Tropopause Variations in Tropical Cyclones: TCI Observations and Modeling

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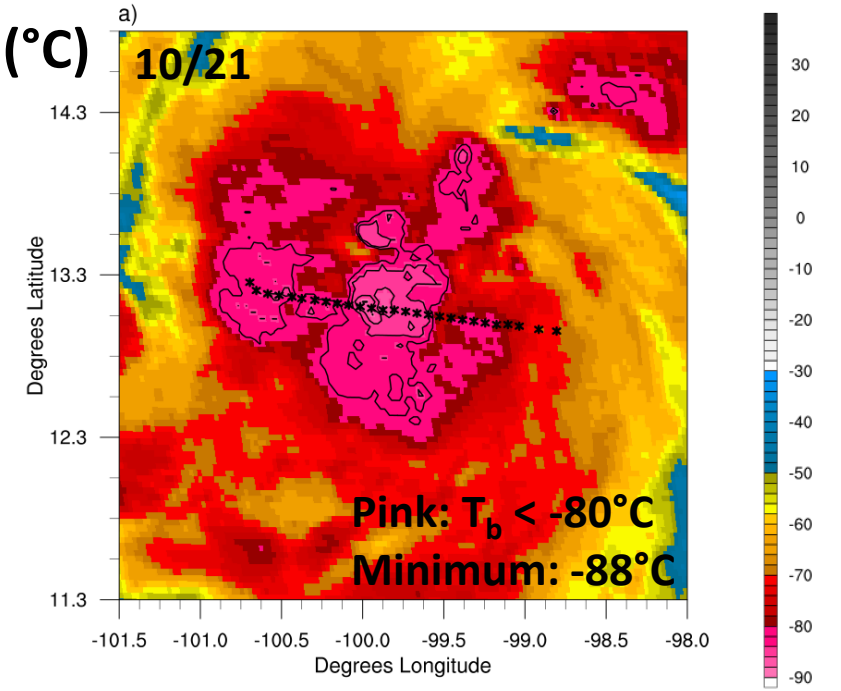
State University of New York

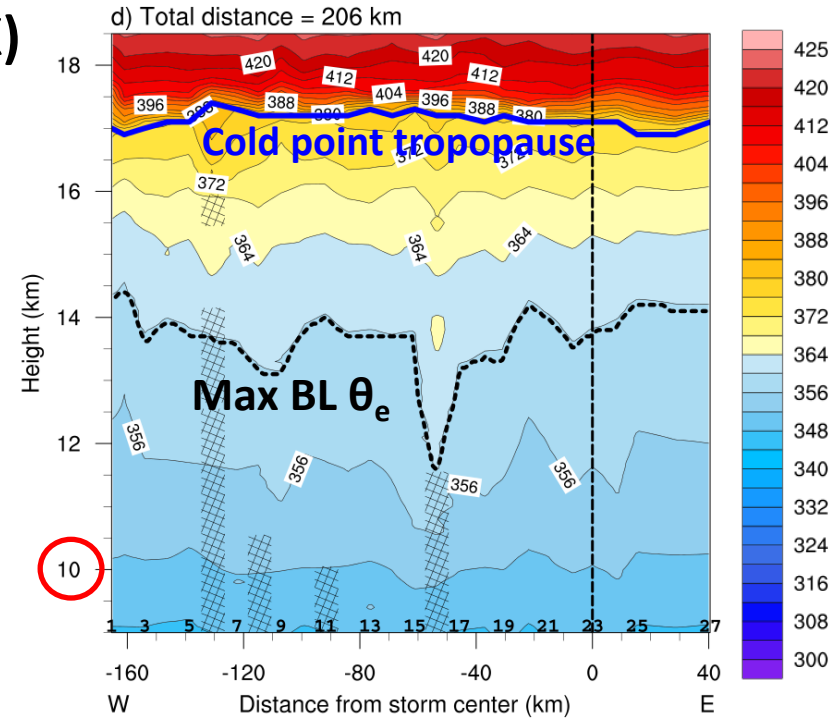
Research Summary

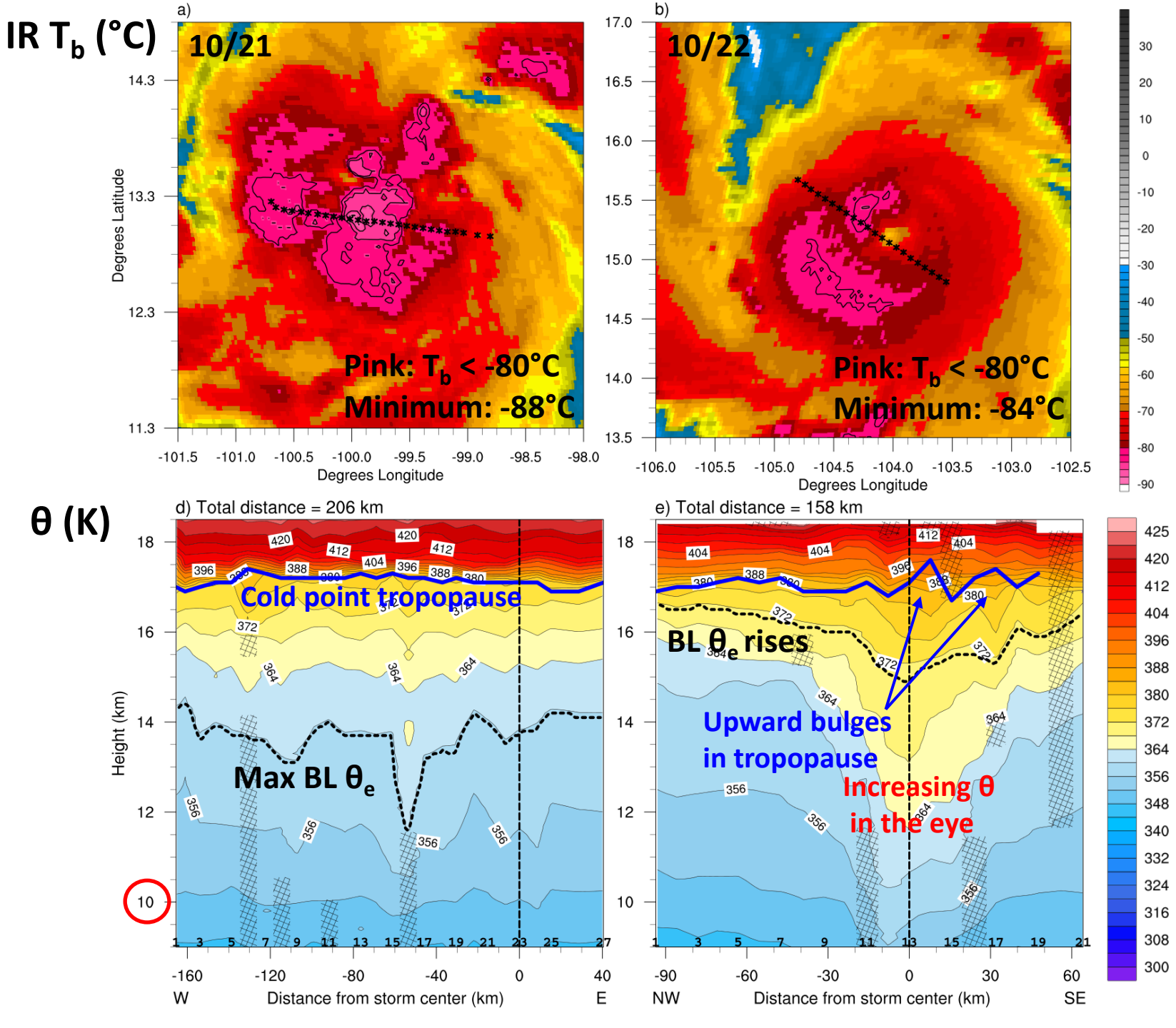
- We will analyze only the ***inner-core tropopause variability*** in Hurricane Patricia between October 21 and 23.
- Interpolate all soundings in the ***high-density transects*** to a uniform grid with 100-m vertical grid spacing.
- Focus on the ***static stability evolution*** near the cold point tropopause and what might cause it.
- Take a preliminary look at tropopause variability in ***idealized simulations*** using CM1.

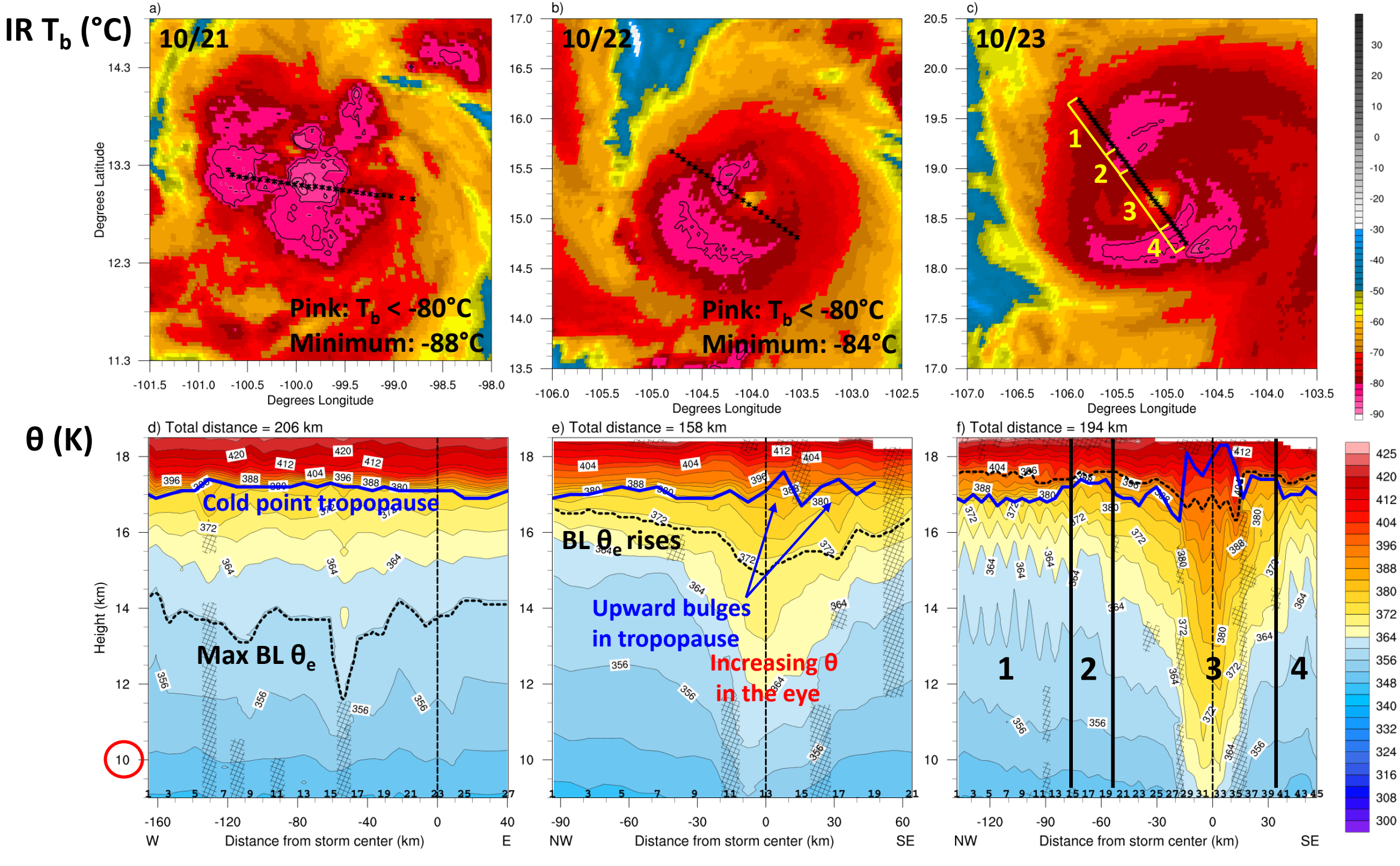
IR T_b (°C)

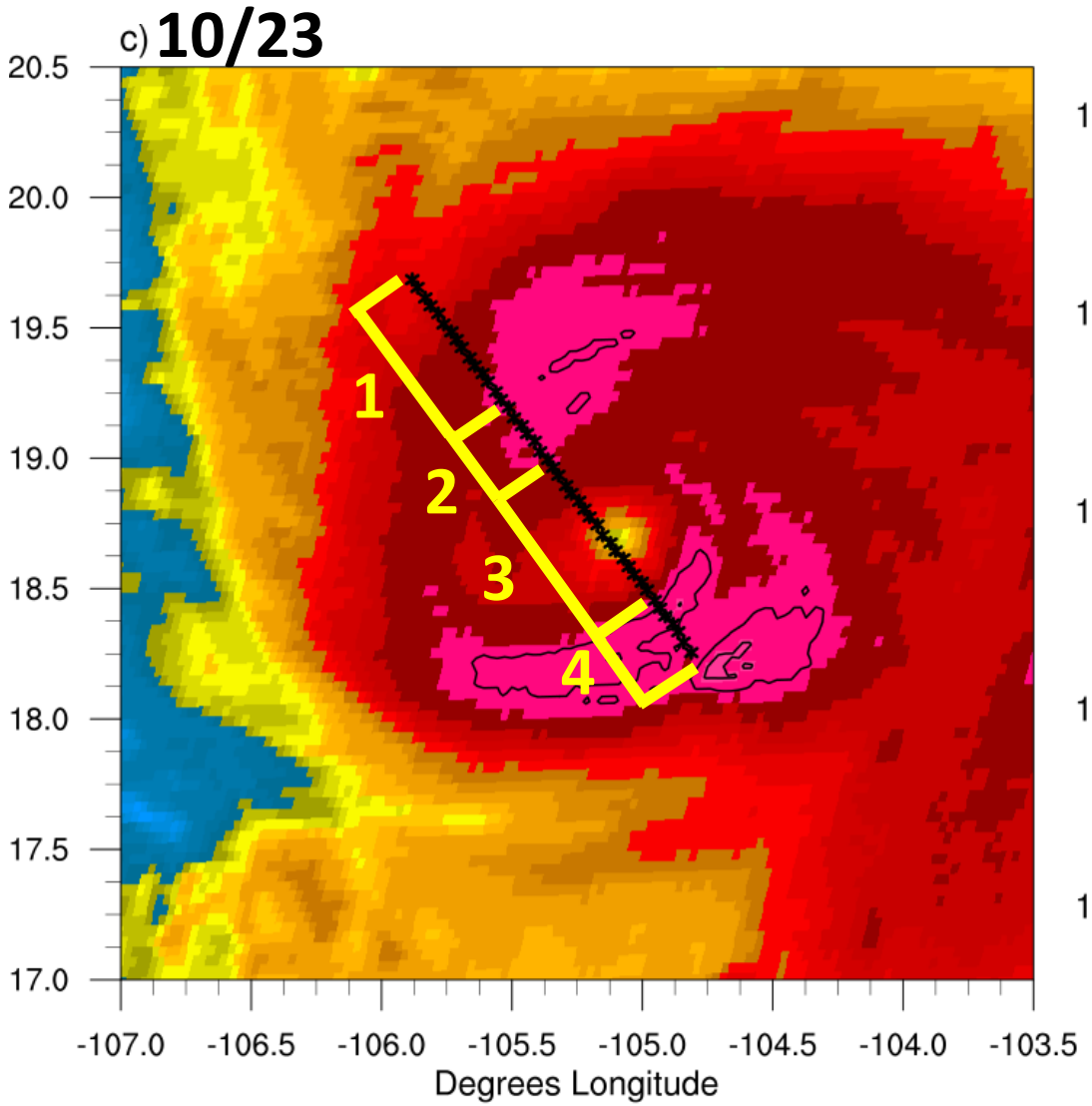

a)
10/21
Pink: T_b < -80°C
Minimum: -88°C
Degrees Latitude
Degrees Longitude
14.3
13.3
12.3
11.3
-101.5
-101.0
-100.5
-100.0
-99.5
-99.0
-98.5
-98.0
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90

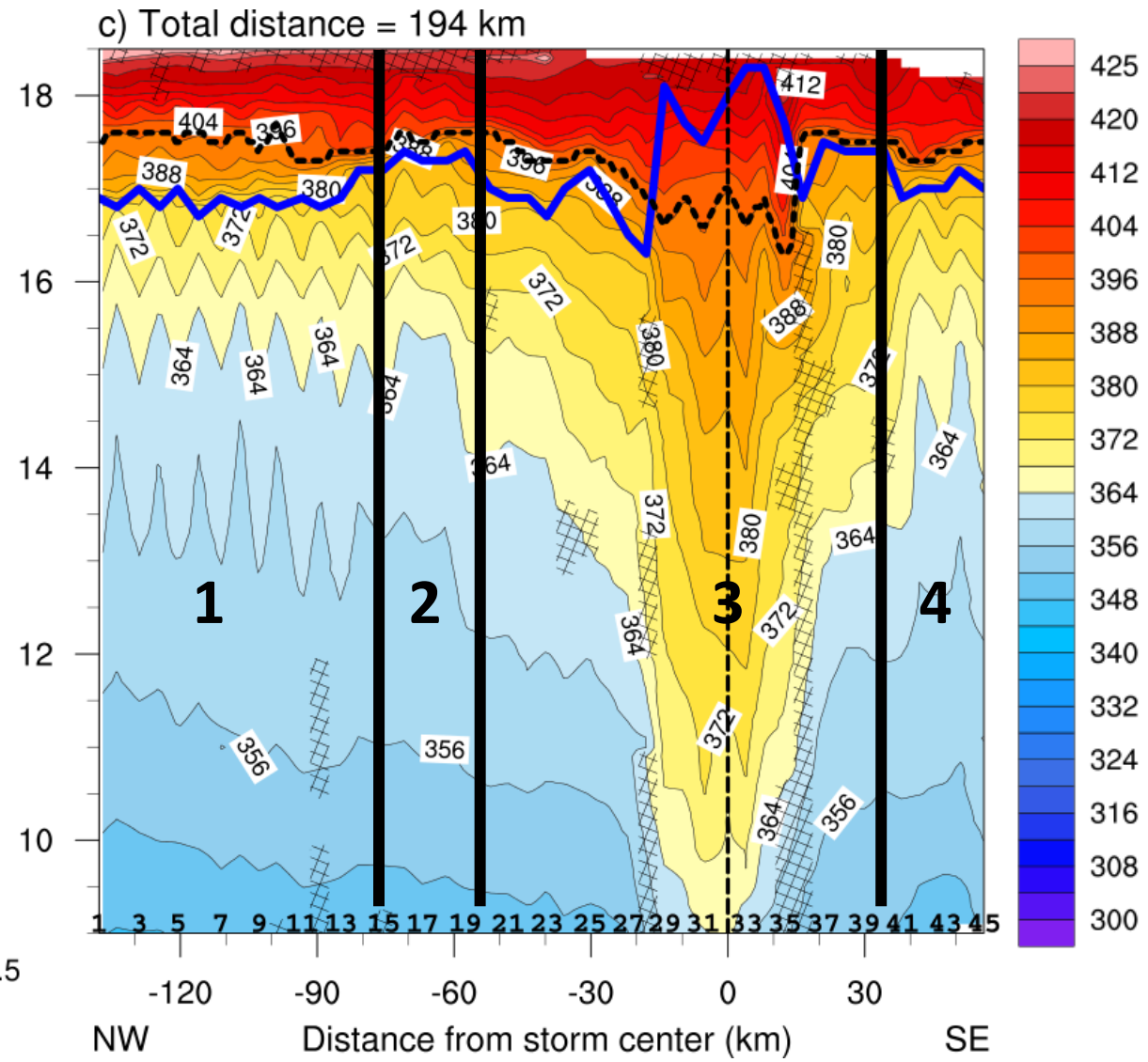
θ (K)


d) Total distance = 206 km
Cold point tropopause
Max BL θ_e
Height (km)
Distance from storm center (km)
W
E
18
16
14
12
10
-160
-120
-80
-40
0
40
425
420
412
404
396
388
380
372
364
356
348
340
332
324
316
308
300


IR T_b (°C)
a)
10/21
Pink: T_b < -80°C
Minimum: -88°C
b)
10/22
Pink: T_b < -80°C
Minimum: -84°C
Degrees Latitude
Degrees Longitude
θ (K)
d) Total distance = 206 km
e) Total distance = 158 km
Cold point tropopause
Max BL θ_e
BL θ_e rises
Upward bulges
in tropopause
Increasing θ
in the eye
Height (km)
W
Distance from storm center (km)
E
NW
SE

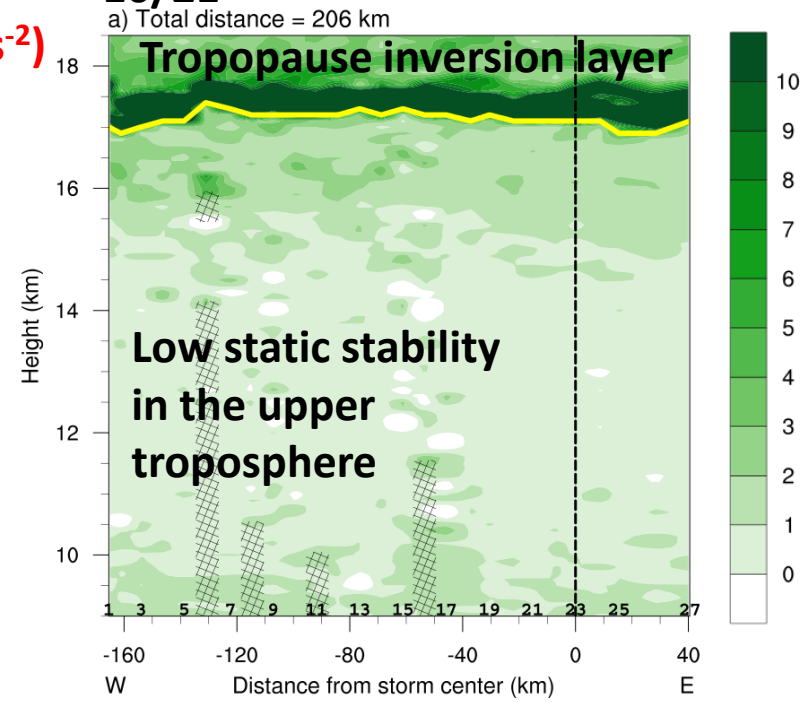

IR T_b (°C)
a)
10/21
Pink: T_b < -80°C
Minimum: -88°C
b)
10/22
Pink: T_b < -80°C
Minimum: -84°C
c)
10/23
1
2
3
4
Degrees Latitude
Degrees Longitude
θ (K)
d) Total distance = 206 km
e) Total distance = 158 km
f) Total distance = 194 km
Cold point tropopause
Max BL θ_e
BL θ_e rises
Upward bulges in tropopause
Increasing θ in the eye
Height (km)
W
E
NW
SE
Distance from storm center (km)


c) 10/23
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
1
2
3
4
-107.0
-106.5
-106.0
-105.5
-105.0
-104.5
-104.0
-103.5
Degrees Longitude

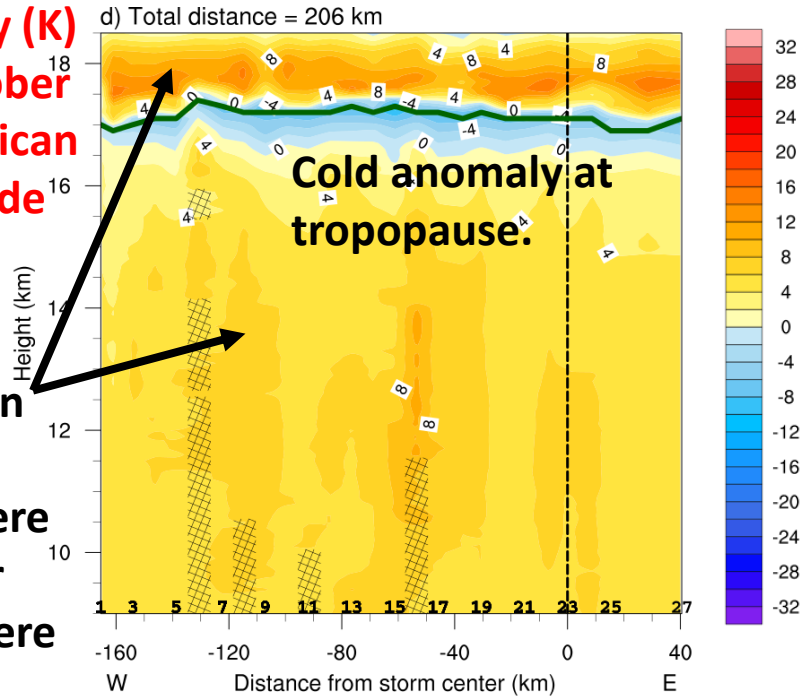

c) Total distance = 194 km
18
16
14
12
10
1
2
3
4
-120
-90
-60
-30
0
30
NW
Distance from storm center (km)
SE
425
420
412
404
396
388
380
372
364
356
348
340
332
324
316
308
300

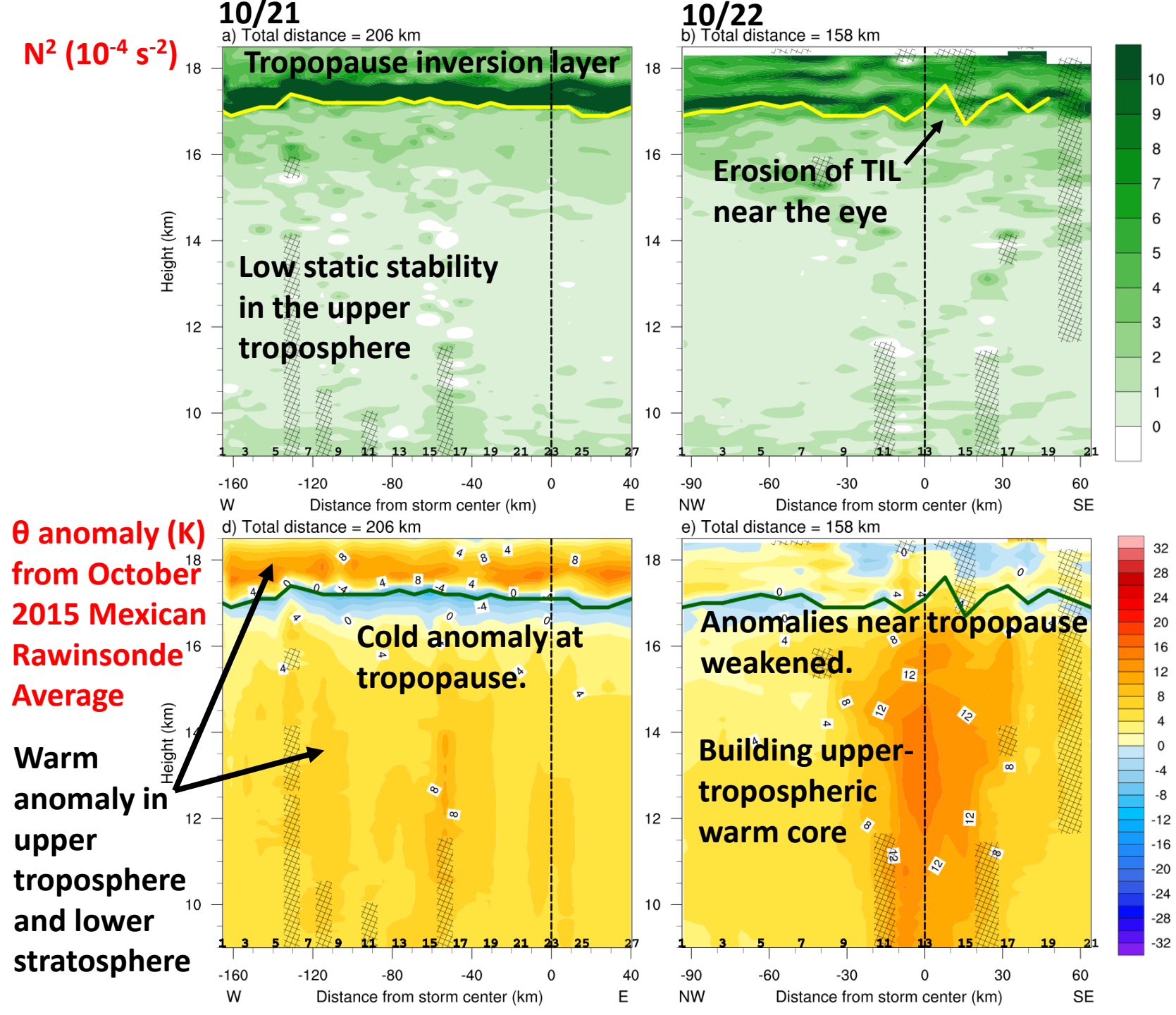
10/21

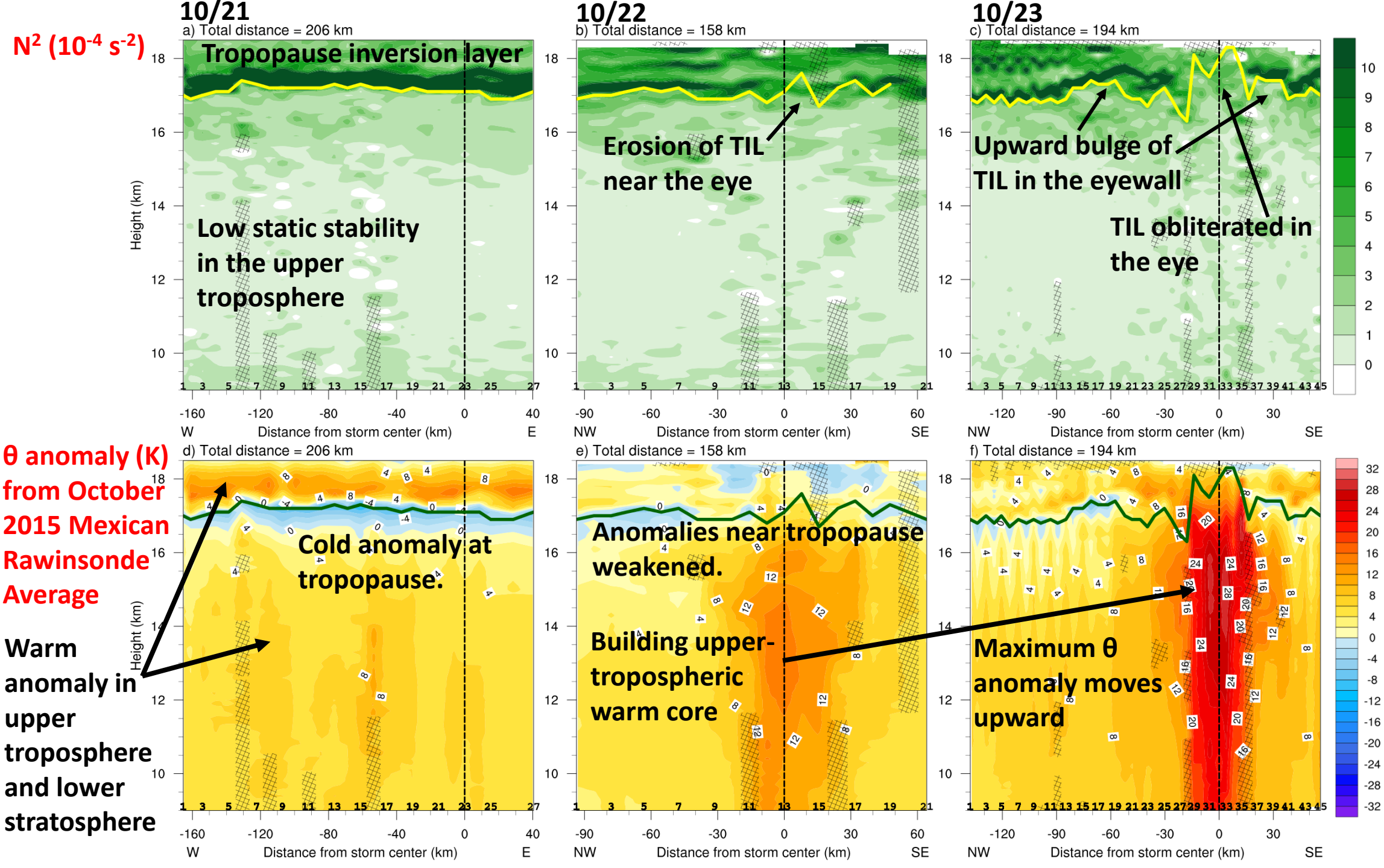
N^2 (10^{-4} s^{-2})



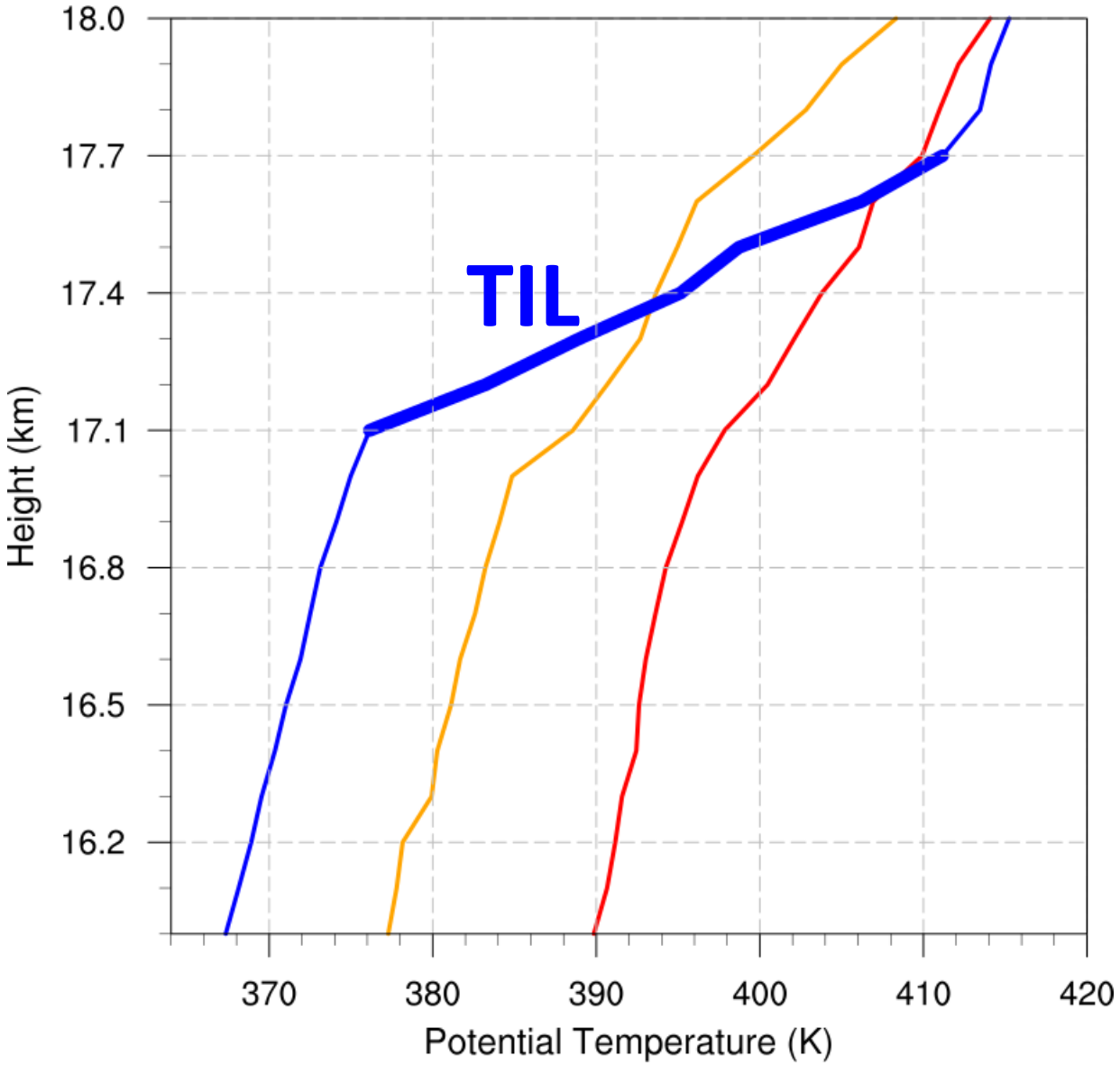
θ anomaly (K) from October 2015 Mexican Rawinsonde Average




10/21
10/22
N² (10⁻⁴ s⁻²)
a) Total distance = 206 km
b) Total distance = 158 km
Tropopause inversion layer
Low static stability in the upper troposphere
Erosion of TIL near the eye
Height (km)
Distance from storm center (km)
W
E
NW
SE
θ anomaly (K) from October 2015 Mexican Rawinsonde Average
d) Total distance = 206 km
e) Total distance = 158 km
Warm anomaly in upper troposphere and lower stratosphere
Cold anomaly at tropopause.
Anomalies near tropopause weakened.
Building upper-tropospheric warm core

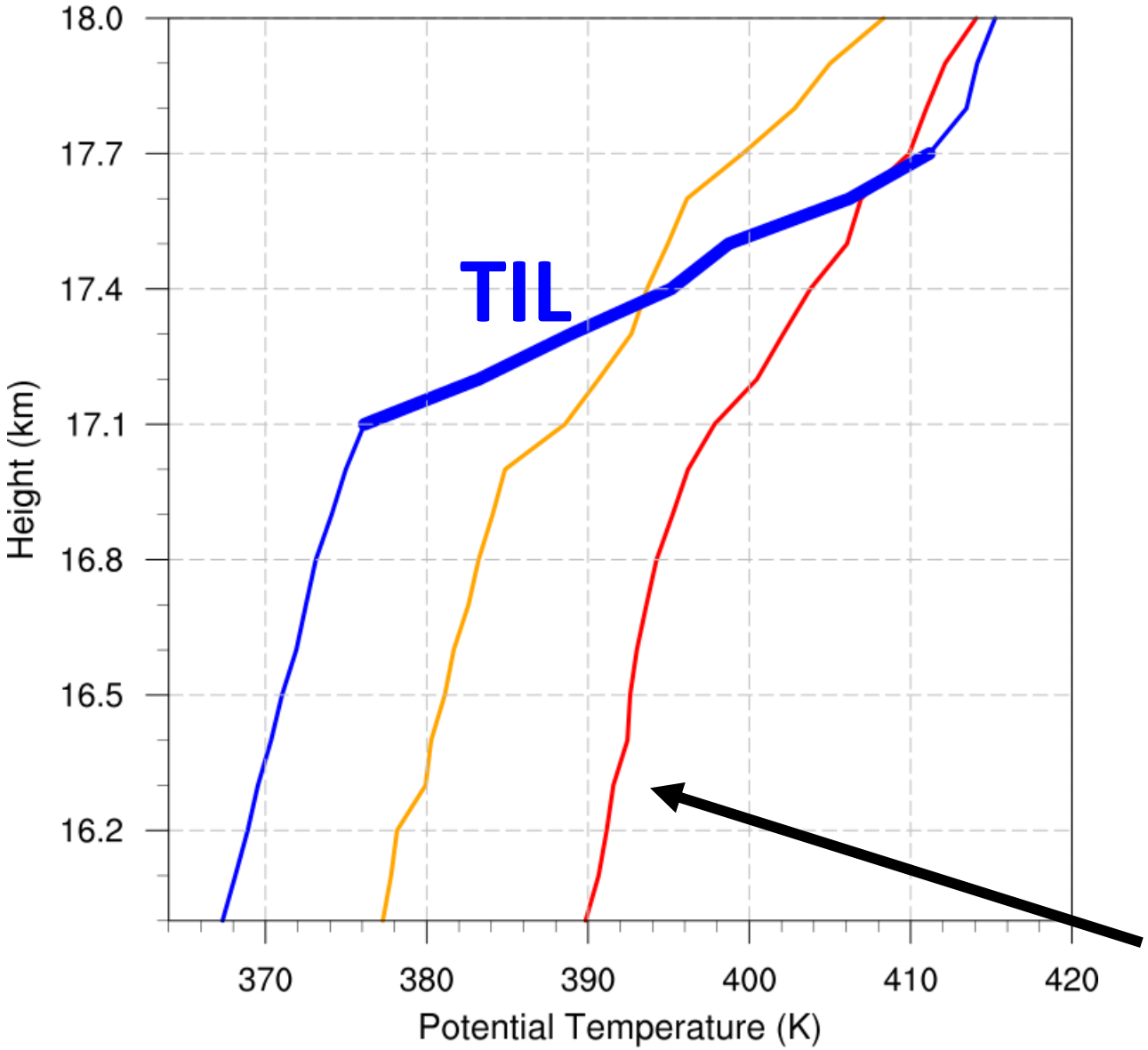

10/21
10/22
10/23
N² (10⁻⁴ s⁻²)
a) Total distance = 206 km
b) Total distance = 158 km
c) Total distance = 194 km
Tropopause inversion layer
Low static stability in the upper troposphere
Erosion of TIL near the eye
Upward bulge of TIL in the eyewall
TIL obliterated in the eye
Height (km)
Distance from storm center (km)
W
E
NW
SE
θ anomaly (K) from October 2015 Mexican Rawinsonde Average
d) Total distance = 206 km
e) Total distance = 158 km
f) Total distance = 194 km
Warm anomaly in upper troposphere and lower stratosphere
Cold anomaly at tropopause.
Anomalies near tropopause weakened.
Building upper-tropospheric warm core
Maximum θ anomaly moves upward

θ from center soundings



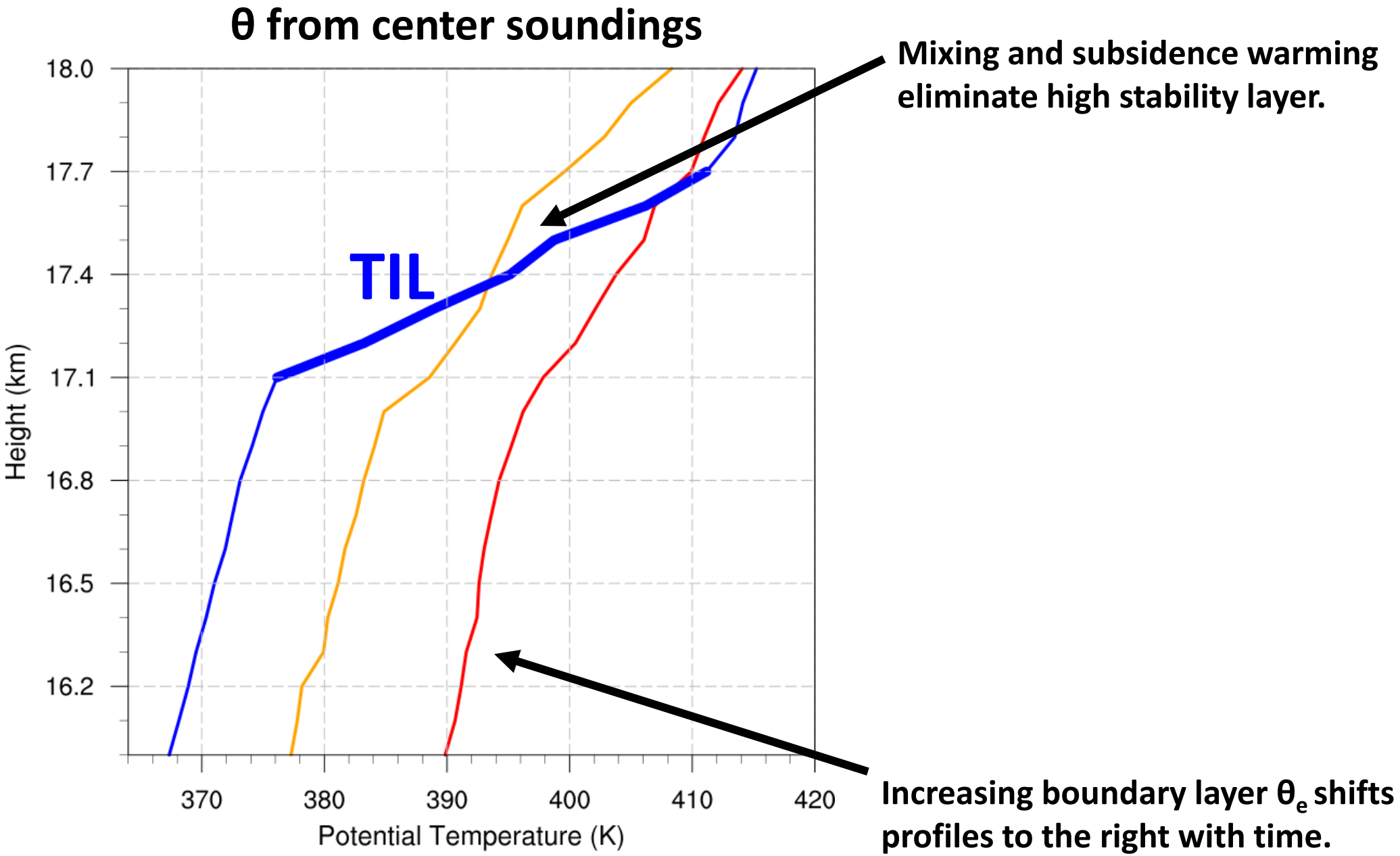
21 October **22 October** **23 October**

θ from center soundings

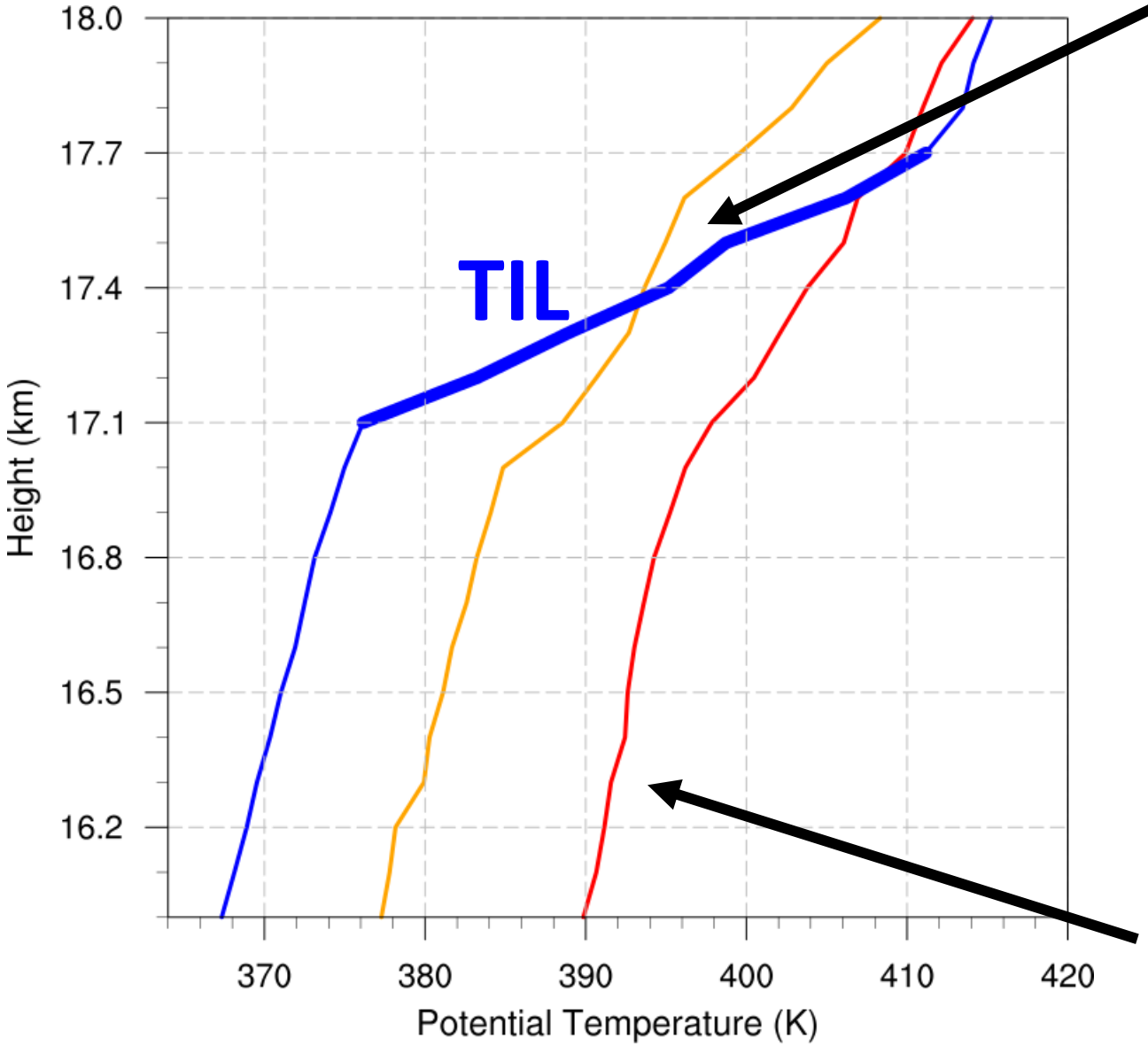


21 October **22 October** **23 October**

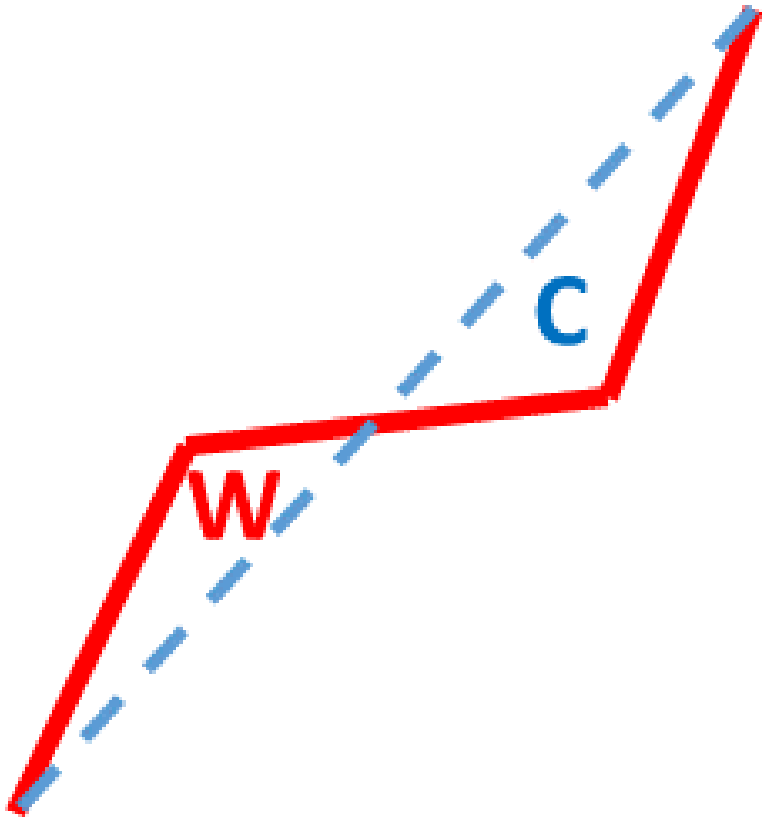
Increasing boundary layer θ_e shifts profiles to the right with time.


θ from center soundings
18.0
17.7
17.4
17.1
16.8
16.5
16.2
Height (km)
TIL
370
380
390
400
410
420
Potential Temperature (K)
Mixing and subsidence warming eliminate high stability layer.
Increasing boundary layer θe shifts profiles to the right with time.
21 October
22 October
23 October

θ from center soundings



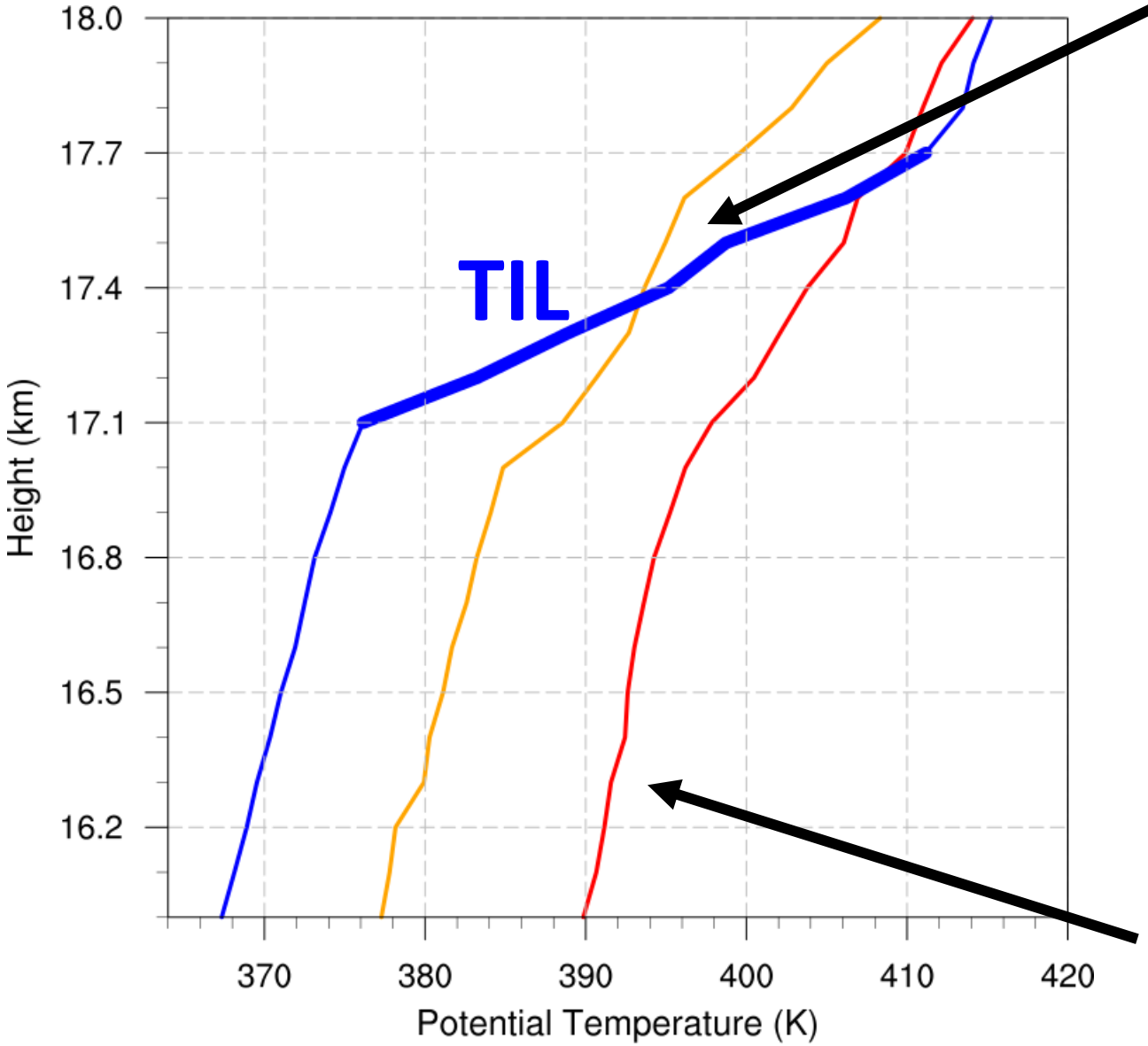
Mixing and subsidence warming eliminate high stability layer.



Increasing boundary layer θ_e shifts profiles to the right with time.

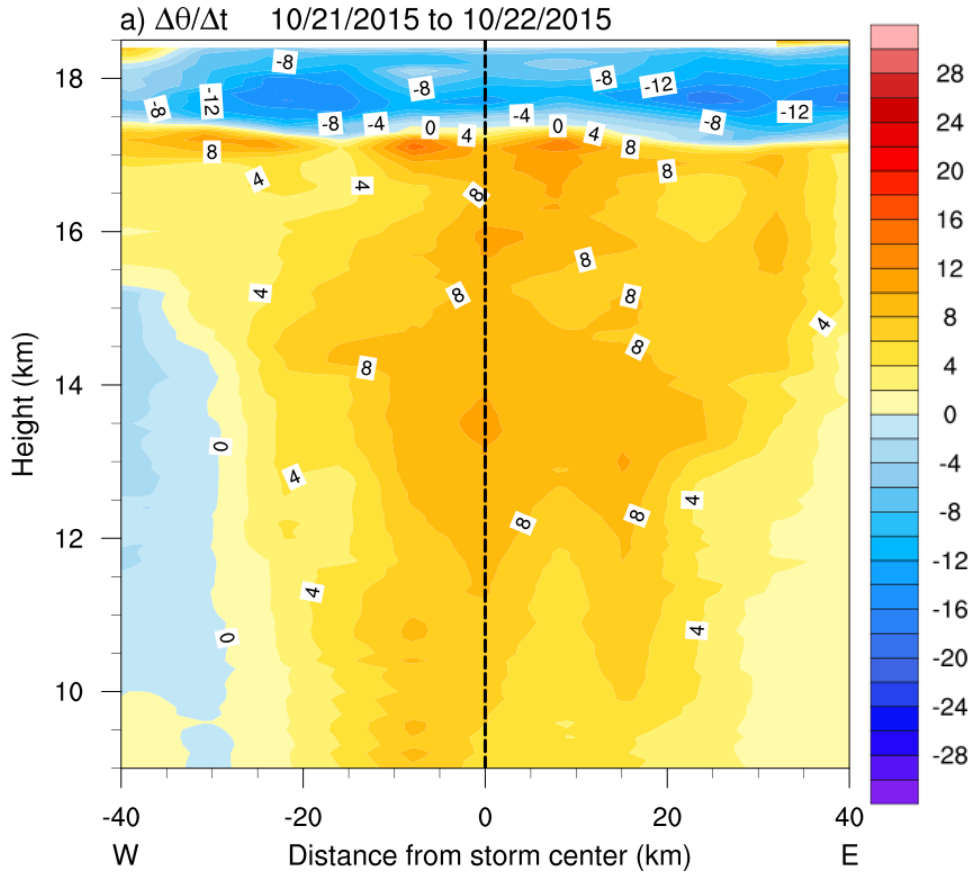
21 October **22 October** **23 October**

θ from center soundings

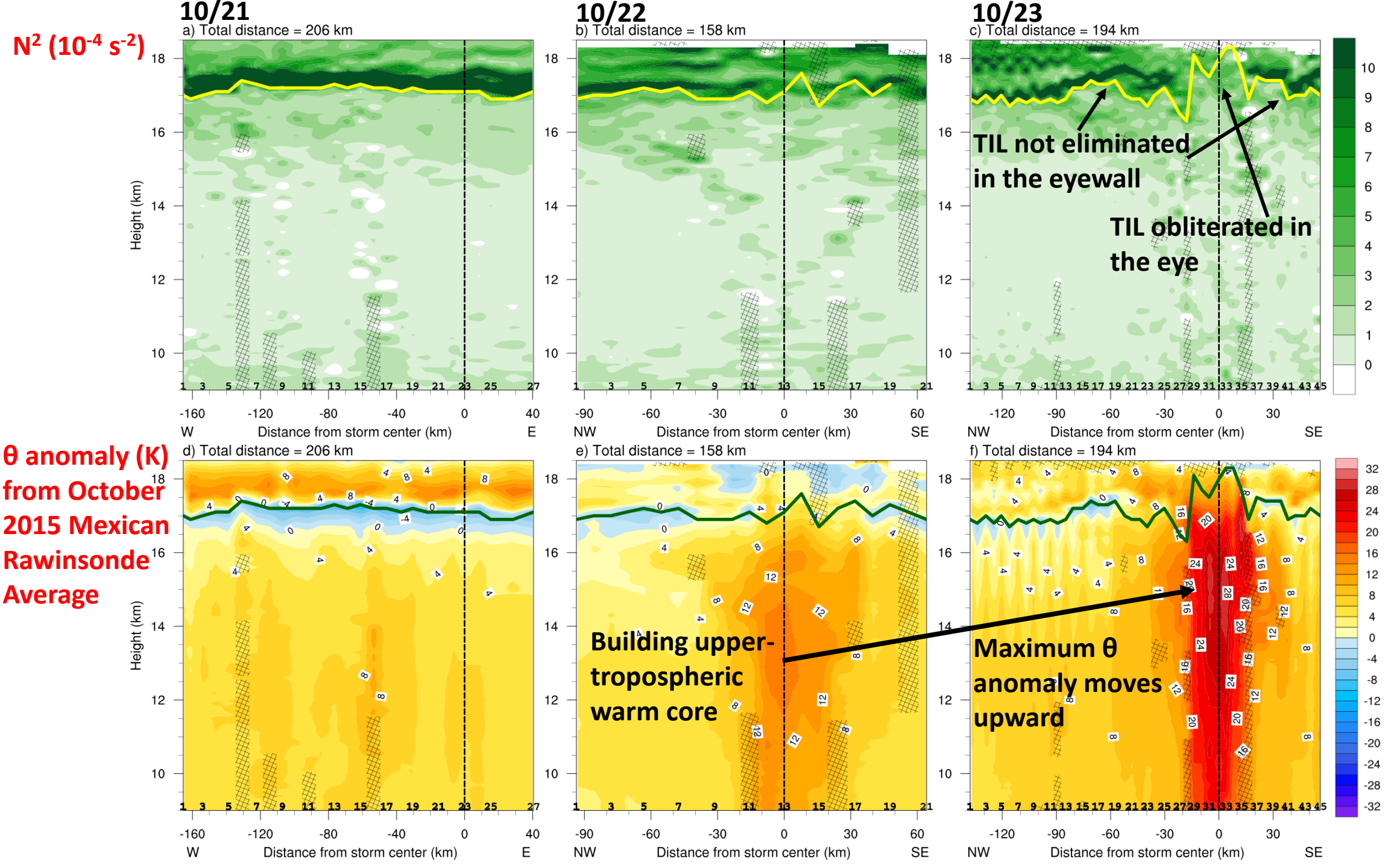


21 October **22 October** **23 October**

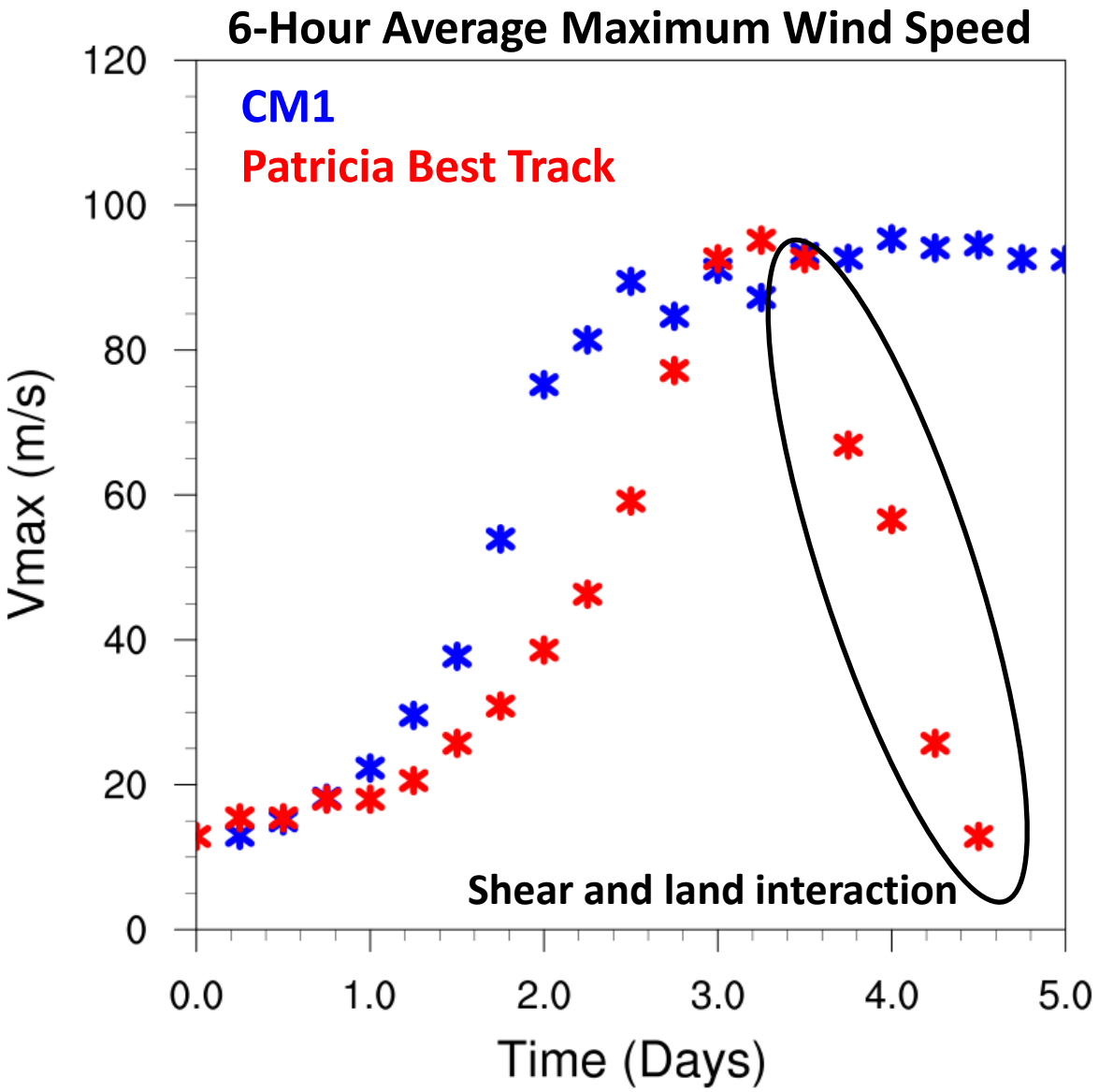
Mixing and subsidence warming eliminate high stability layer.



Increasing boundary layer θ_e shifts profiles to the right with time.

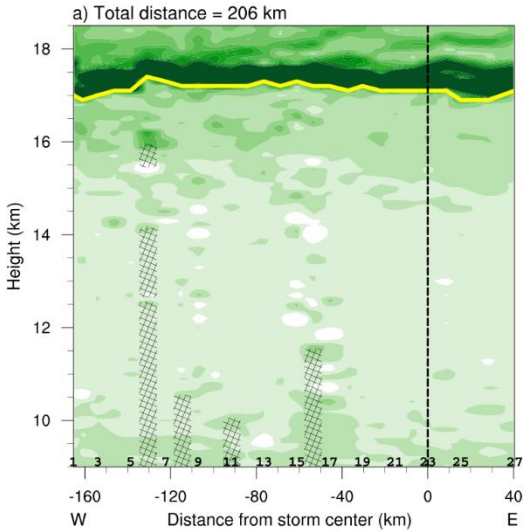

N² (10⁻⁴ s⁻²)
θ anomaly (K) from October 2015 Mexican Rawinsonde Average
10/21
10/22
10/23
a) Total distance = 206 km
b) Total distance = 158 km
c) Total distance = 194 km
d) Total distance = 206 km
e) Total distance = 158 km
f) Total distance = 194 km
Height (km)
Distance from storm center (km)
W
E
NW
SE
TIL not eliminated in the eyewall
TIL obliterated in the eye
Building upper-tropospheric warm core
Maximum θ anomaly moves upward

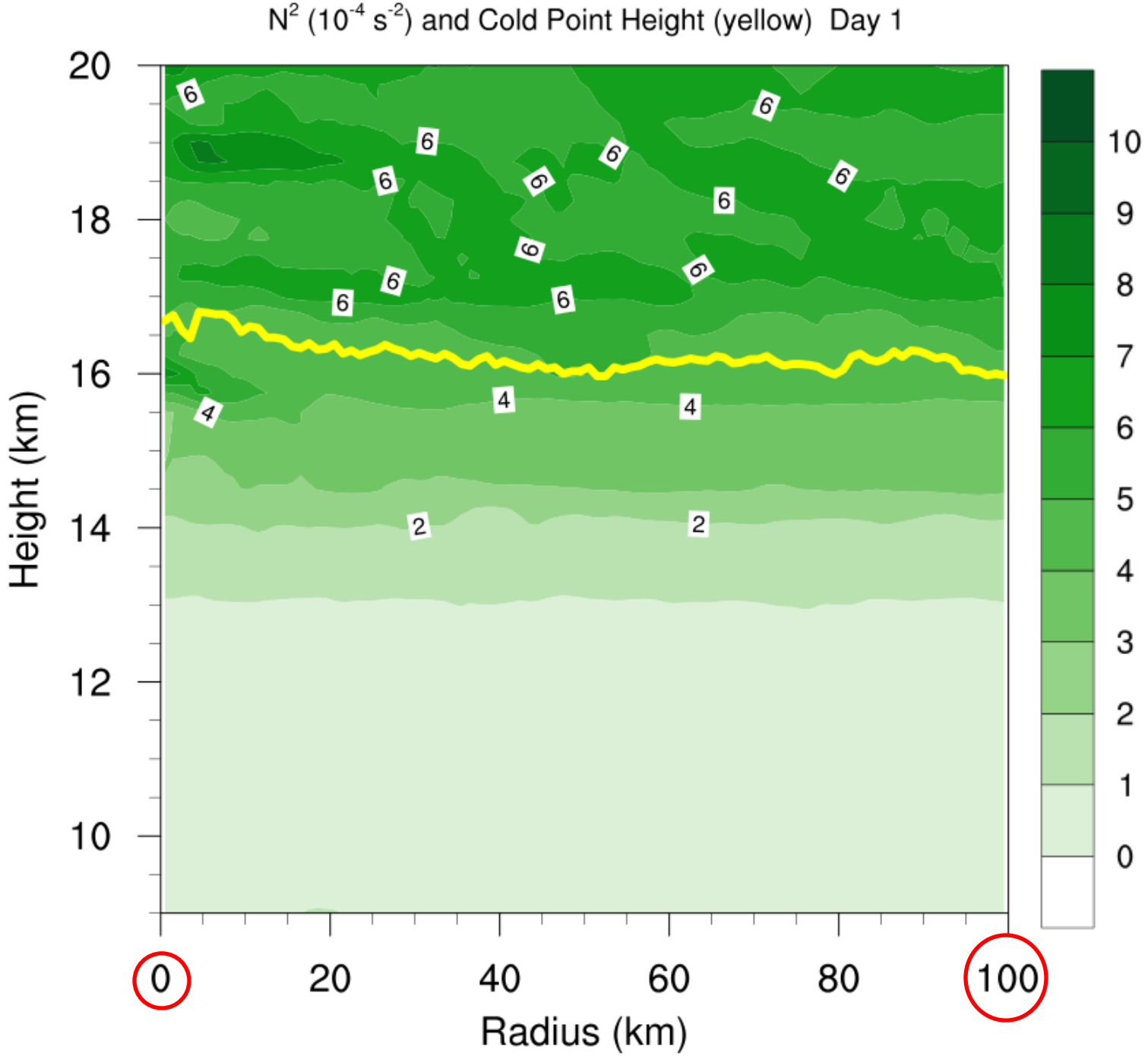
Preliminary Simulations of Tropopause Variability

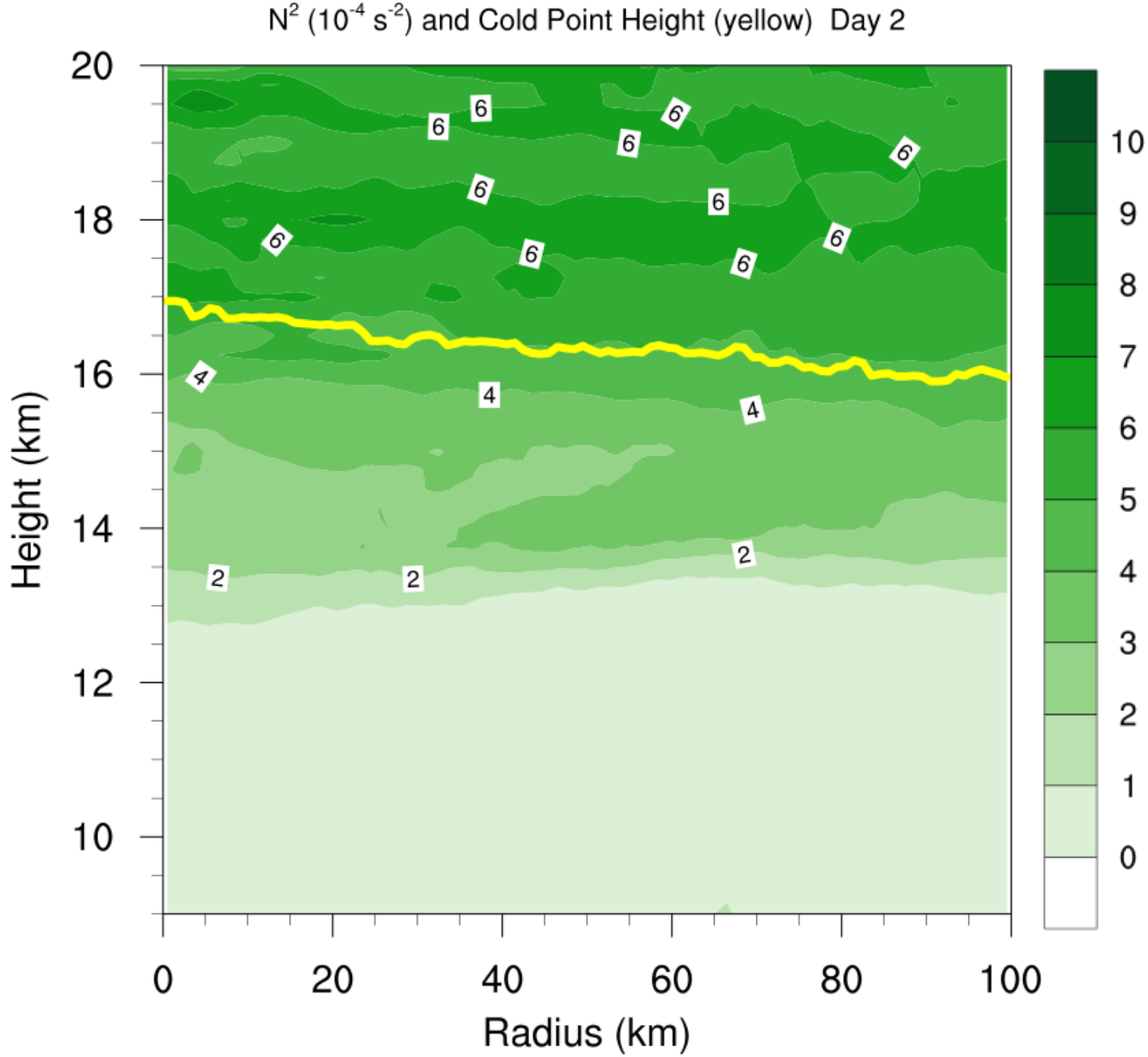


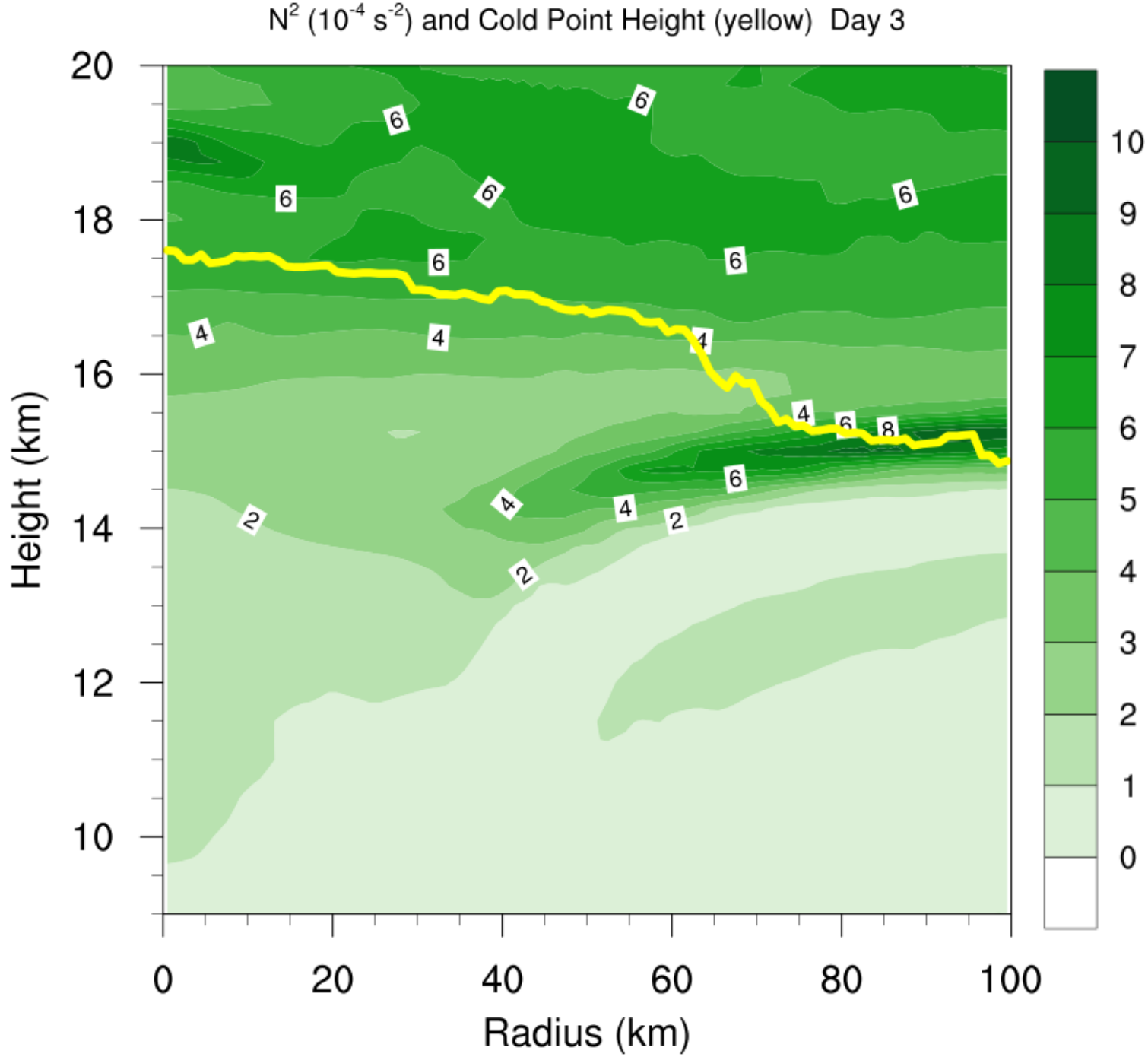
- CM1 version 18 in axisymmetric configuration
- 1 km horizontal, 250 m vertical grid spacing
- 0-6000 km radius, 0-25 km height
- Rotunno-Emanuel (1987) initial sounding
- Rotunno-Emanuel (1987) initial vortex
- SST fixed at 28°C
- Thompson Microphysics
- NASA-Goddard Radiation

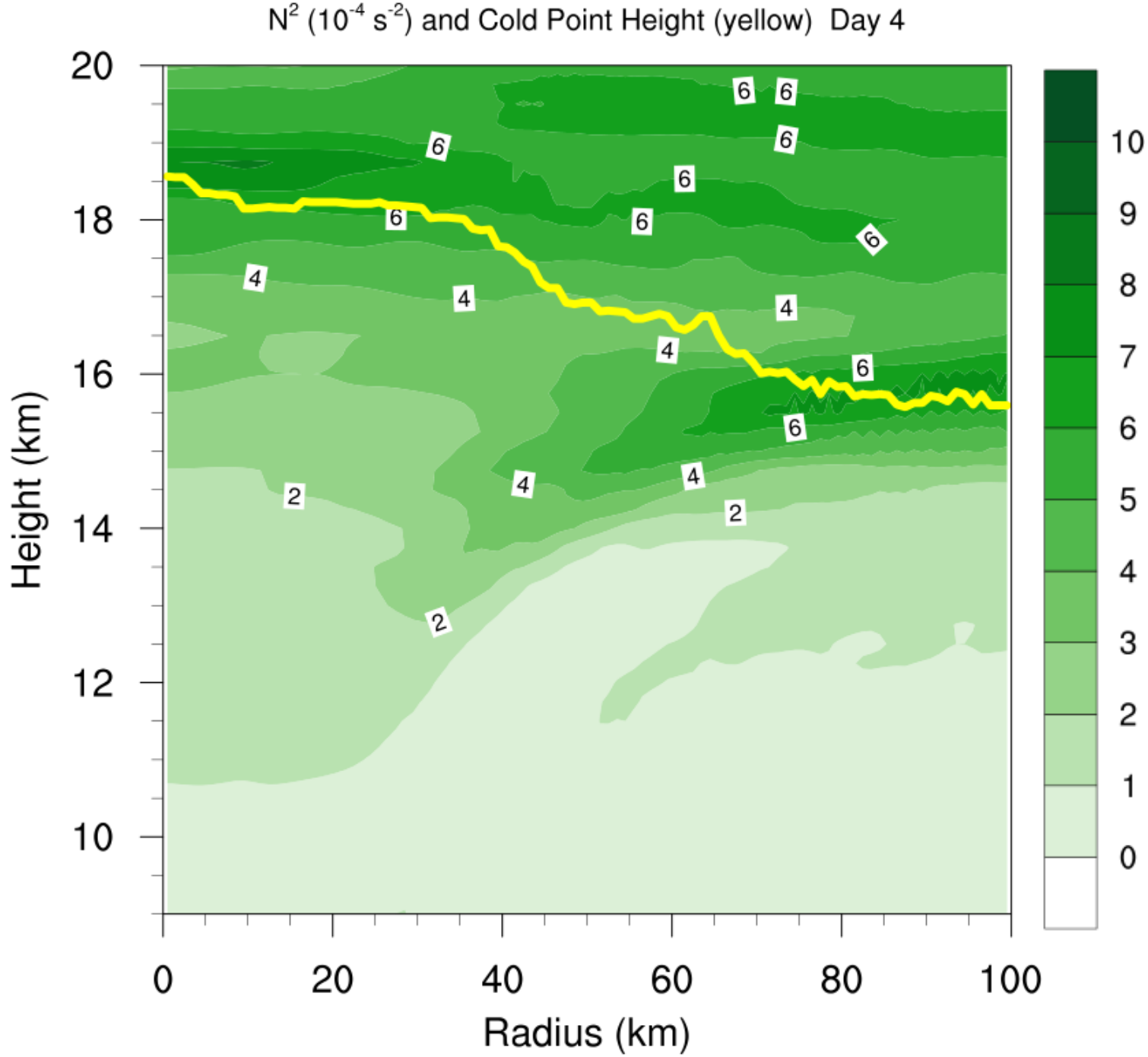
For now, we will examine 24-hour averages of Brunt-Väisälä frequency squared and tropopause height.

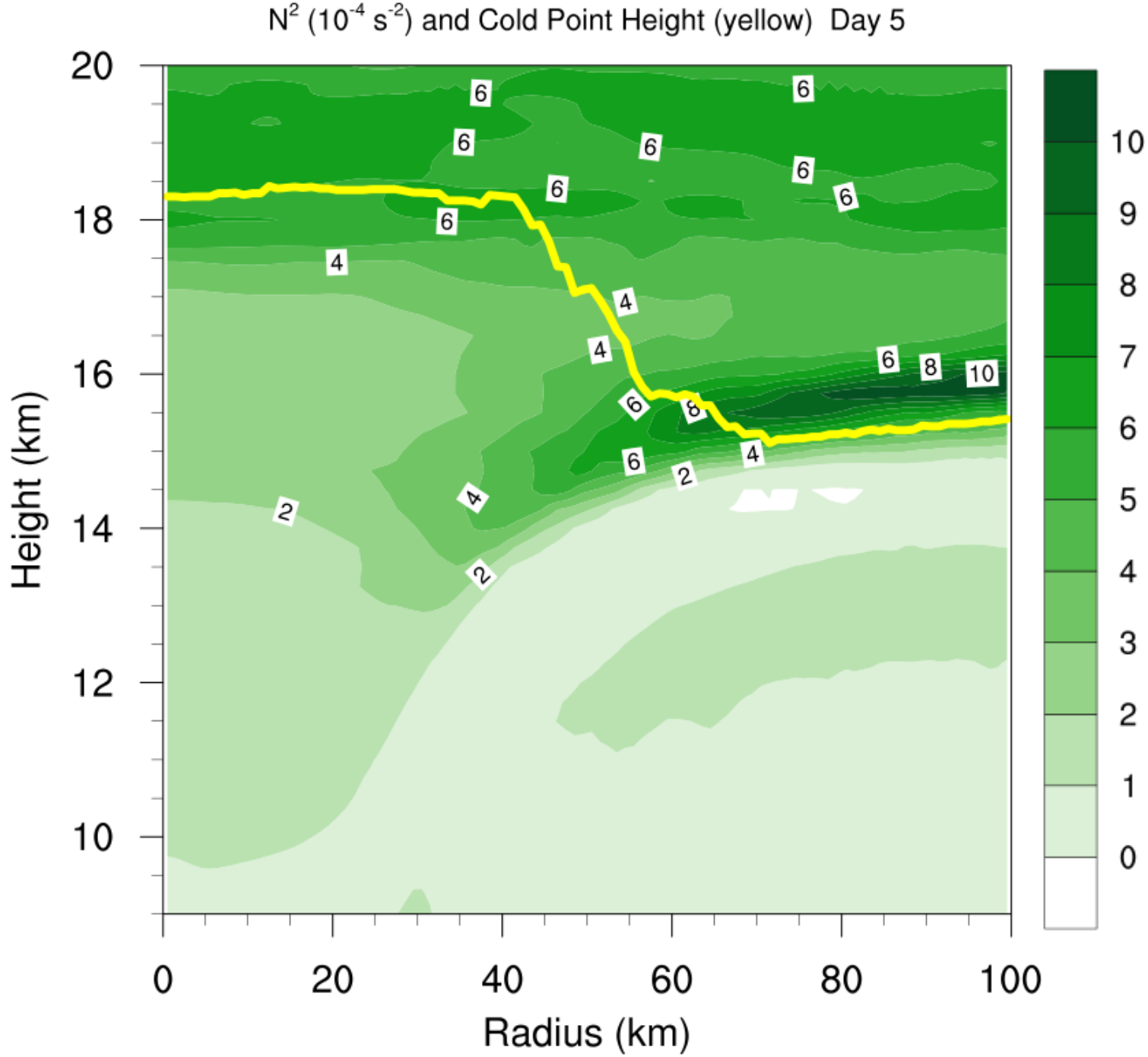

a) Total distance = 206 km
Height (km)
18
16
14
12
10
1 3 5 7 9 11 13 15 17 19 21 23 25 27
-160 -120 -80 -40 0 40
W
Distance from storm center (km)
E


N^2 (10^{-4} s^{-2}) and Cold Point Height (yellow) Day 1
Height (km)
20
18
16
14
12
10
6
4
2
0
20
40
60
80
100
Radius (km)
10
9
8
7
6
5
4
3
2
1
0


N² (10⁻⁴ s⁻²) and Cold Point Height (yellow) Day 2
Height (km)
20
18
16
14
12
10
0
20
40
60
80
100
Radius (km)
10
9
8
7
6
5
4
3
2
1
0


N² (10⁻⁴ s⁻²) and Cold Point Height (yellow) Day 3
Height (km)
20
18
16
14
12
10
0
20
40
60
80
100
Radius (km)
10
9
8
7
6
5
4
3
2
1
0


N² (10⁻⁴ s⁻²) and Cold Point Height (yellow) Day 4
Height (km)
20
18
16
14
12
10
0
20
40
60
80
100
Radius (km)
10
9
8
7
6
5
4
3
2
1
0


N² (10⁻⁴ s⁻²) and Cold Point Height (yellow) Day 5
Height (km)
20
18
16
14
12
10
0
20
40
60
80
100
Radius (km)
10
9
8
7
6
5
4
3
2
1
0

Summary and Future Work

- A strong tropopause inversion layer (TIL) existed over Patricia prior to its RI period.
- During RI, the ***TIL over Patricia's eye eroded completely***.
  - This led to a ***rise in the tropopause height, accompanied by warming at the tropopause***.
  - Early in Patricia's RI, the potential temperature evolution near the tropopause is consistent with ***strong mixing***.
  - Later in the period, dramatic upper-tropospheric warming within the eye – probably due to ***subsidence from the stratosphere*** – further decreased the static stability.
- An axisymmetric CM1 simulation depicted a similar inner-core tropopause evolution.
  - **Potential temperature budgets** and **static stability tendencies** will be used to determine what led to this evolution in the simulated storm.