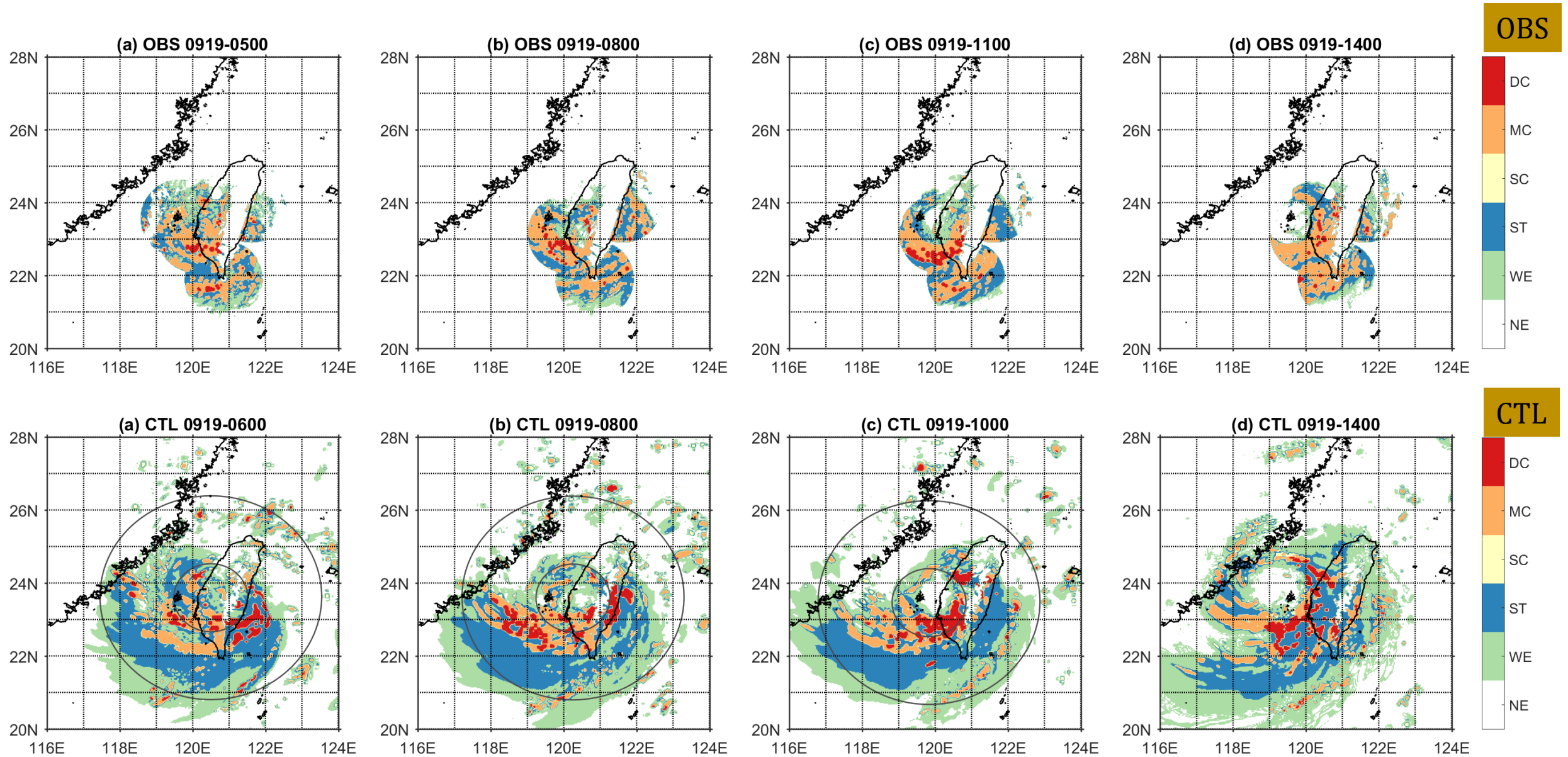
WE (Weak Echo):
$Z_e < 20$ dBZ
ST (Stratiform):
$Z_e \ge 20$ dBZ

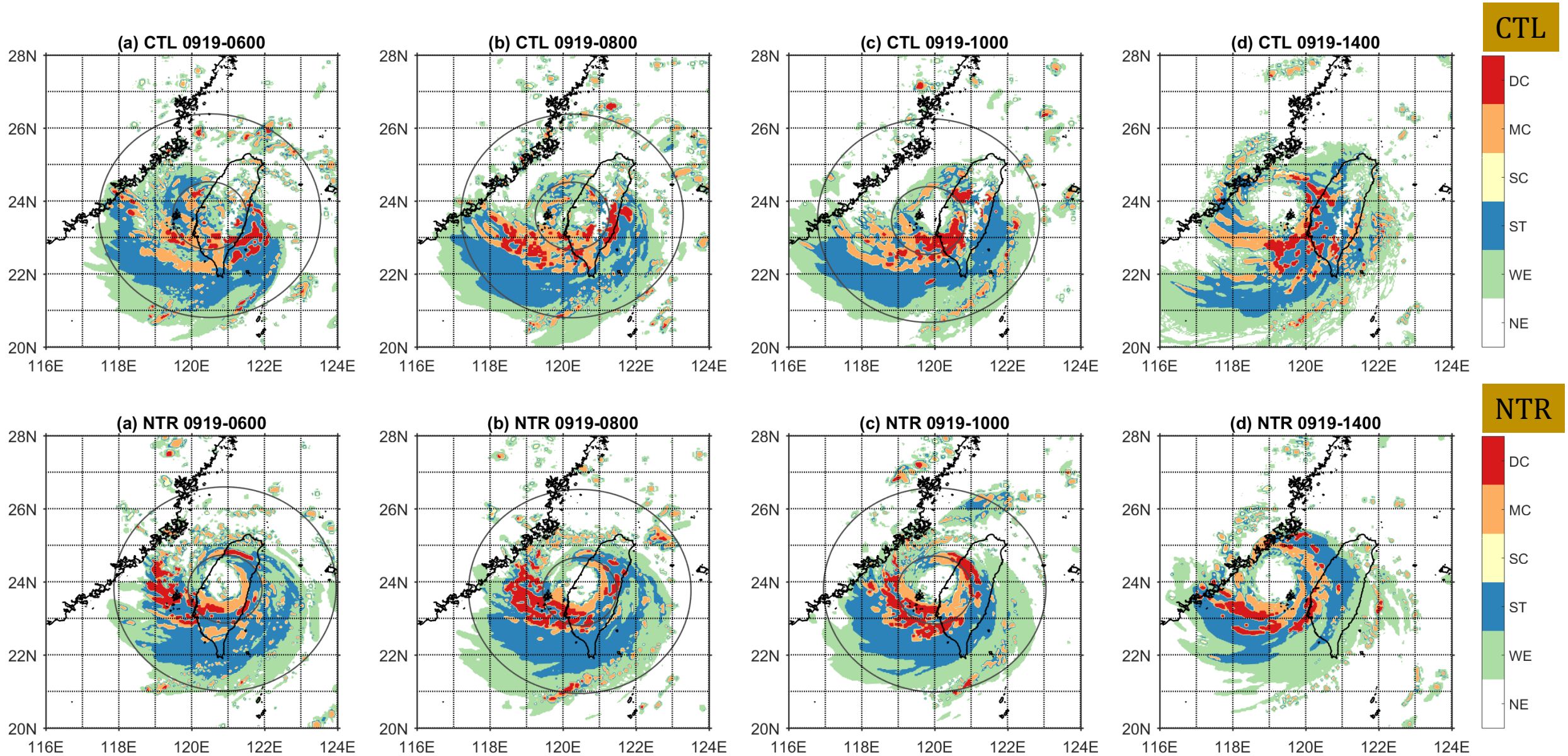


at 2-km height

Steiner et al., 1995

(RCCG/RCHL/RCKT/RCMK/RCCK)

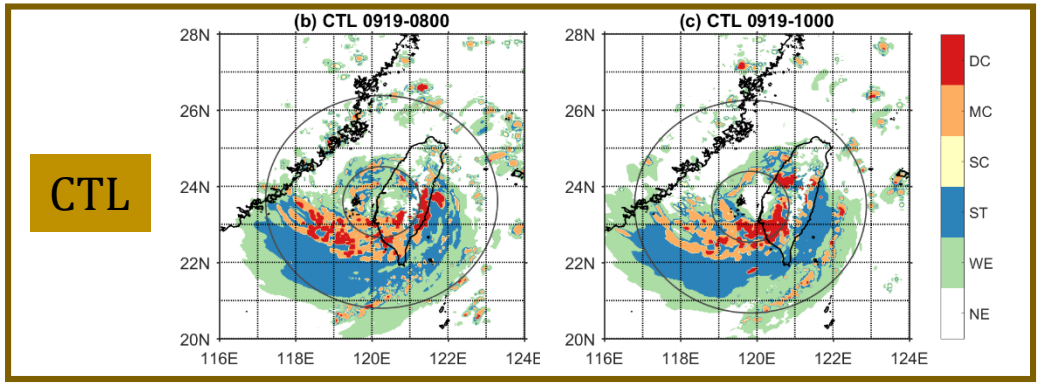



(a) CTL 0919-0600
(b) CTL 0919-0800
(c) CTL 0919-1000
(d) CTL 0919-1400
(a) NTR 0919-0600
(b) NTR 0919-0800
(c) NTR 0919-1000
(d) NTR 0919-1400
28N
26N
24N
22N
20N
116E
118E
120E
122E
124E
CTL
NTR
DC
MC
SC
ST
WE
NE

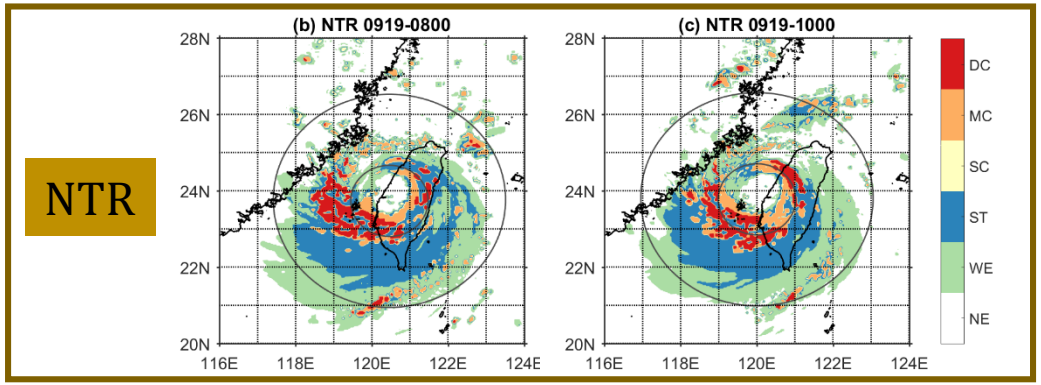
OBS

Time (UTC)	Time	Stratiform	No/Weak Echo	Shallow Convection	Moderate Convection	Deep Convection
05:00	T-4	18.25	38.26	0.08	36.18	7.23
06:00	T-3	17.74	49.35	0.82	25.62	6.48
07:00	T-2	21.89	42.68	0.97	27.52	6.93
08:00	T-1	20.24	31.21	0.99	37.12	10.44
09:00	T	17.48	32.48	1.90	37.09	11.06
10:00	T+1	23.82	26.94	0.96	39.42	8.86
11:00	T+2	19.73	34.83	0.94	35.14	9.36
12:00	T+3	14.85	52.81	1.47	27.19	3.67
13:00	T+4	8.17	59.54	1.74	28.52	2.02
14:00	T+5	6.02	68.09	0.42	24.15	1.32
Average		16.82	43.62	1.03	31.80	6.74

CTL



NTR



CTL

Time (UTC)	Time	Stratiform	No/Weak Echo	Shallow Convection	Moderate Convection	Deep Convection
06:00	T-3	31.84	32.75	0.63	26.39	8.39
07:00	T-2	29.47	42.23	0.26	20.40	7.65
08:00	T-1	22.48	44.22	0.29	24.82	8.19
09:00	T	20.00	43.22	0.14	19.17	17.46
10:00	T+1	18.49	44.19	0.57	17.12	19.63
11:00	T+2	20.09	41.74	0.34	15.04	22.80
12:00	T+3	16.38	56.78	0.68	11.70	14.47
13:00	T+4	16.58	58.23	1.60	12.10	11.50
14:00	T+5	12.87	58.72	2.45	18.80	7.16
Average		20.91	46.90	0.77	18.39	13.03

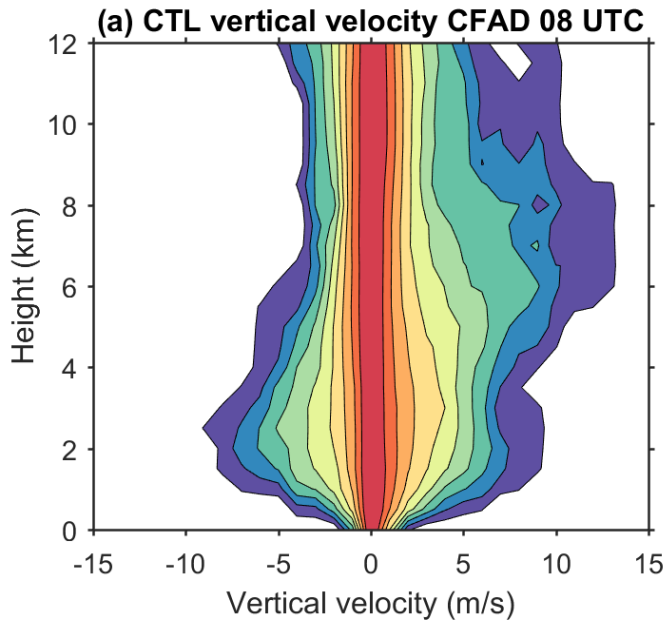
NTR

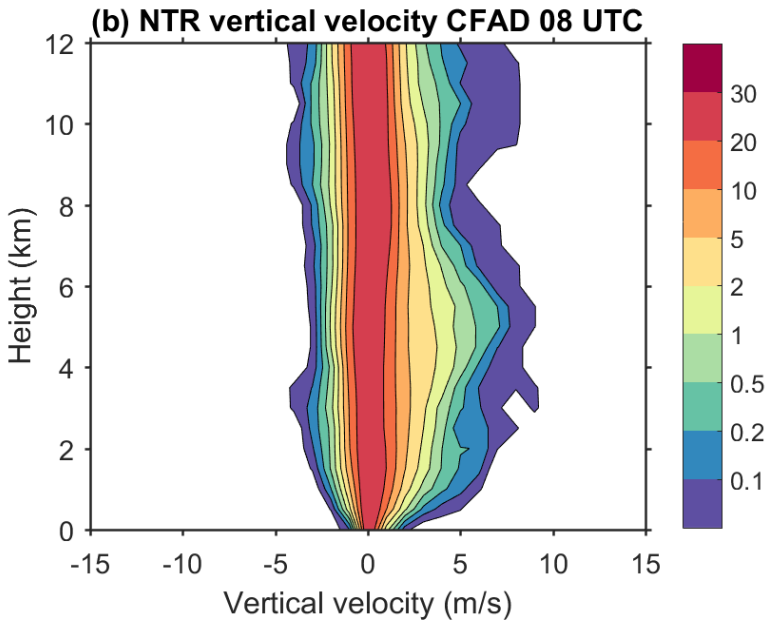
Time (UTC)	Time	Stratiform	No/Weak Echo	Shallow Convection	Moderate Convection	Deep Convection
06:00	T-3	31.64	36.26	2.25	19.29	10.56
07:00	T-2	25.16	38.97	1.40	21.43	13.04
08:00	T-1	26.36	35.89	2.00	20.46	15.29
09:00	T	23.97	32.72	2.48	22.08	18.74
10:00	T+1	19.80	37.55	1.51	28.25	12.90
11:00	T+2	20.86	38.29	2.48	29.59	8.79
12:00	T+3	19.54	46.31	2.03	26.56	5.56
13:00	T+4	15.35	49.64	3.97	21.31	9.73
14:00	T+5	21.03	47.02	1.17	22.23	8.56
Average		22.63	40.29	2.14	23.46	11.46

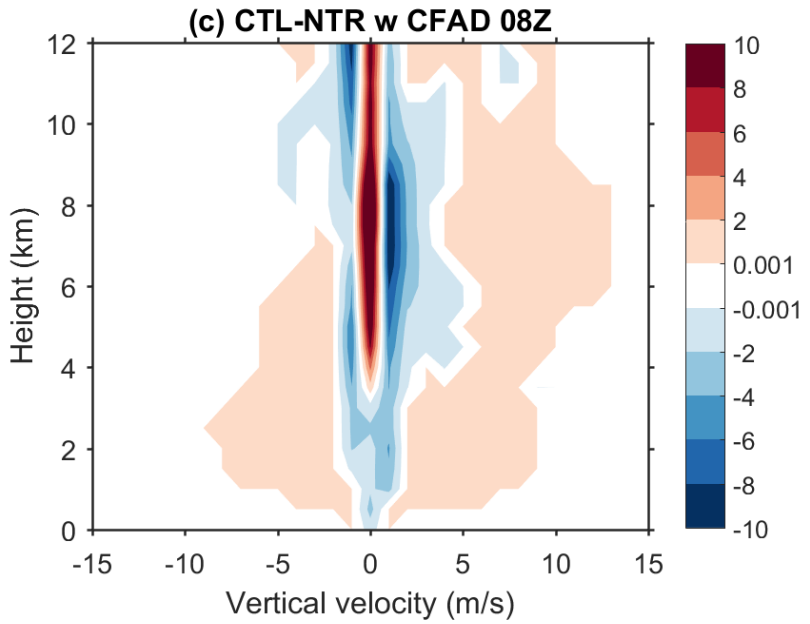
CTL

NTR

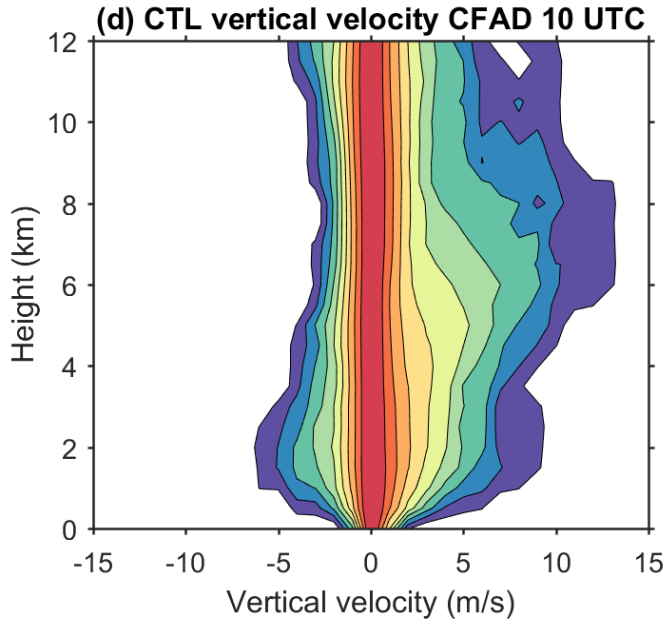
CTL-NTR

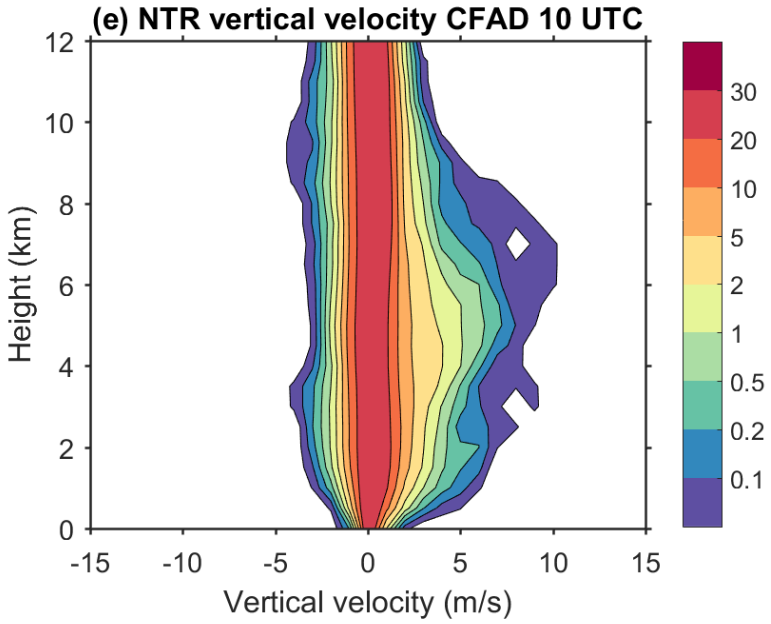


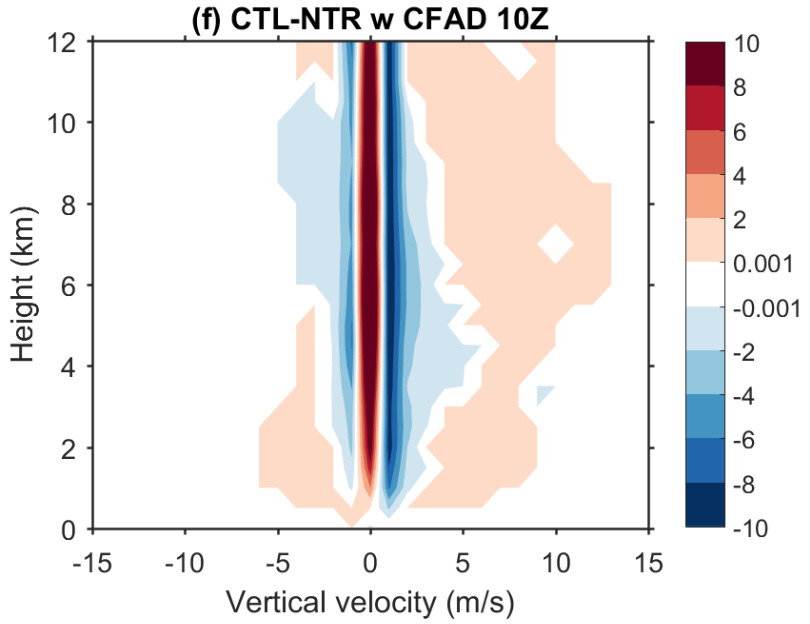




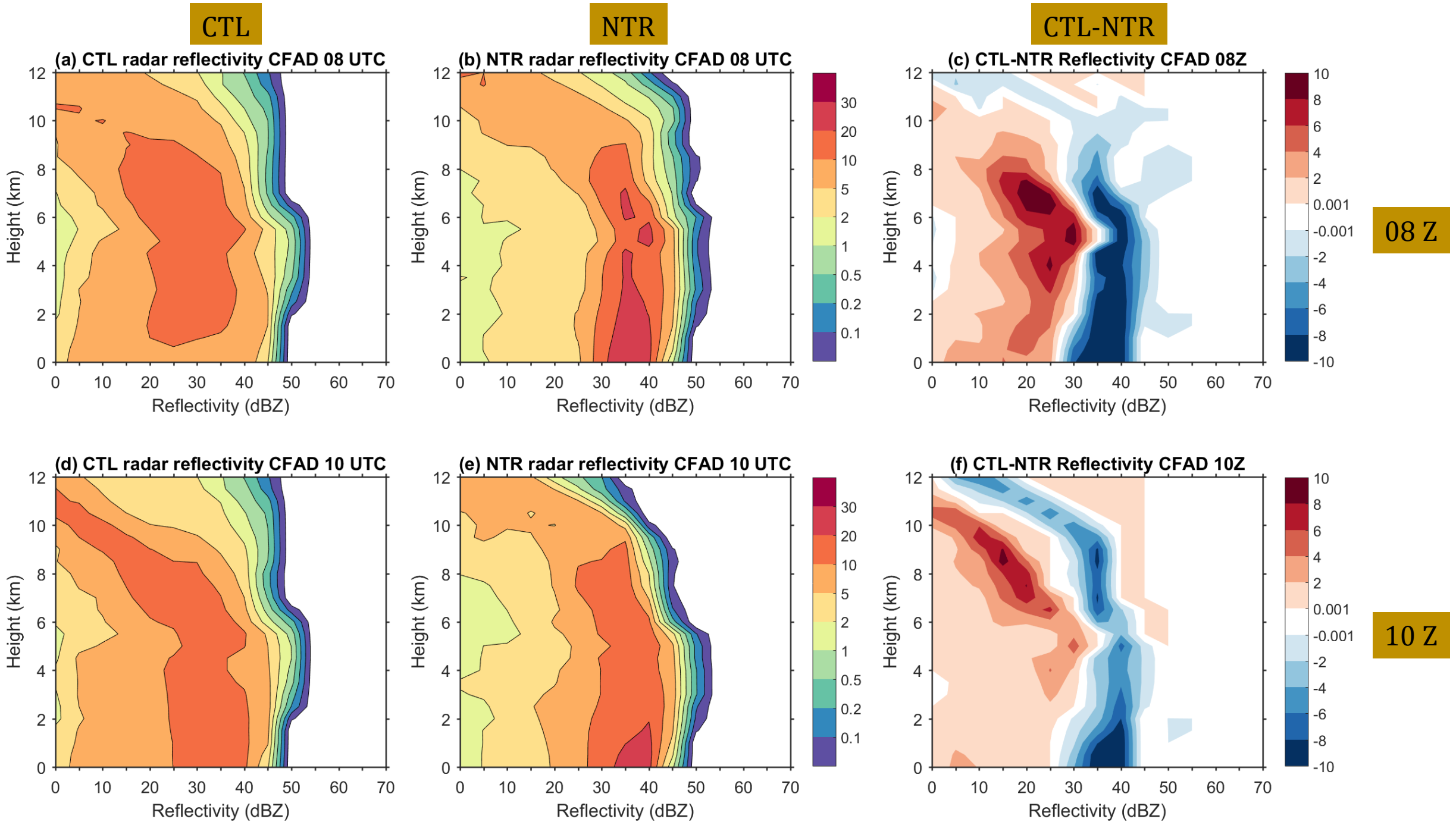
08 Z



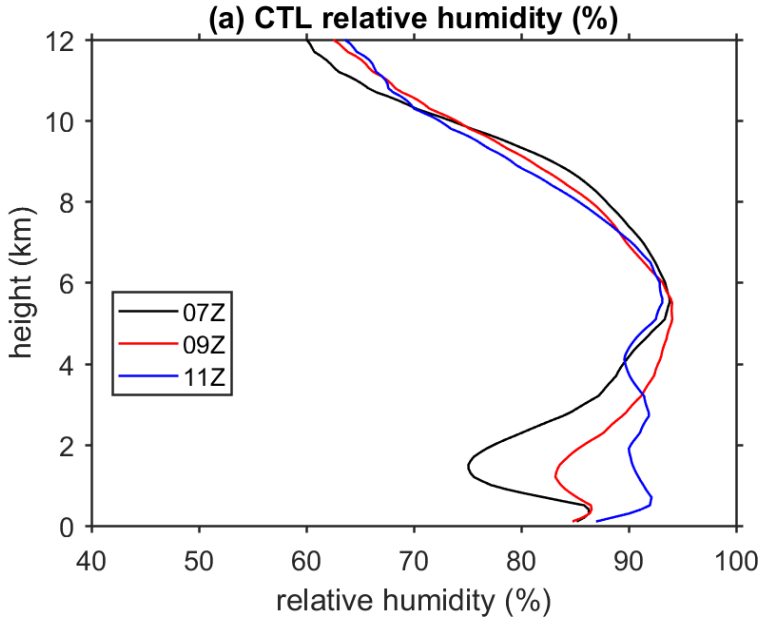


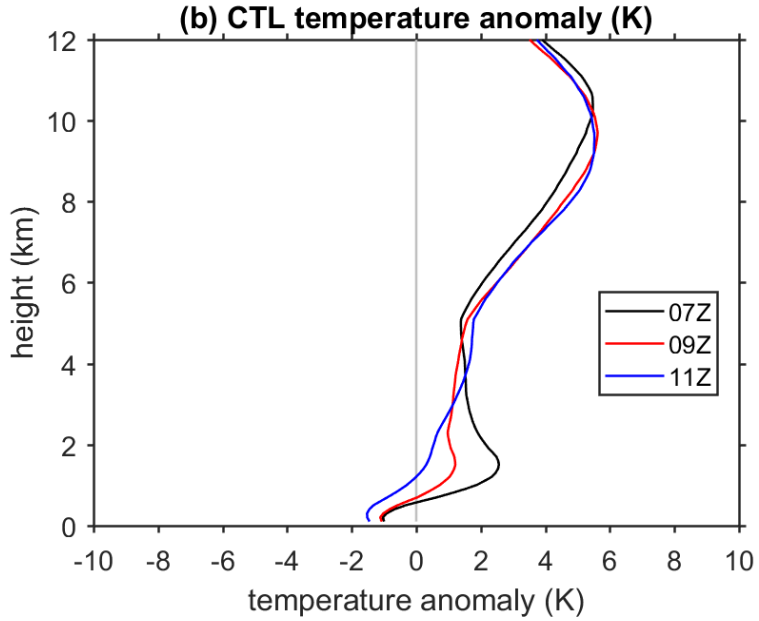


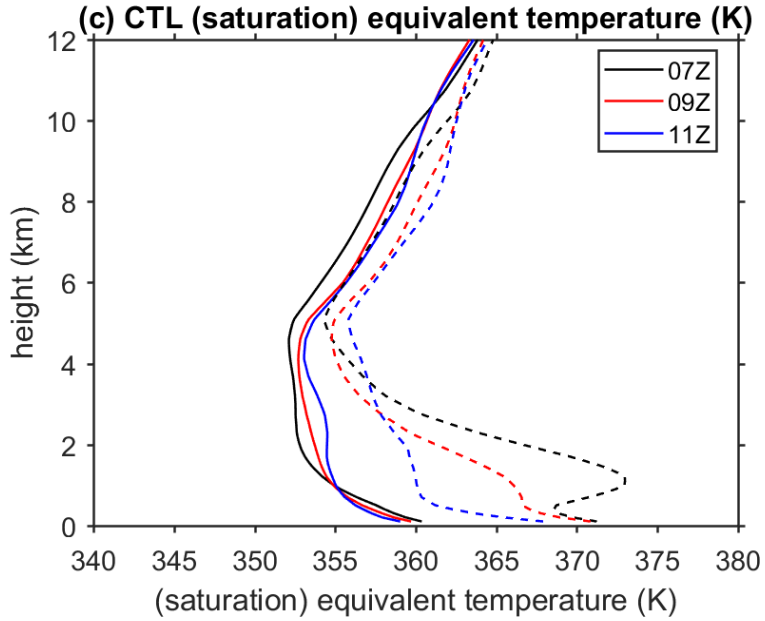
10 Z


CTL
NTR
CTL-NTR
(a) CTL radar reflectivity CFAD 08 UTC
(b) NTR radar reflectivity CFAD 08 UTC
(c) CTL-NTR Reflectivity CFAD 08Z
(d) CTL radar reflectivity CFAD 10 UTC
(e) NTR radar reflectivity CFAD 10 UTC
(f) CTL-NTR Reflectivity CFAD 10Z
Height (km)
Reflectivity (dBZ)
30
20
10
5
2
1
0.5
0.2
0.1
10
8
6
4
2
0.001
-0.001
-2
-4
-6
-8
-10
08 Z
10 Z

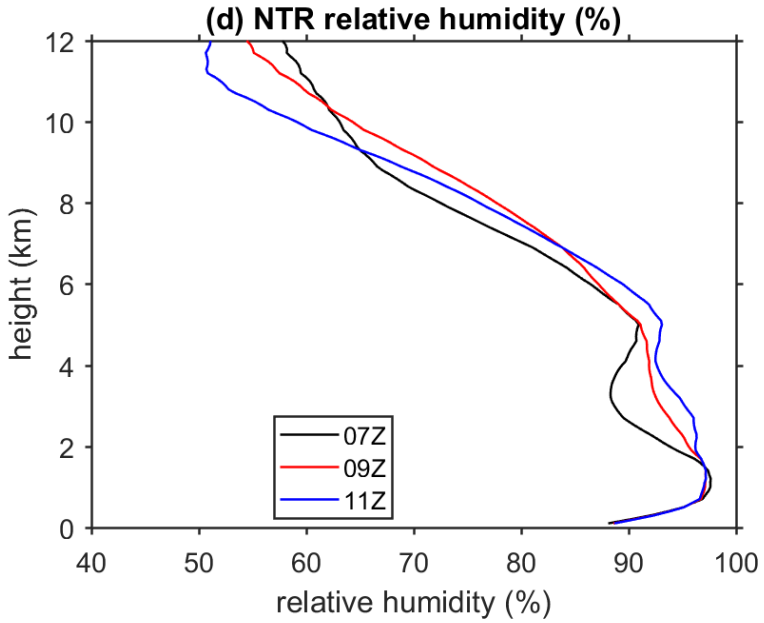
T_{100}-$T_{300\text{-}700}$

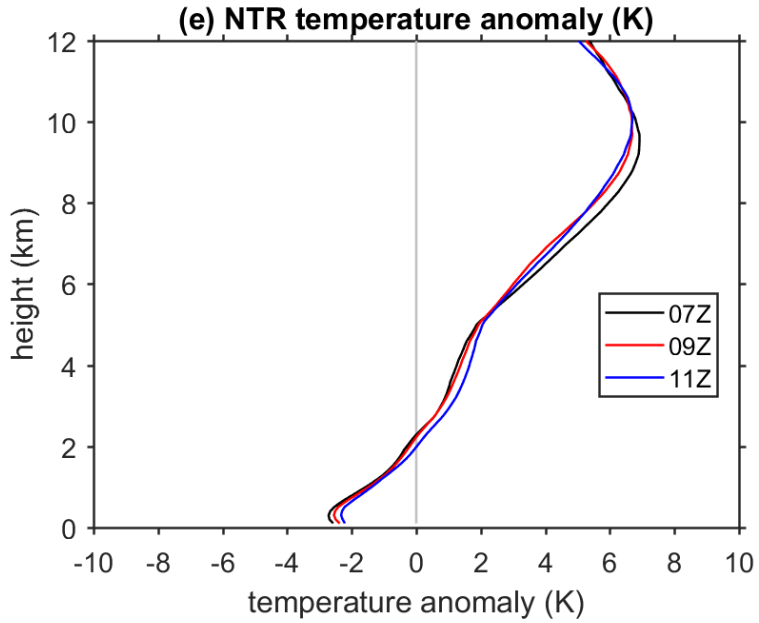


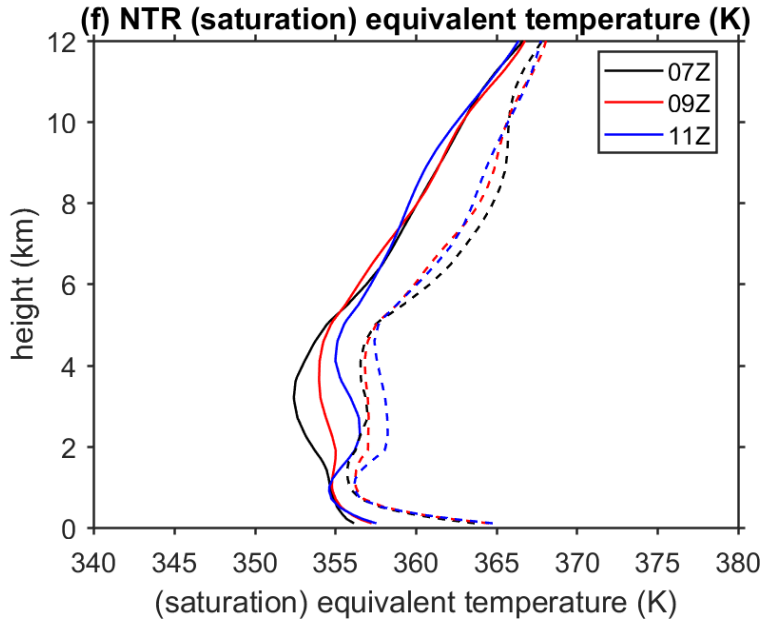




CTL







NTR

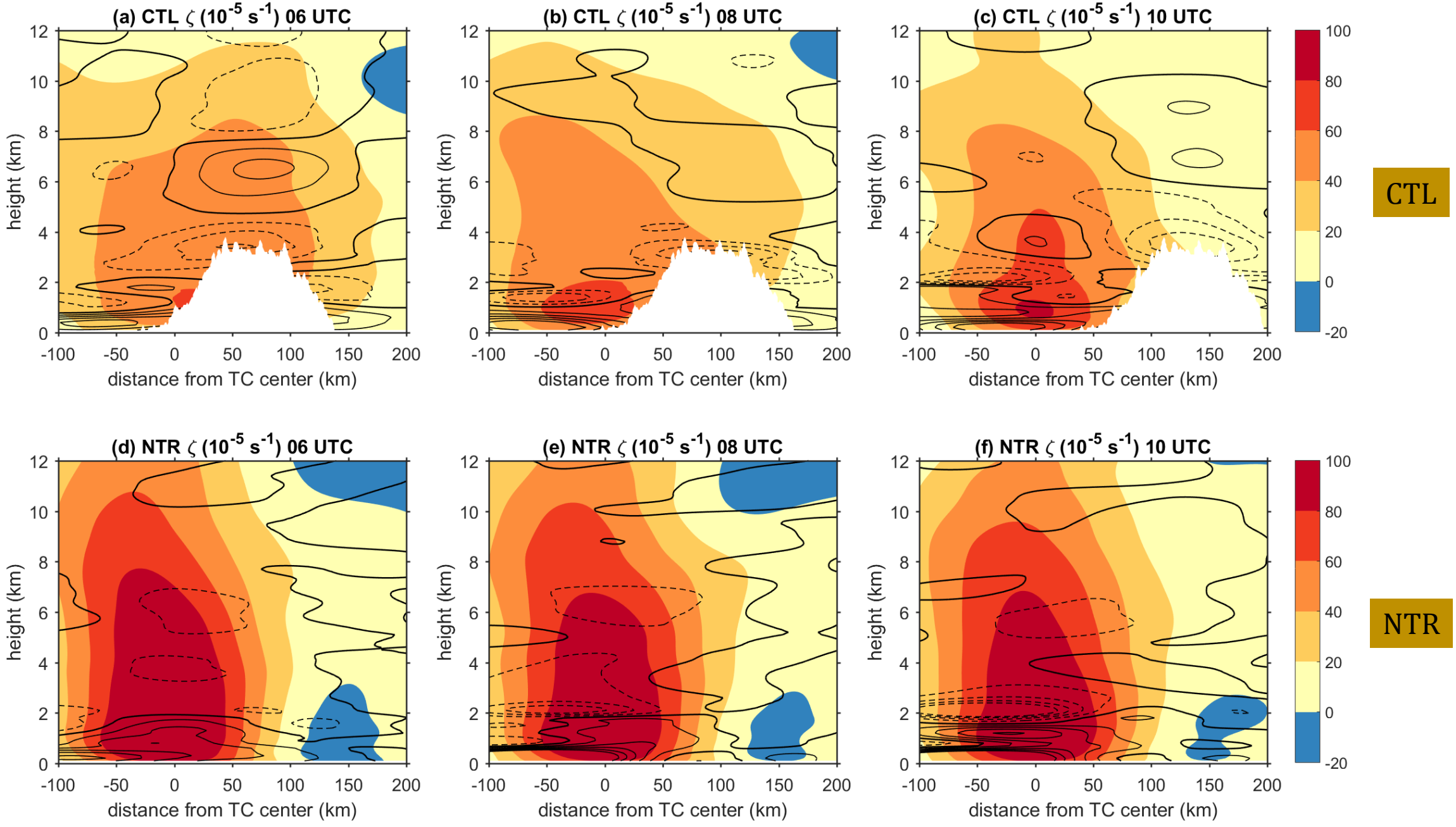
Vorticity budget equation

$$\frac{\partial \zeta}{\partial t} = -(V_h - C)\cdot\nabla(\zeta + f) - w\frac{\partial \zeta}{\partial z} - (\zeta + f)\nabla_h \cdot (V_h - C) - \left(\frac{\partial v}{\partial z}\frac{\partial w}{\partial x} - \frac{\partial u}{\partial z}\frac{\partial w}{\partial y}\right)$$

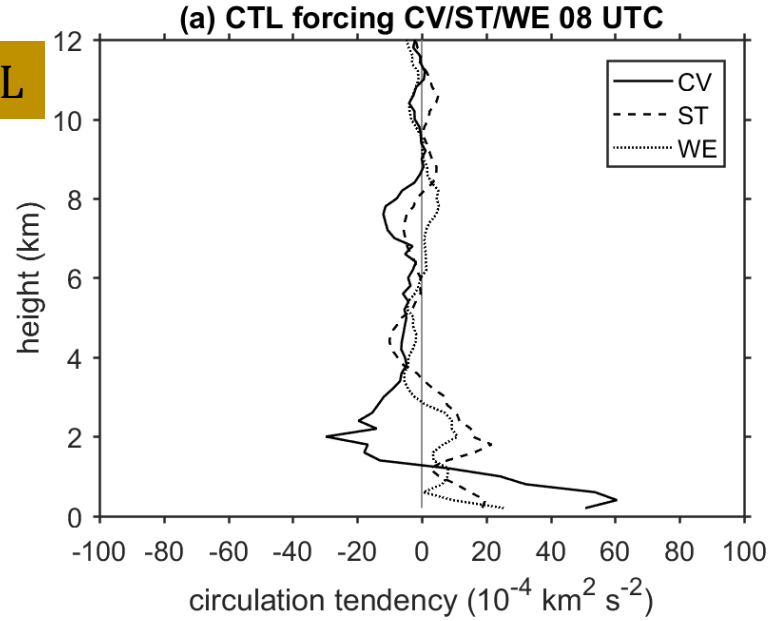
TND HAD VAD STR TIL

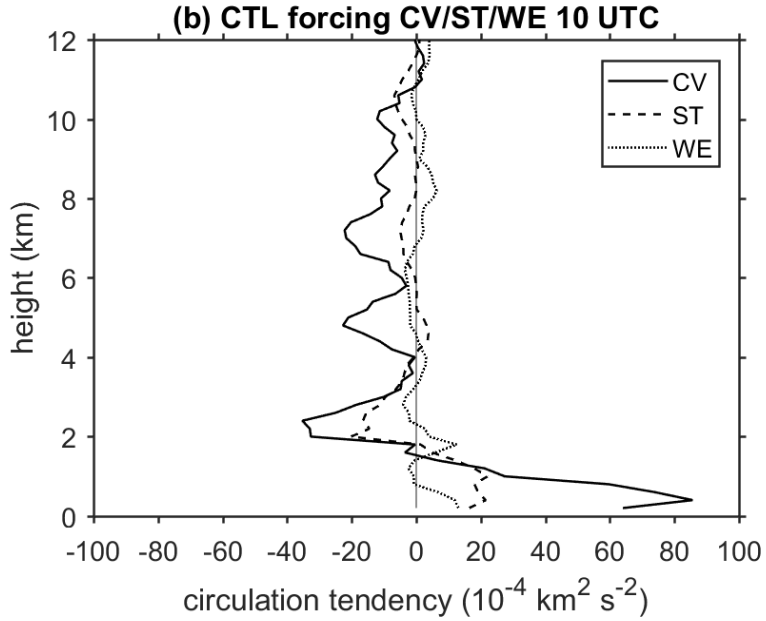
source/sink

TND	local vorticity tendency
HAD	horizontal vorticity advection
VAD	vertical vorticity advection
STR	stretching
TIL	tilting

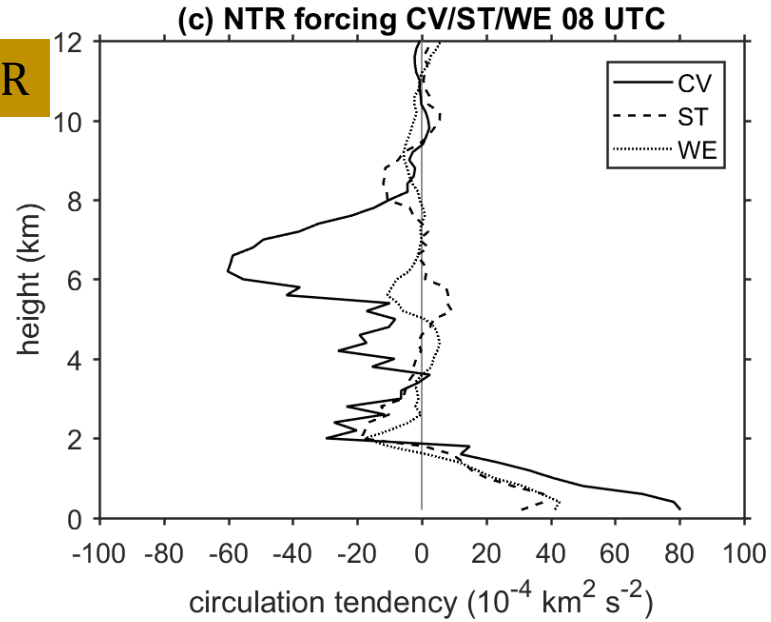

(a) CTL ζ (10^-5 s^-1) 06 UTC
(b) CTL ζ (10^-5 s^-1) 08 UTC
(c) CTL ζ (10^-5 s^-1) 10 UTC
(d) NTR ζ (10^-5 s^-1) 06 UTC
(e) NTR ζ (10^-5 s^-1) 08 UTC
(f) NTR ζ (10^-5 s^-1) 10 UTC
height (km)
distance from TC center (km)
CTL
NTR

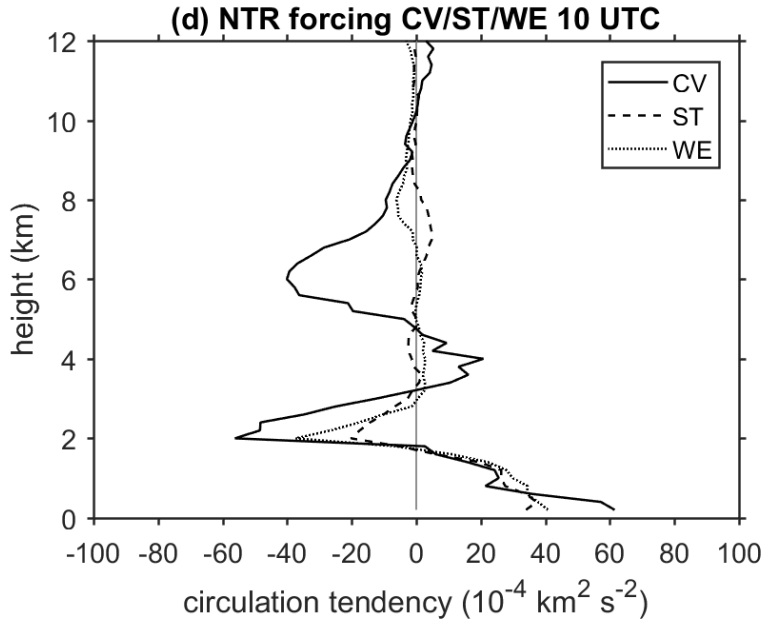
CTL


(a) CTL forcing CV/ST/WE 08 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})


(b) CTL forcing CV/ST/WE 10 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

NTR

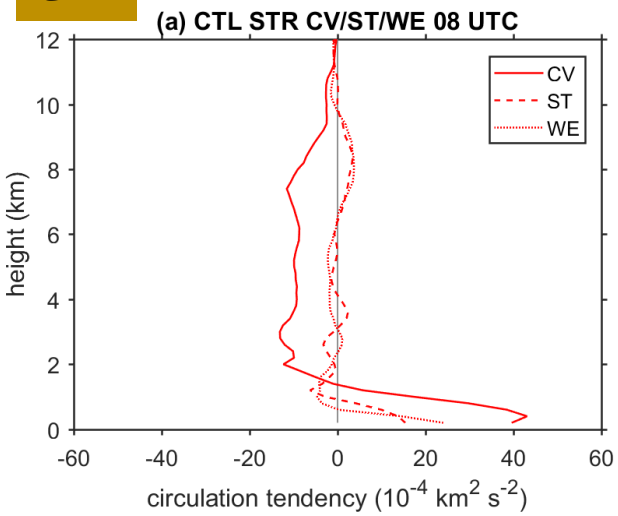

(c) NTR forcing CV/ST/WE 08 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

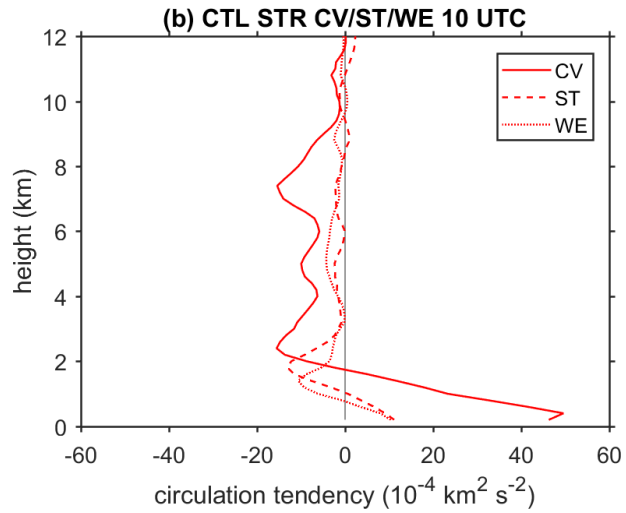

(d) NTR forcing CV/ST/WE 10 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

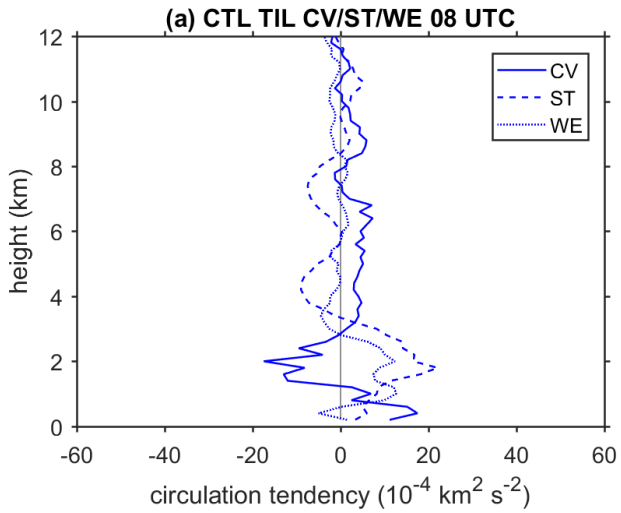
CTL

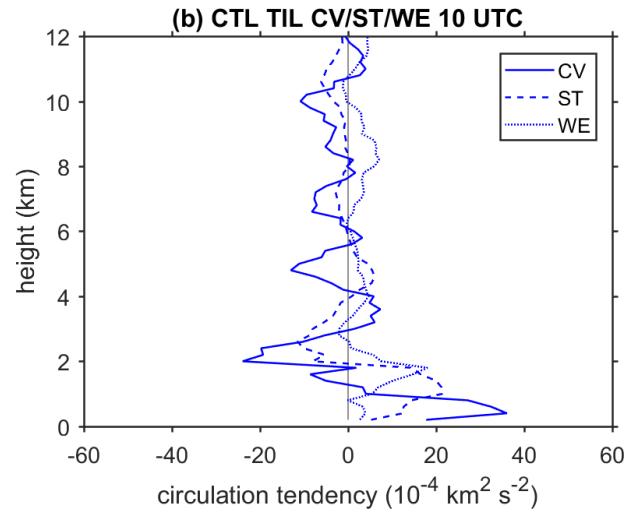
STR

TIL

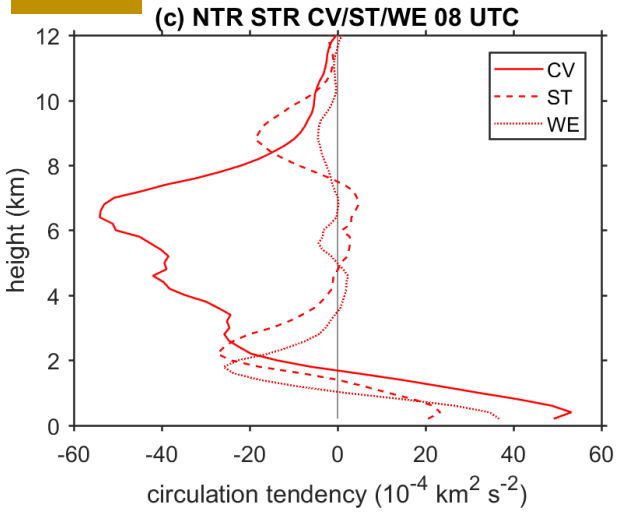


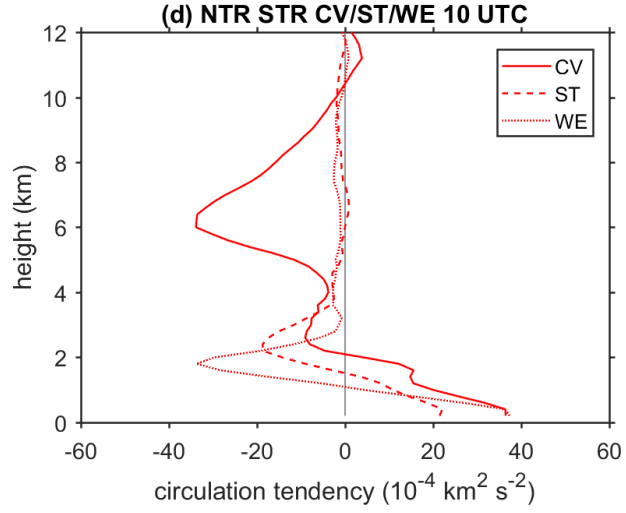


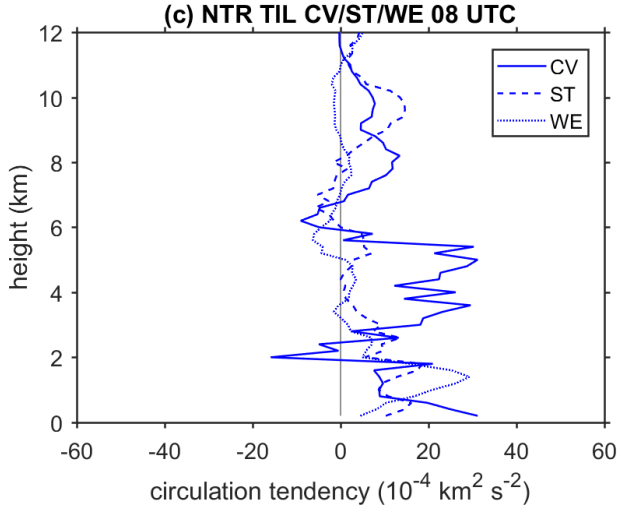


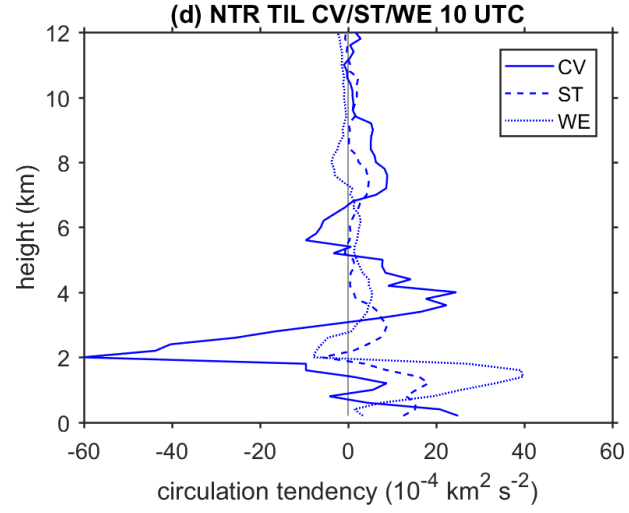


NTR

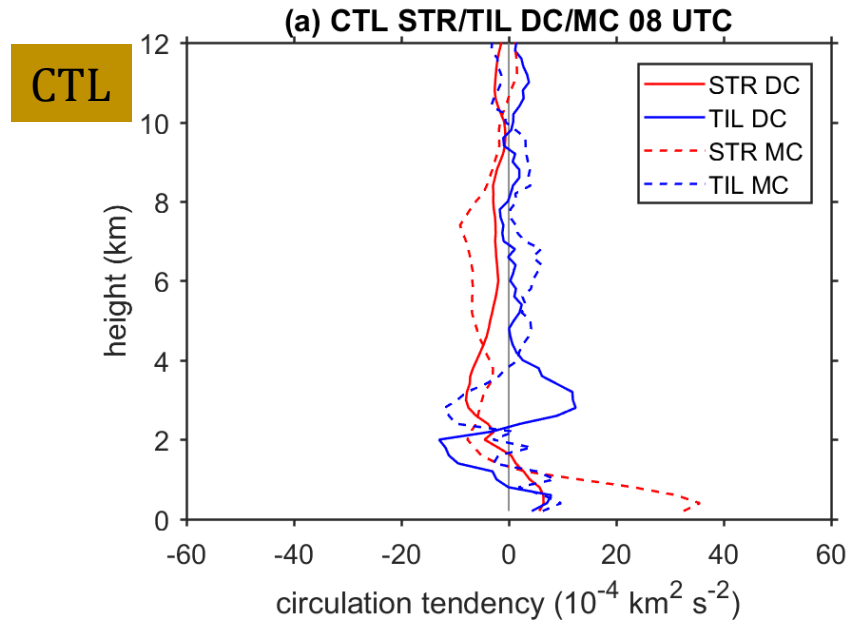


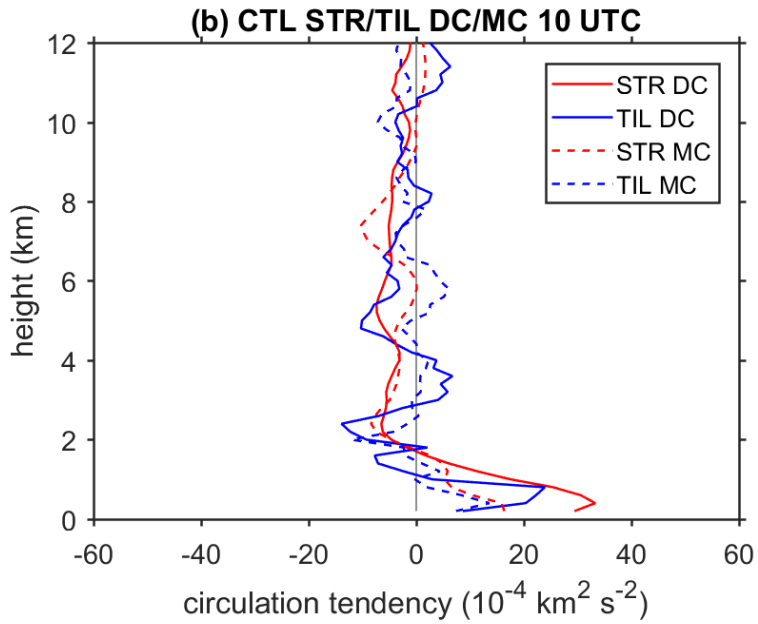




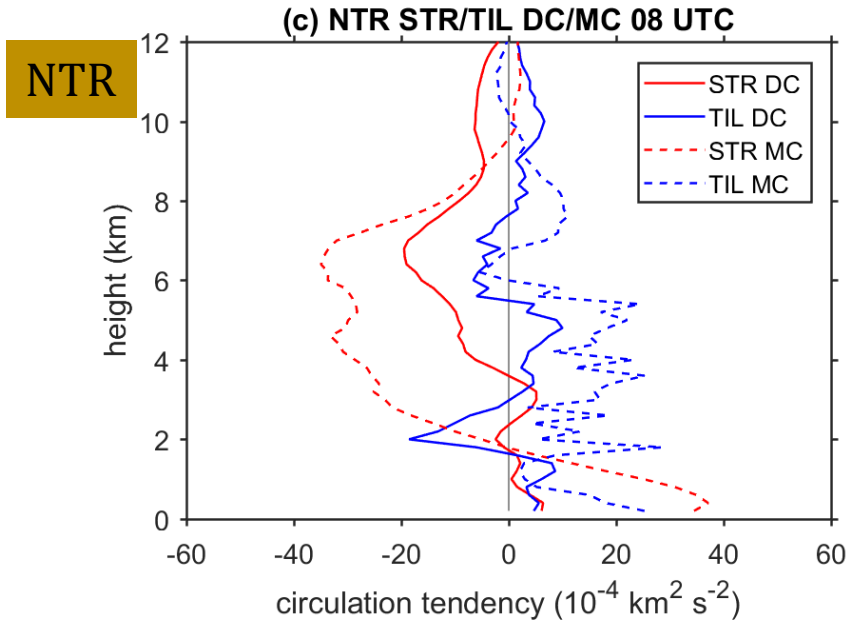


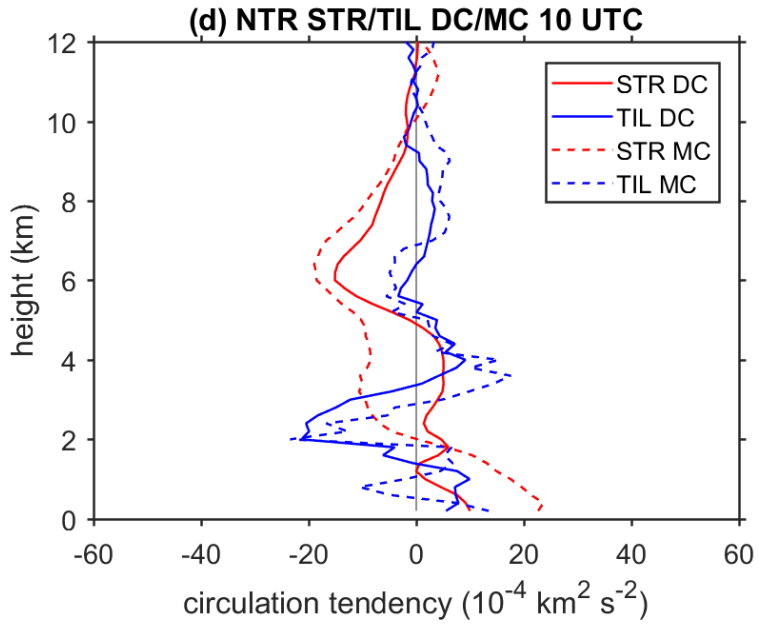
CTL

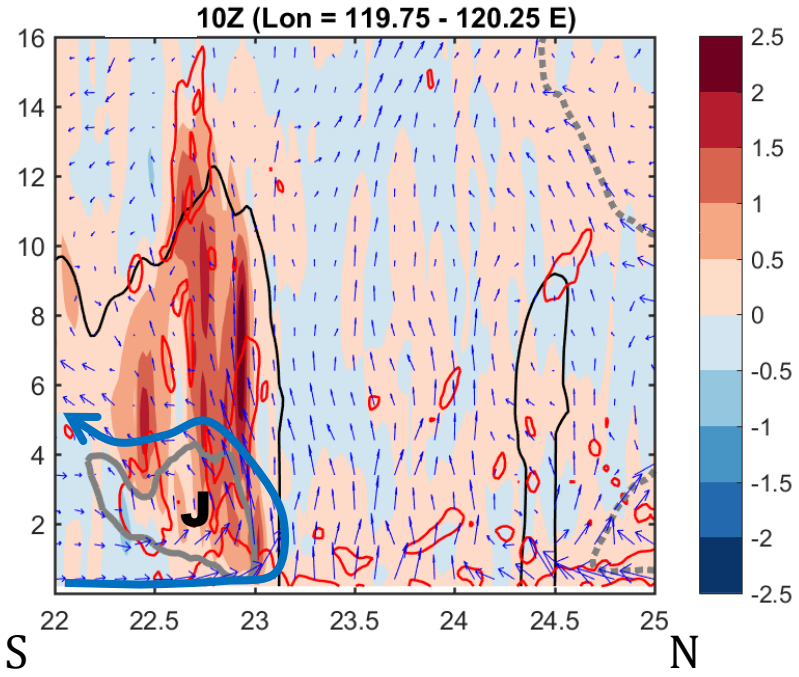

(a) CTL STR/TIL DC/MC 08 UTC
STR DC
TIL DC
STR MC
TIL MC
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

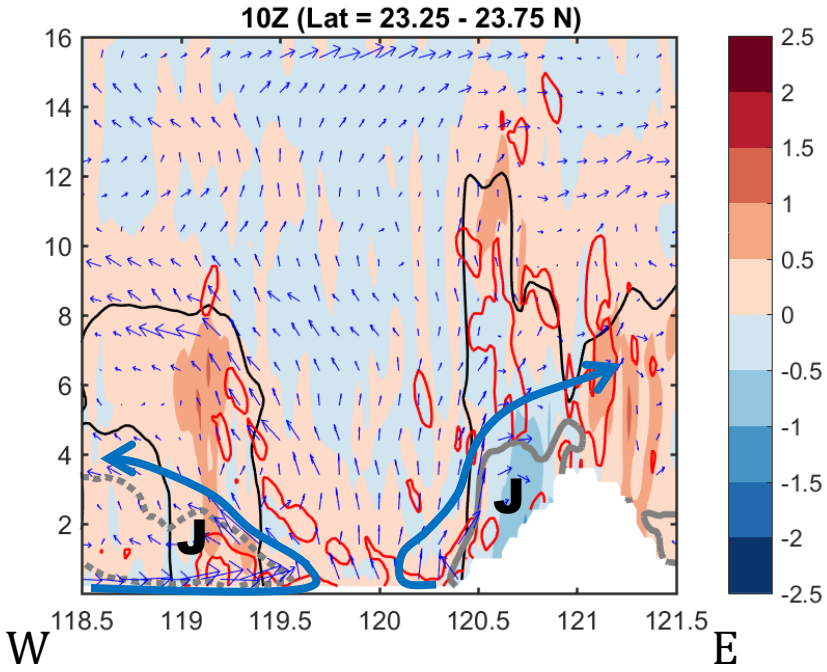

(b) CTL STR/TIL DC/MC 10 UTC
STR DC
TIL DC
STR MC
TIL MC
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

NTR


(c) NTR STR/TIL DC/MC 08 UTC
STR DC
TIL DC
STR MC
TIL MC
height (km)
circulation tendency (10^{-4} km^2 s^{-2})


(d) NTR STR/TIL DC/MC 10 UTC
STR DC
TIL DC
STR MC
TIL MC
height (km)
circulation tendency (10^{-4} km^2 s^{-2})



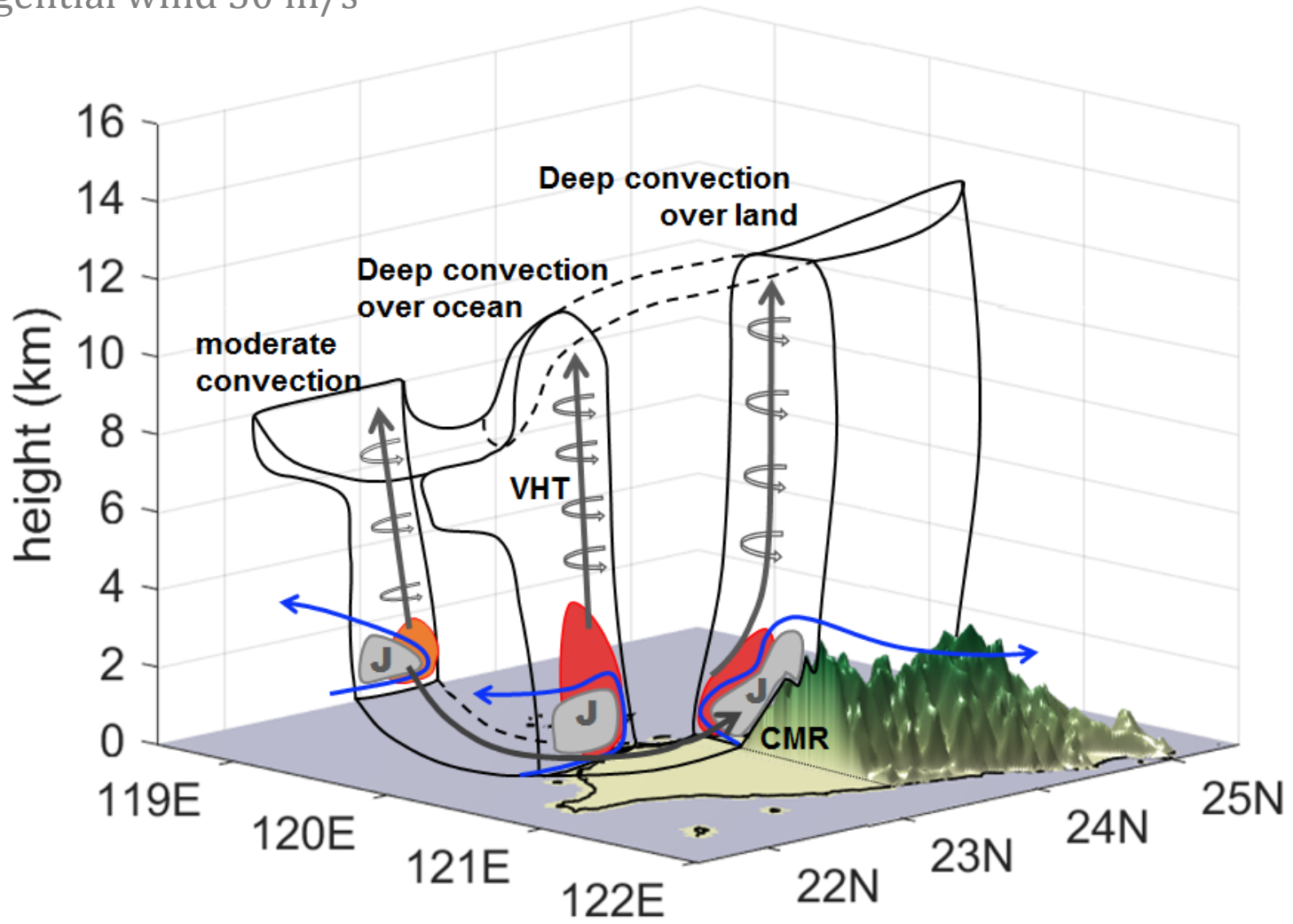


Radar echo 20 dBZ

Tangential wind 30 m/s

STR

TIL

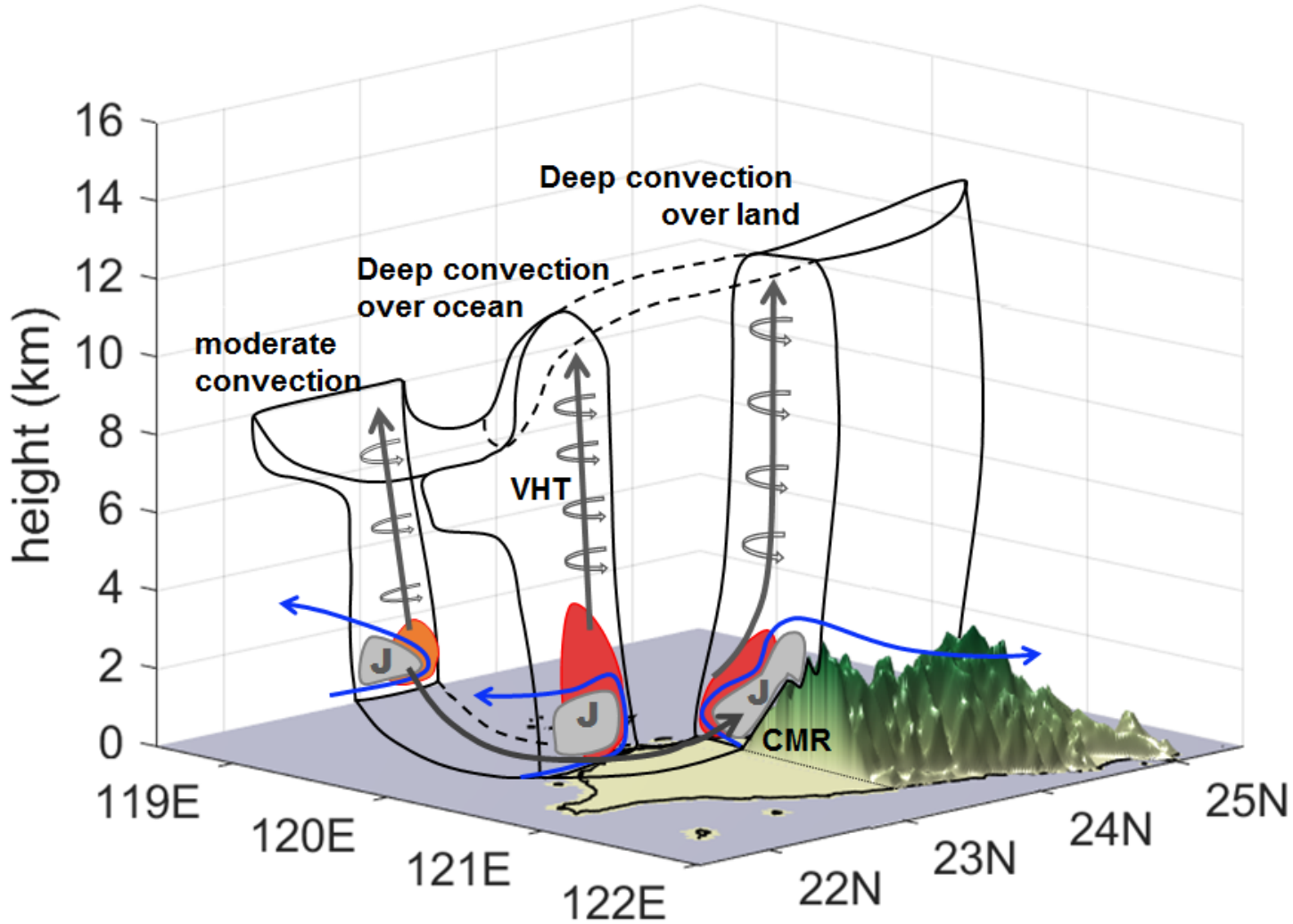


Conclusions

The percentage of deep convection increased from 8% to 20% when TC Fanapi underwent an eyewall reorganization process in the CTL experiment. In contrast, moderate convection occupied most of the convective regions during the period of Fanapi's crossing Taiwan Island in the NTR experiment.

In the CTL experiment, the more unstable environment and steep CMR terrain made deep convection develop favorably than the NTR experiment.

At the beginning of Fanapi's eyewall reconstruction, the positive total vorticity stretching in moderate convection was greater than that in deep convection. Total vorticity stretching in deep convection increased after the eyewall organization, and later became stronger than that in moderate convection. In the absence of the break down and reconstruction of the eyewall, total vorticity stretching in moderate convection dominated in the NTR experiment.

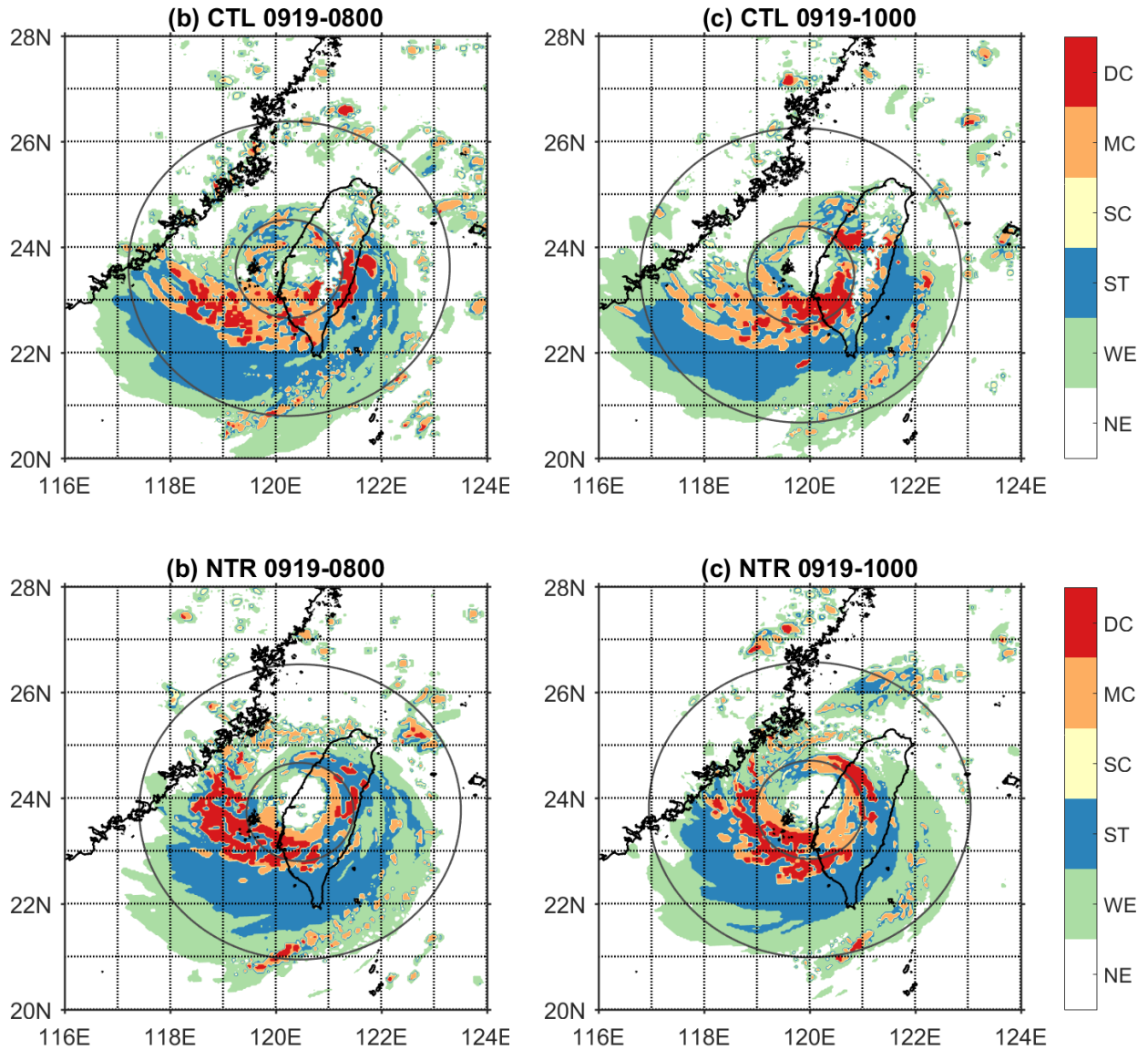

height (km)
16
14
12
10
8
6
4
2
0
119E
120E
121E
122E
22N
23N
24N
25N
Deep convection
over land
Deep convection
over ocean
moderate
convection
VHT
J
J
J
CMR

CTL

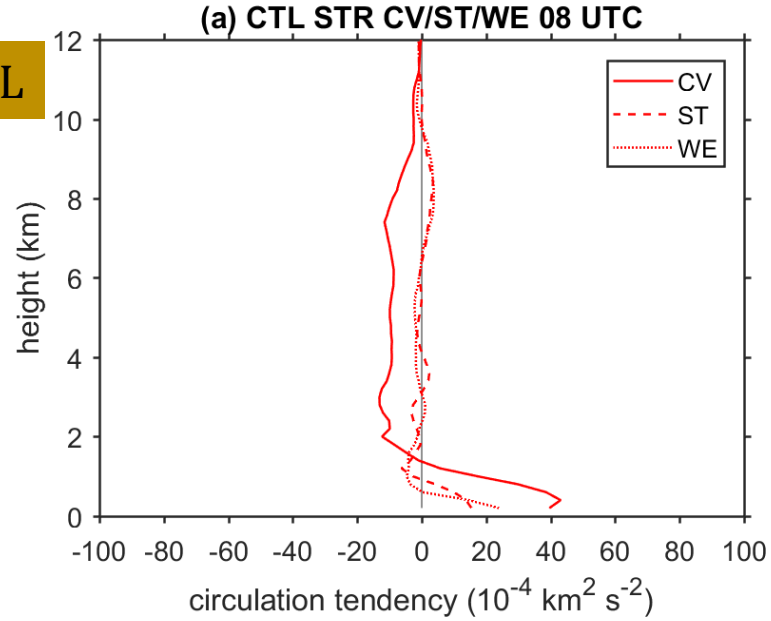
Time (UTC)	Stratiform	No/Weak Echo	Shallow Convection	Moderate Convection	Deep Convection
06:00	31.84	32.75	0.63	26.39	8.39
07:00	29.47	42.23	0.26	20.40	7.65
08:00	22.48	44.22	0.29	24.82	8.19
09:00	20.00	43.22	0.14	19.17	17.46
10:00	18.49	44.19	0.57	17.12	19.63
11:00	20.09	41.74	0.34	15.04	22.80
12:00	16.38	56.78	0.68	11.70	14.47
Average	22.68	43.59	0.42	19.23	14.08

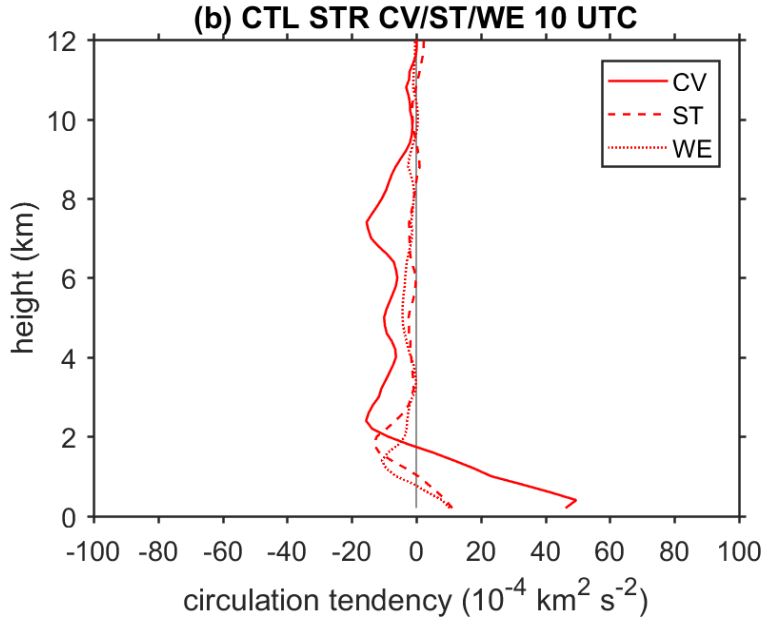
NTR

Time (UTC)	Stratiform	No/Weak Echo	Shallow Convection	Moderate Convection	Deep Convection
06:00	31.64	36.26	2.25	19.29	10.56
07:00	25.16	38.97	1.40	21.43	13.04
08:00	26.36	35.89	2.00	20.46	15.29
09:00	23.97	32.72	2.48	22.08	18.74
10:00	19.80	37.55	1.51	28.25	12.90
11:00	20.86	38.29	2.48	29.59	8.79
12:00	19.54	46.31	2.03	26.56	5.56
Average	23.90	38.00	2.02	23.95	12.13

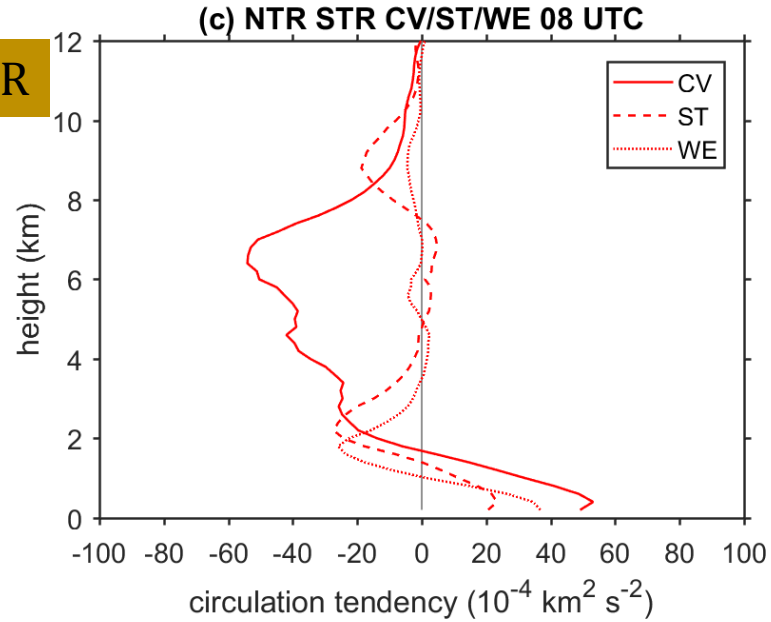


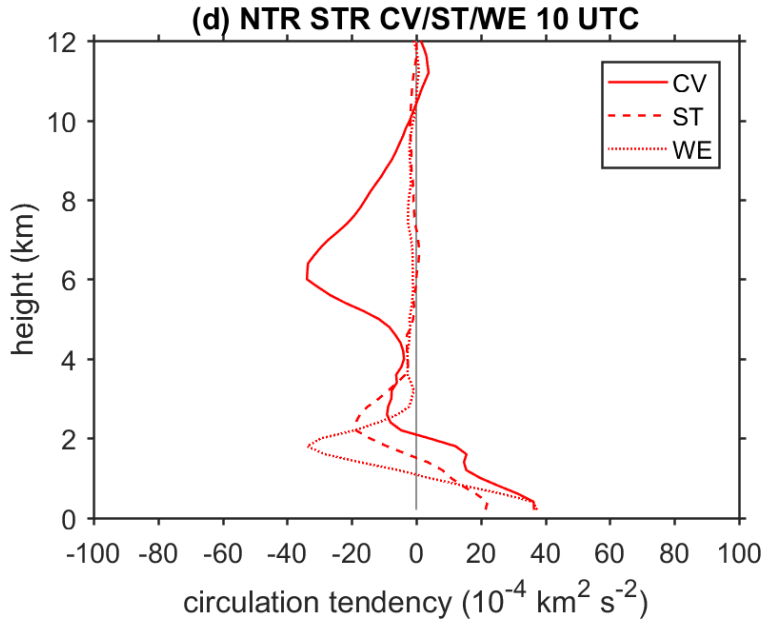
CTL


(a) CTL STR CV/ST/WE 08 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

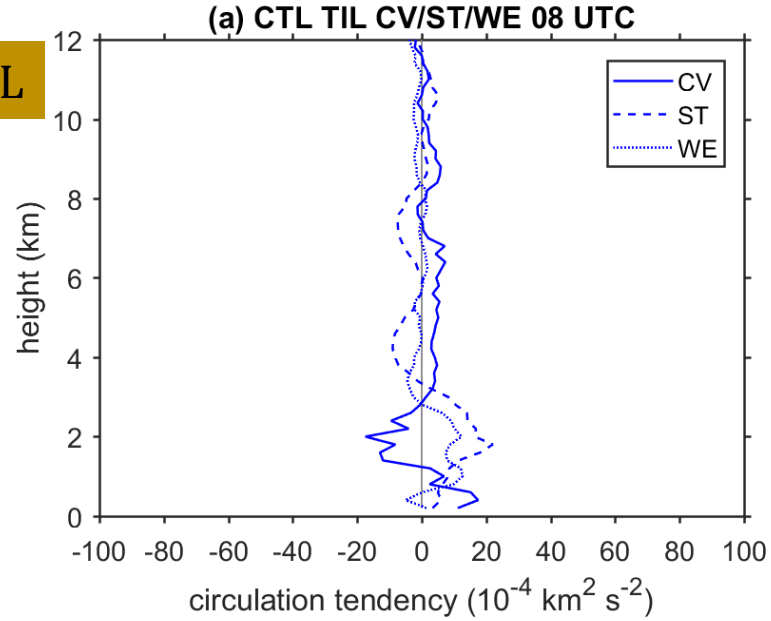

(b) CTL STR CV/ST/WE 10 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

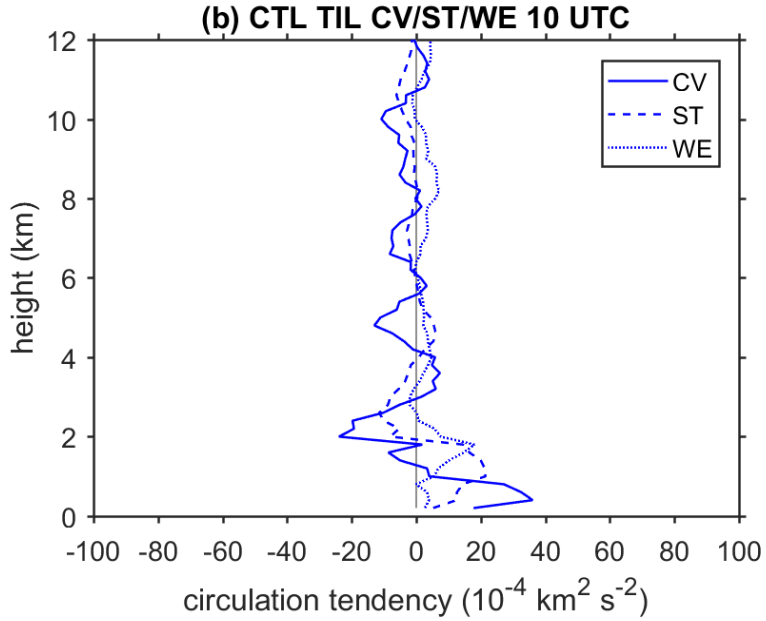
NTR


(c) NTR STR CV/ST/WE 08 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

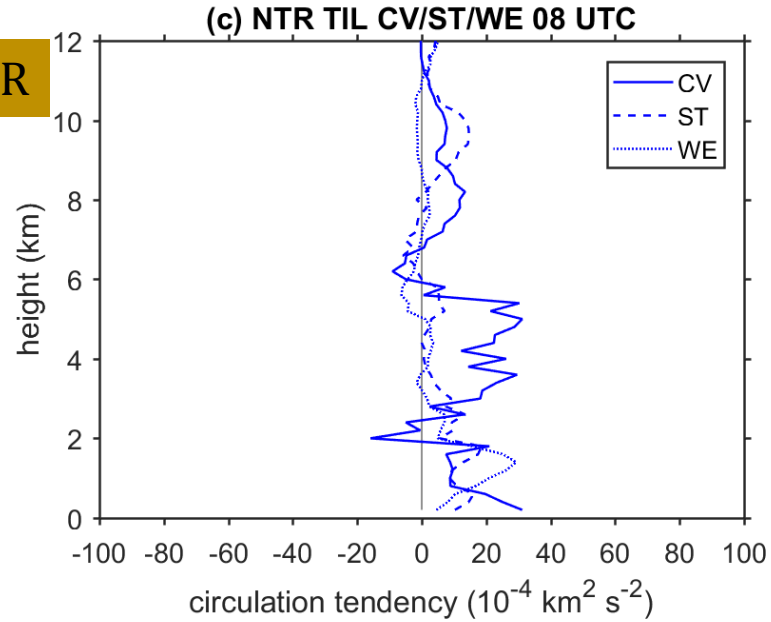

(d) NTR STR CV/ST/WE 10 UTC
CV
ST
WE
height (km)
circulation tendency (10^{-4} km^2 s^{-2})

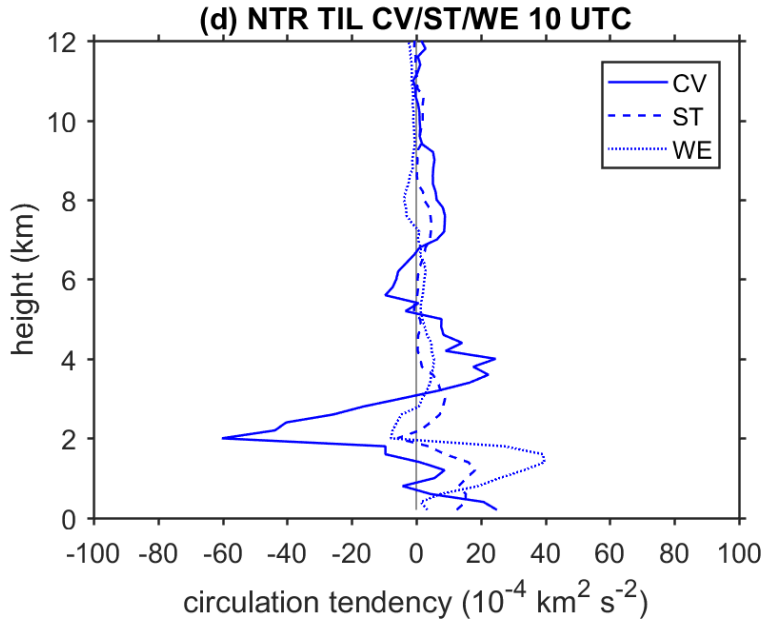
CTL


(a) CTL TIL CV/ST/WE 08 UTC
CV
ST
WE
height (km)
0
2
4
6
8
10
12
-100 -80 -60 -40 -20 0 20 40 60 80 100
circulation tendency (10^{-4} km^2 s^{-2})


(b) CTL TIL CV/ST/WE 10 UTC
CV
ST
WE
height (km)
0
2
4
6
8
10
12
-100 -80 -60 -40 -20 0 20 40 60 80 100
circulation tendency (10^{-4} km^2 s^{-2})

NTR


(c) NTR TIL CV/ST/WE 08 UTC
CV
ST
WE
height (km)
0
2
4
6
8
10
12
-100 -80 -60 -40 -20 0 20 40 60 80 100
circulation tendency (10^{-4} km^2 s^{-2})


(d) NTR TIL CV/ST/WE 10 UTC
CV
ST
WE
height (km)
0
2
4
6
8
10
12
-100 -80 -60 -40 -20 0 20 40 60 80 100
circulation tendency (10^{-4} km^2 s^{-2})