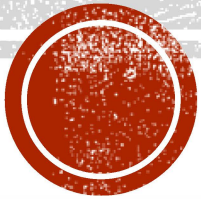
SESSION 8: BOUNDARY LAYER STRUCTURE AND EVOLUTION



ABL EVOLUTION

- The primary components of the boundary layer include:
  - The mixed layer (ML)
  - The entrainment zone (EZ)

  } Daytime

  - The stable boundary layer (SBL)
  - The residual layer (RL)
  - The capping inversion (CI)

  } Nighttime

  - The free atmosphere
  - The surface layer (SL)

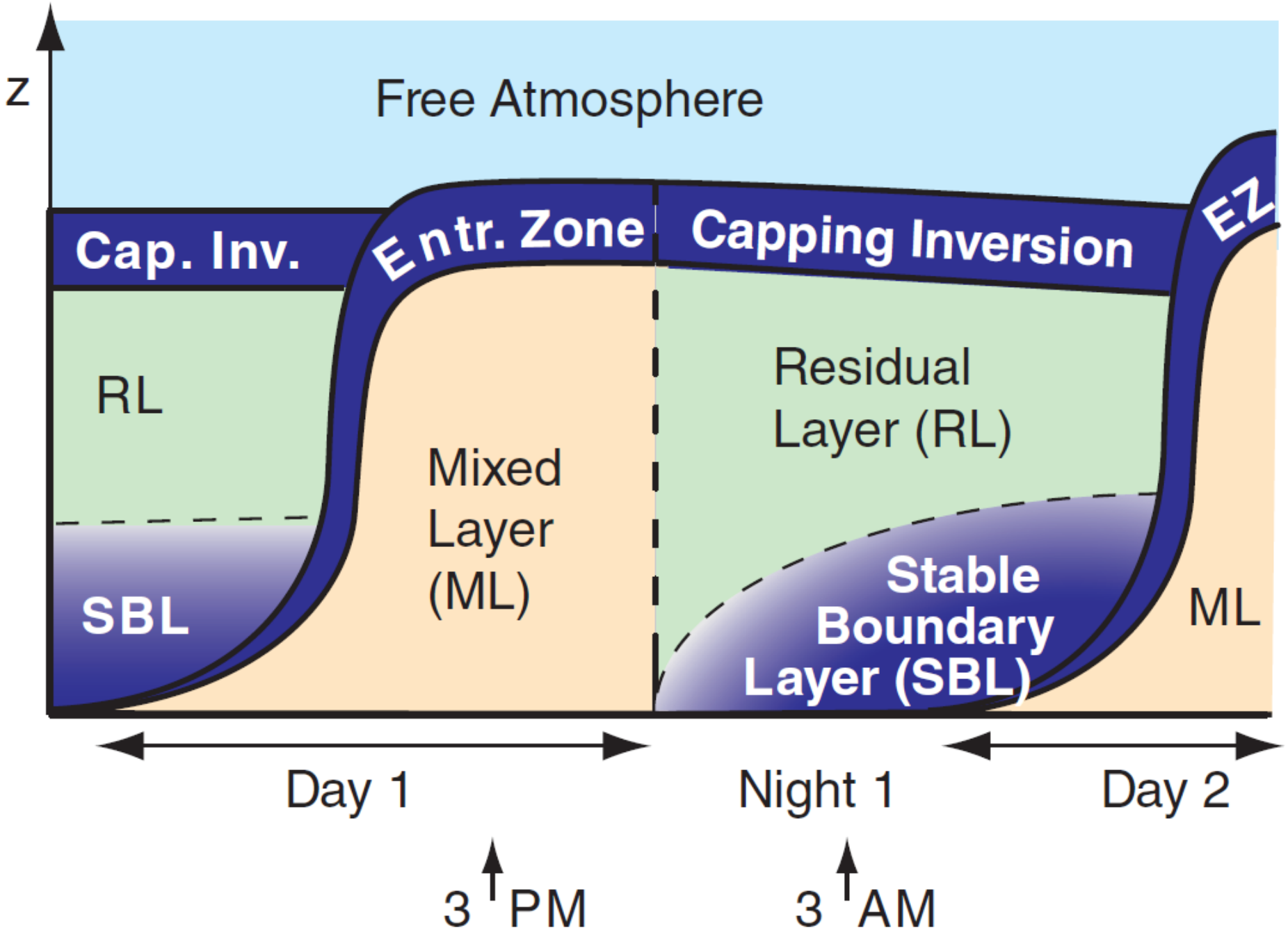
  } All the time

CONSISTENT FEATURES

- The surface layer
  - Bottom 20 – 200 m of the ABL
  - Frictional drag, conduction, and evaporation
  - Known as the constant flux layer
- The free atmosphere
  - Unmodified tropospheric air
  - Little turbulence

ABL EVOLUTION

- Compare daytime vs. nighttime

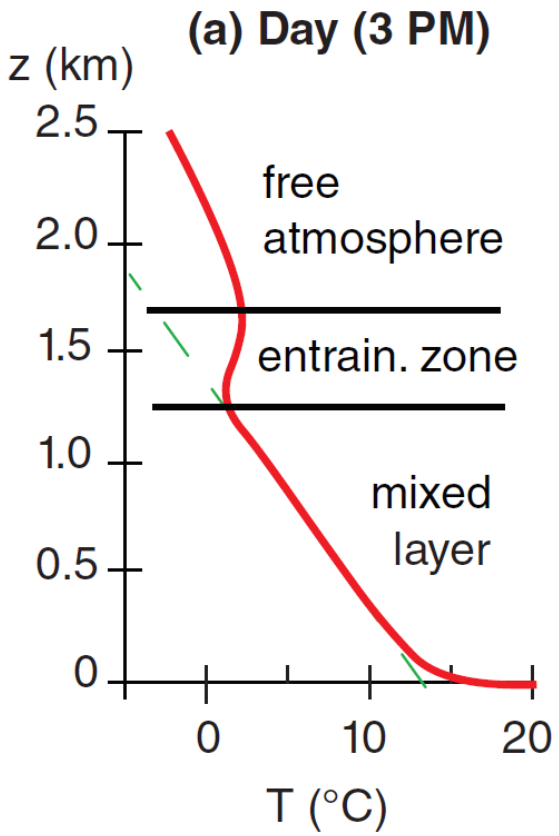

z
Free Atmosphere
Cap. Inv.
Entr. Zone
Capping Inversion
EZ
RL
Residual
Layer (RL)
Mixed
Layer
(ML)
SBL
Stable
Boundary
Layer (SBL)
ML
Day 1
Night 1
Day 2
3 PM
3 AM

DAY TIME EVOLUTION

- The sun warms the surface layer making it statically unstable.
- The rising warm air (thermals) generates turbulence and entrains the stable above it
- This creates a layer of well mixed air. Pollutants, moisture, and heat are well mixed in this layer.
- Through the entrainment process (and in the entrainment zone), the ML increases in depth throughout the day.

DAY TIME EVOLUTION

- In an idealized sense, the SL, ML, and bottom part of the EZ are all statically unstable.
- EZ acts as a one-way valve: FA air can mix in, but pollutants and moisture cannot mix out.
- The environmental lapse rate is nearly adiabatic.



DAY TIME EVOLUTION

- ML depth (or mixing height; z_i) is the distance between the ground and the center of the EZ.

- ML depth is dependent on heat, so it will be greater at lower latitudes and in warmer seasons:

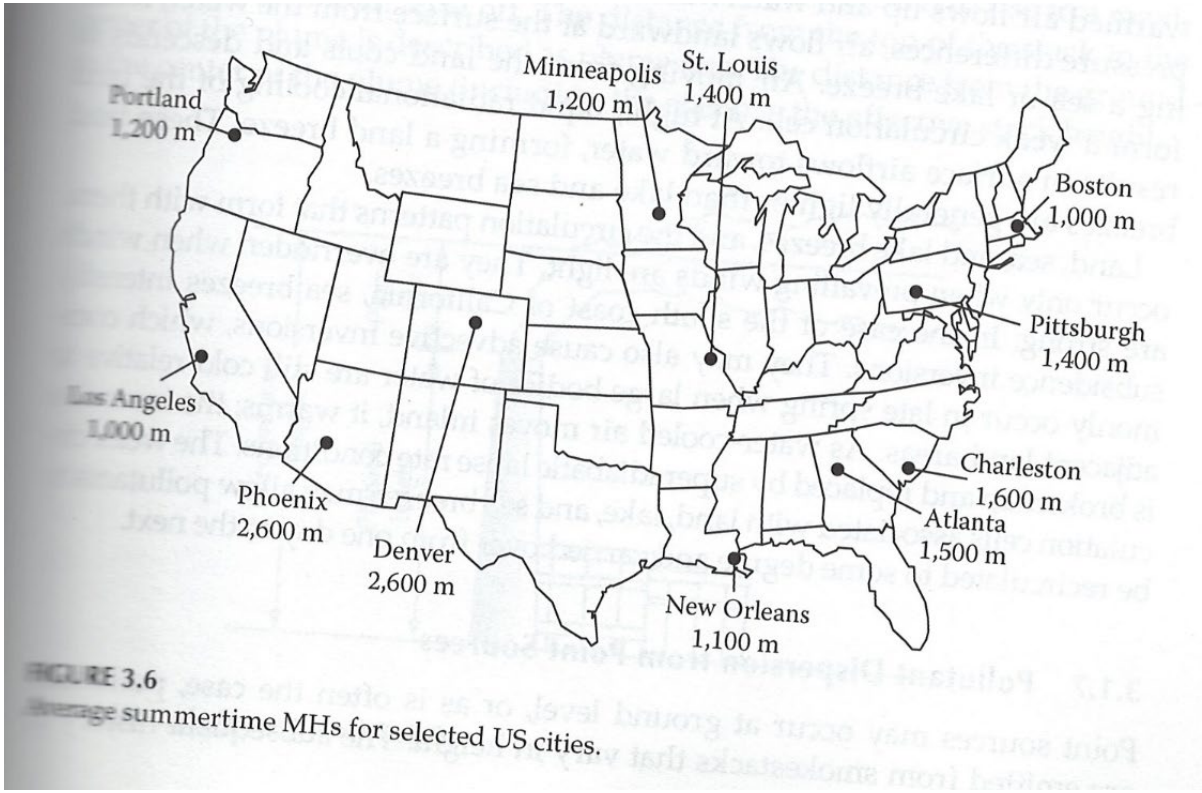
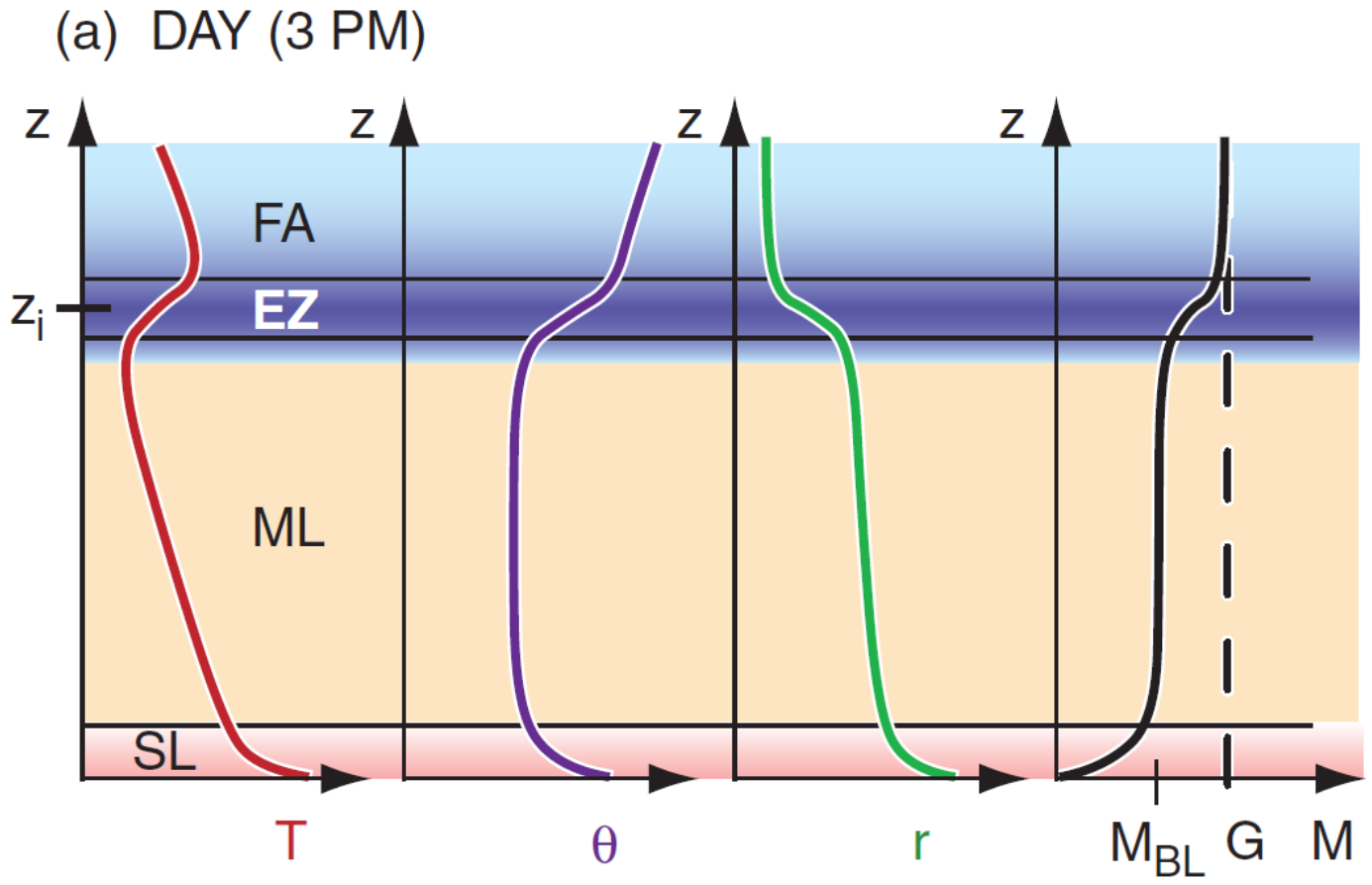


FIGURE 3.6
Average summertime MHs for selected US cities.

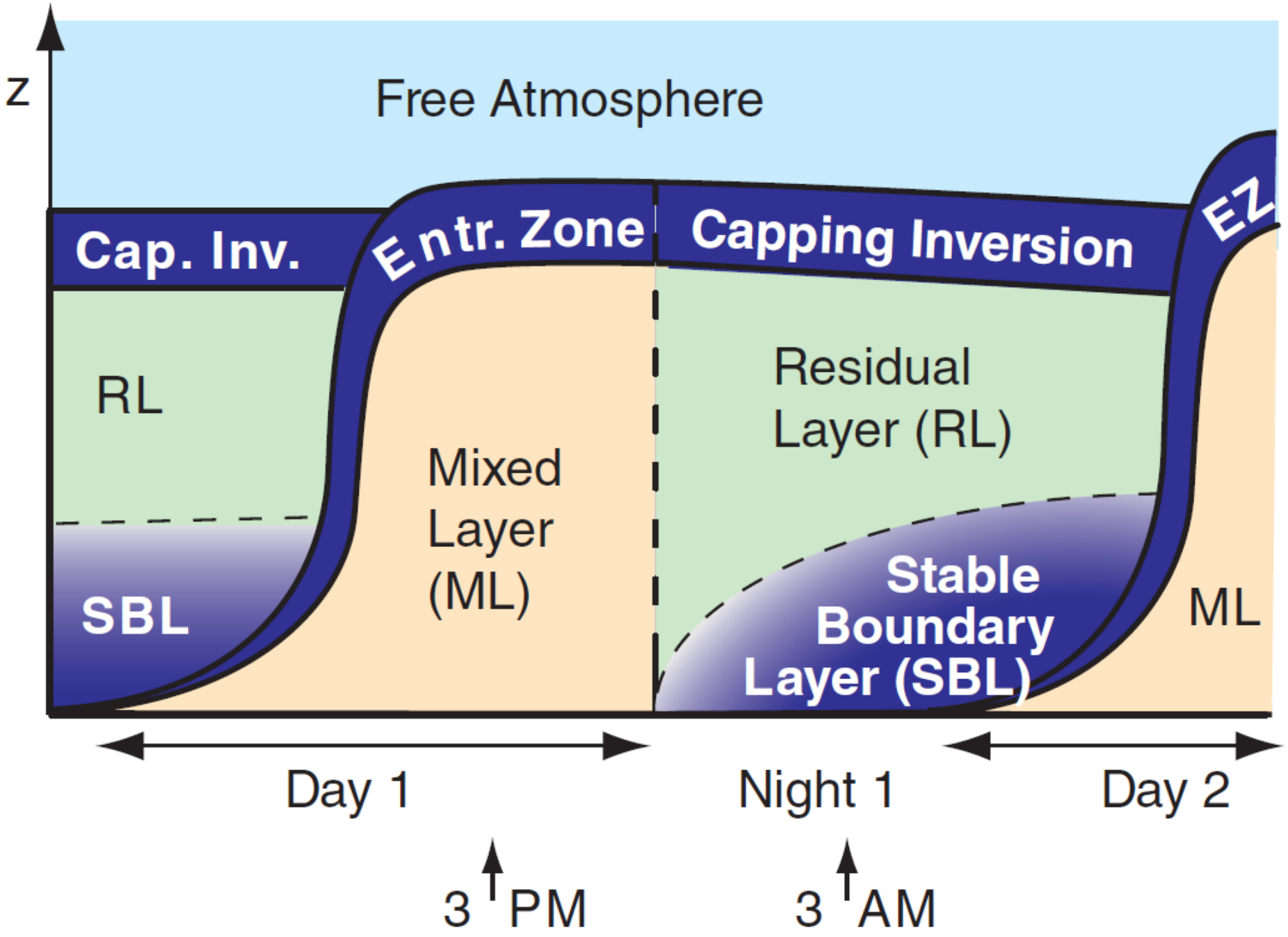
DAY TIME EVOLUTION



- Variables other than temperature are also modified because of this mixing.

NIGHT TIME EVOLUTION

- As the solar radiation weakens, the surface layers cools.
  - Radiational Cooling → outgoing energy exceeds incoming energy.
- This cooling works upward through the mixed layer, with each level being slightly warmer than the level below it.
- The result is a stable ABL (SBL) and likely a radiation inversion.
- The rest of the mixed layer is unchanged and maintains the adiabatic lapse rate and the residual pollutants and moisture. Hence the residual layer.
- EZ no longer entrains, but caps instead.


z
Free Atmosphere
Cap. Inv.
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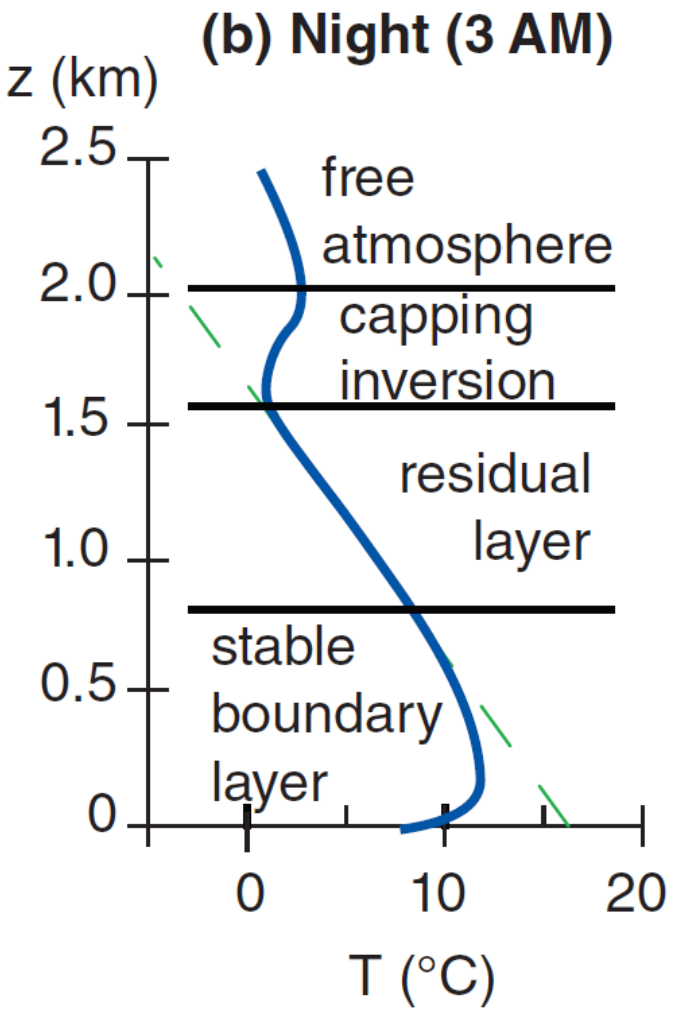
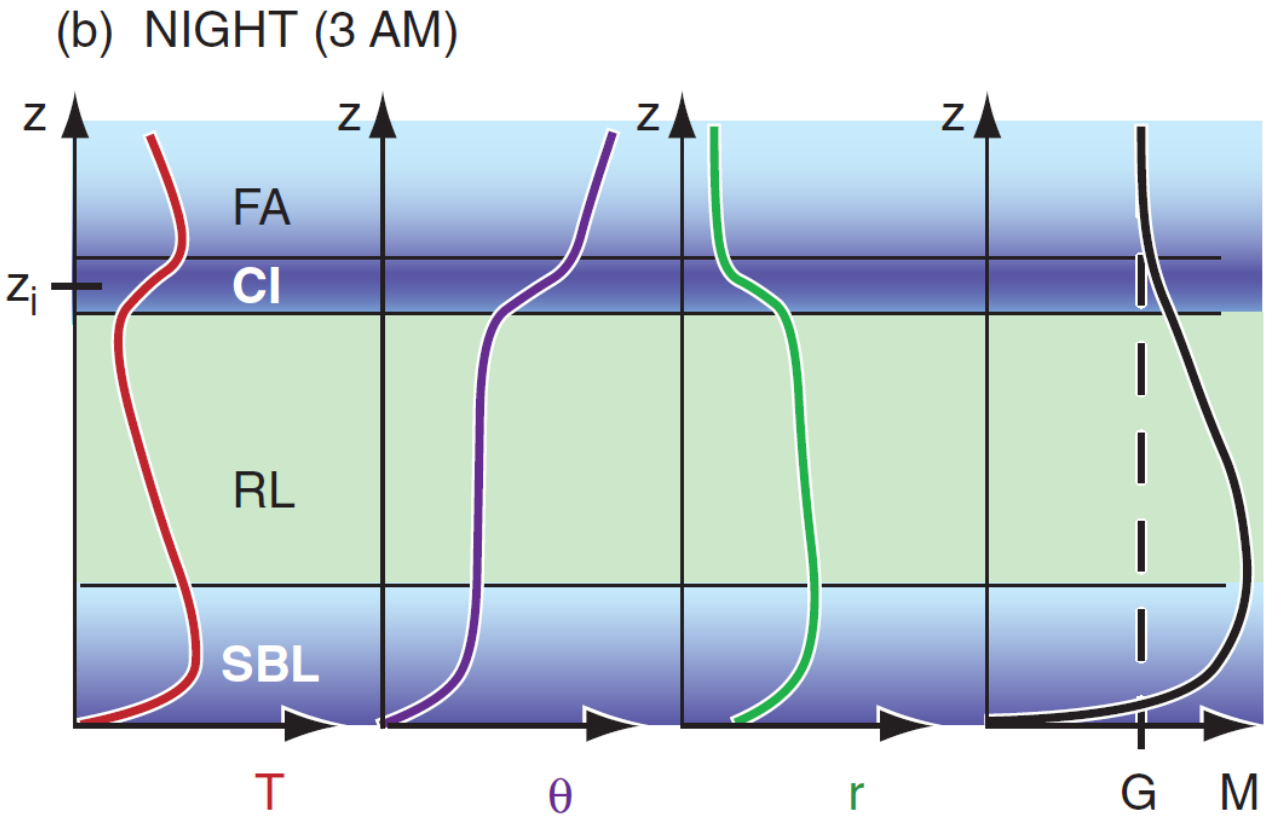
EZ
RL
Residual
Layer (RL)
Mixed
Layer
(ML)
SBL
Stable
Boundary
Layer (SBL)
ML
Day 1
Night 1
Day 2
3 PM
3 AM

NIGHT TIME EVOLUTION

- The resulting BL is statically stable.
  - Surface "decoupled"
- Surface-based clouds (cumulus – type) dissipate.
- Turbulence becomes intermittent
- Cool air drains downhill
  - Katabatic winds

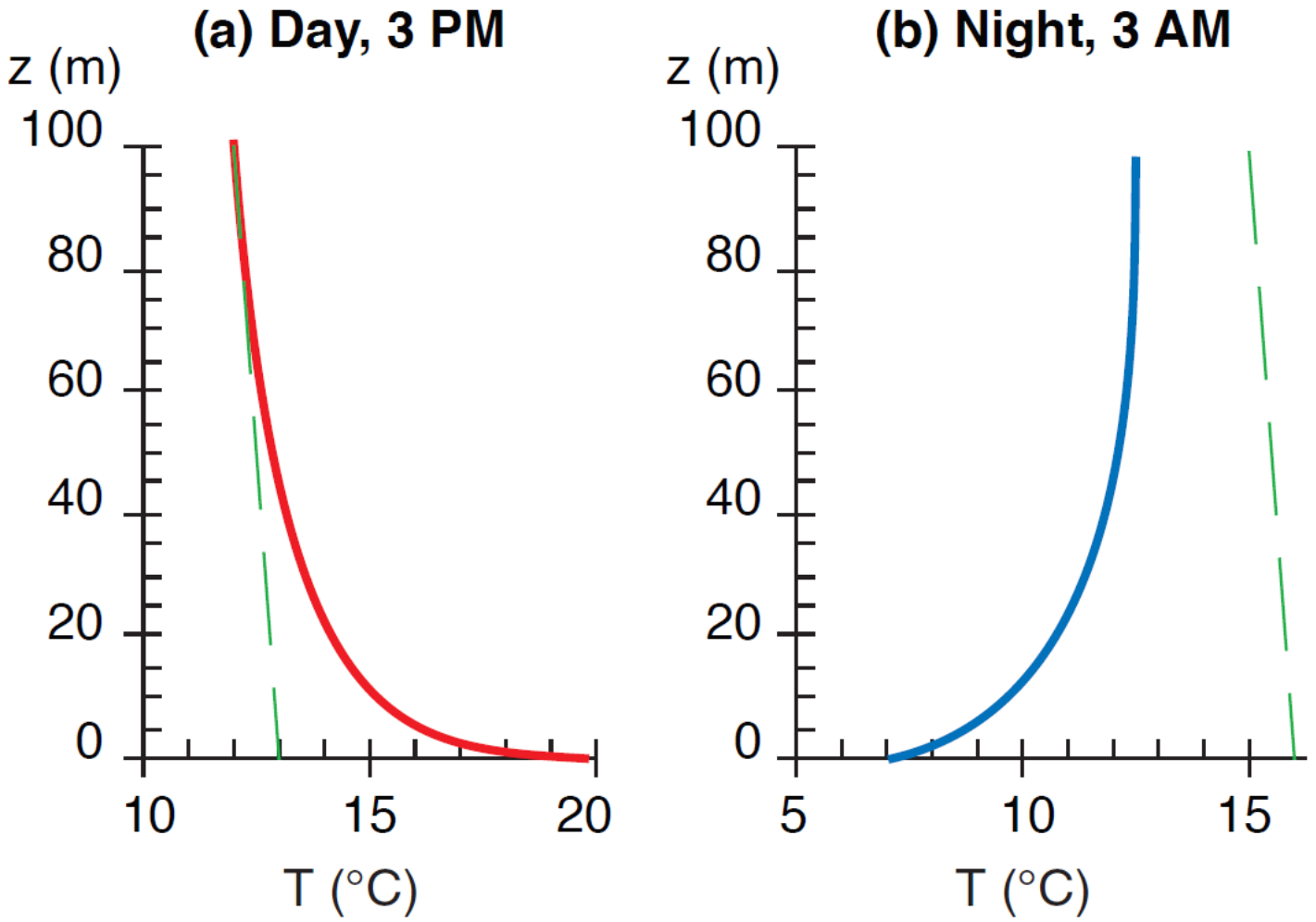


NIGHT TIME EVOLUTION



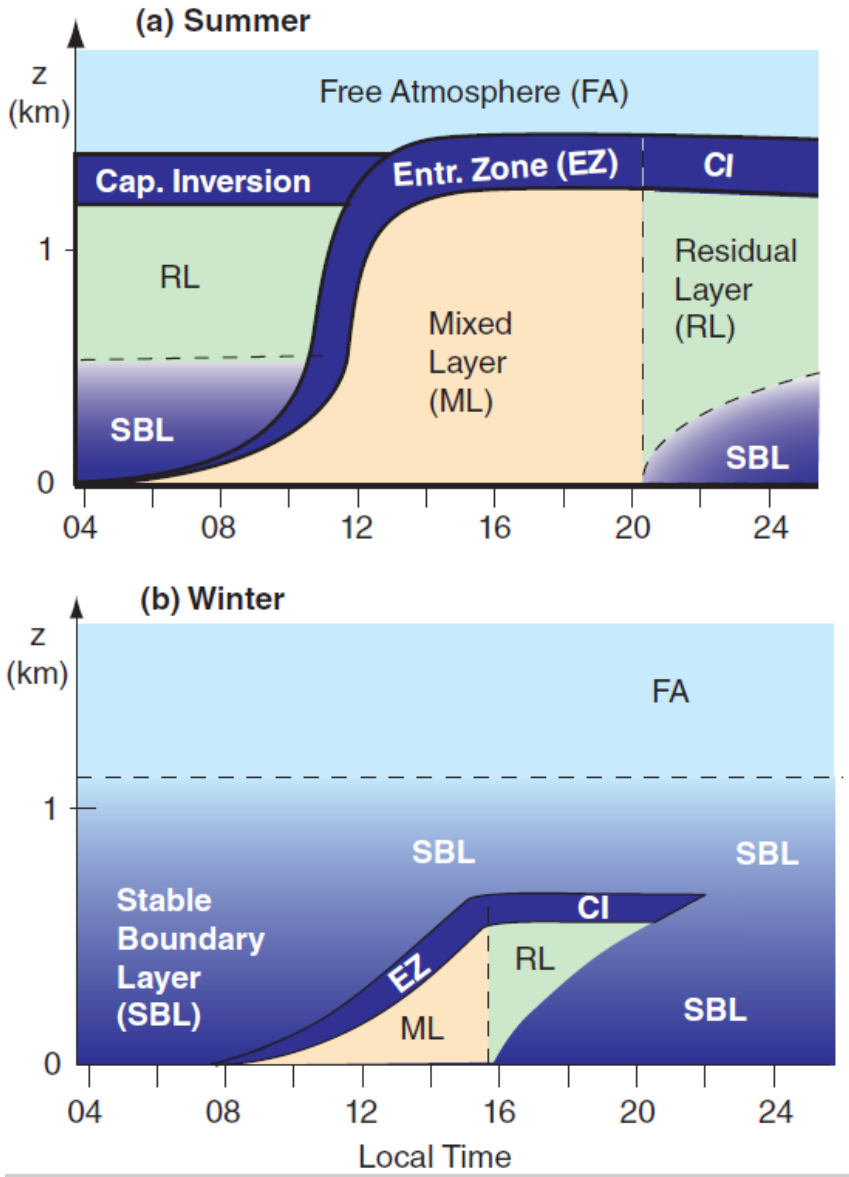
- This evolution has a large impact on the wind field as well.

DAYTIME, NIGHTTIME COMPARISON



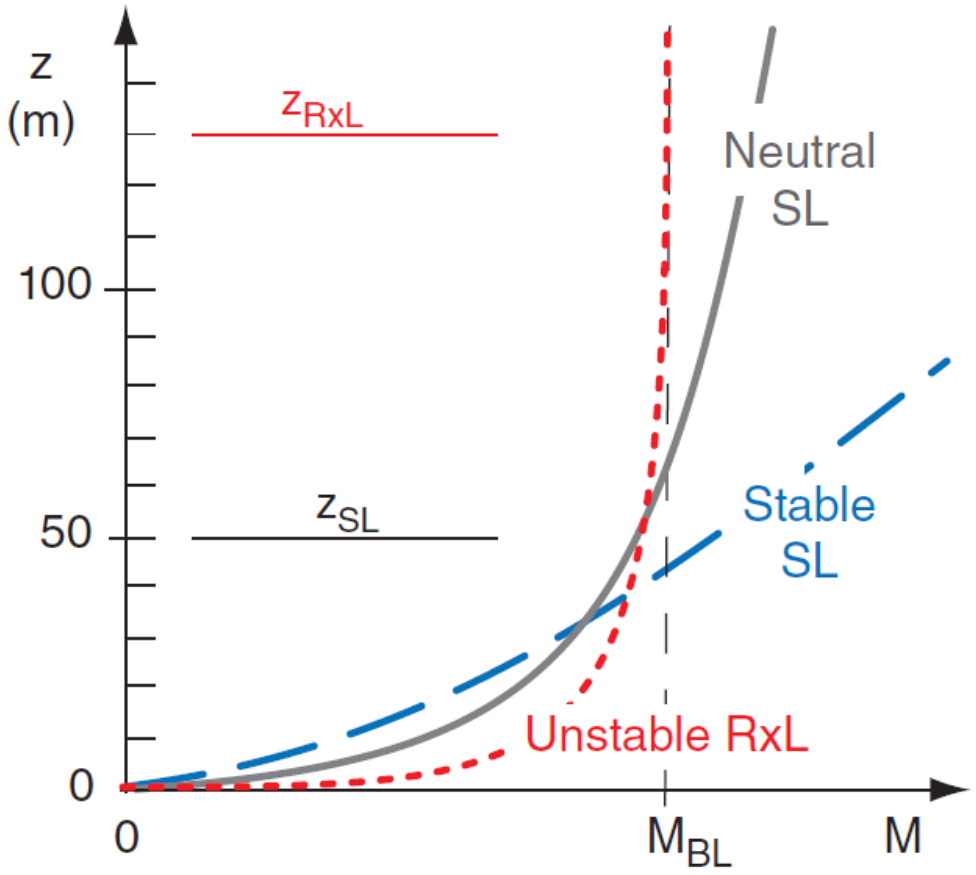
SEASONALITY

- The boundary layer features are less developed in the winter.
- Less energy in (shorter days, lower sun angles).
- SBL more prevalent.
- Mixed layer is weakly unstable, while RL is neutral.
- Pollution dispersion will occur at different rates.



WIND IN THE ATMOSPHERE

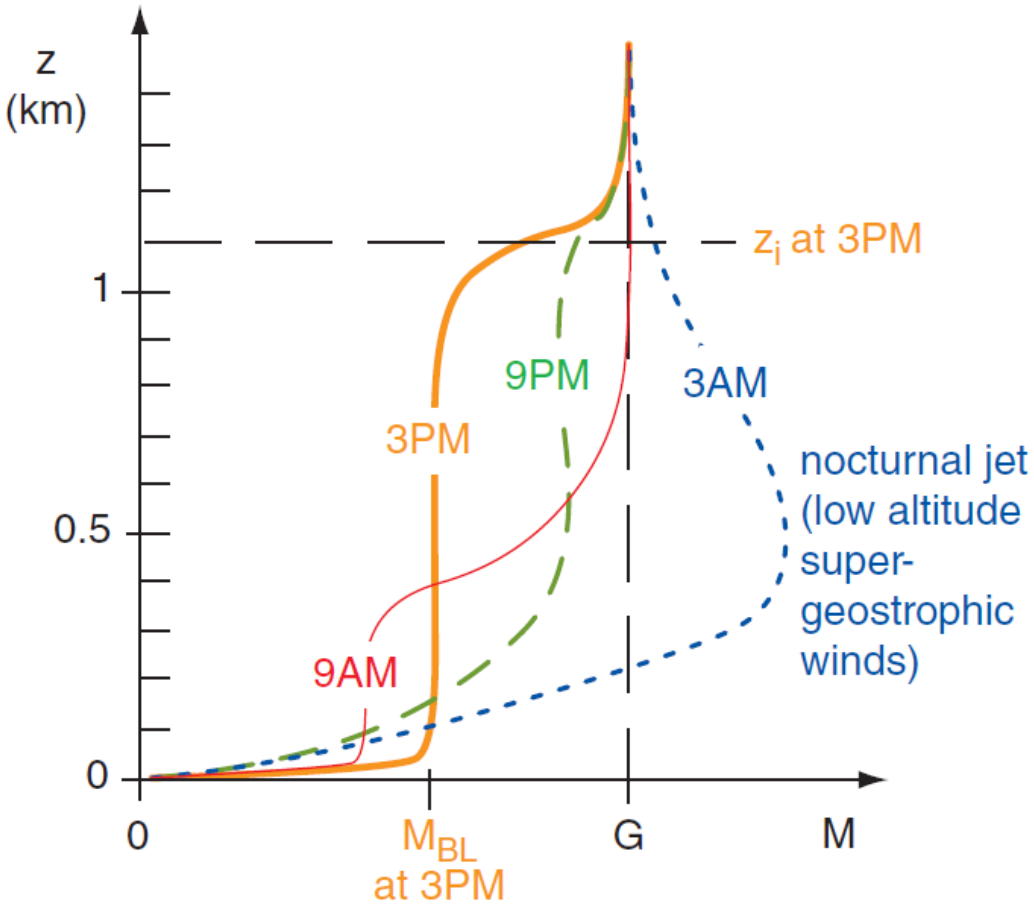
- However, the shape of the wind profile close to the ground depends on stability:



WIND IN THE ATMOSPHERE

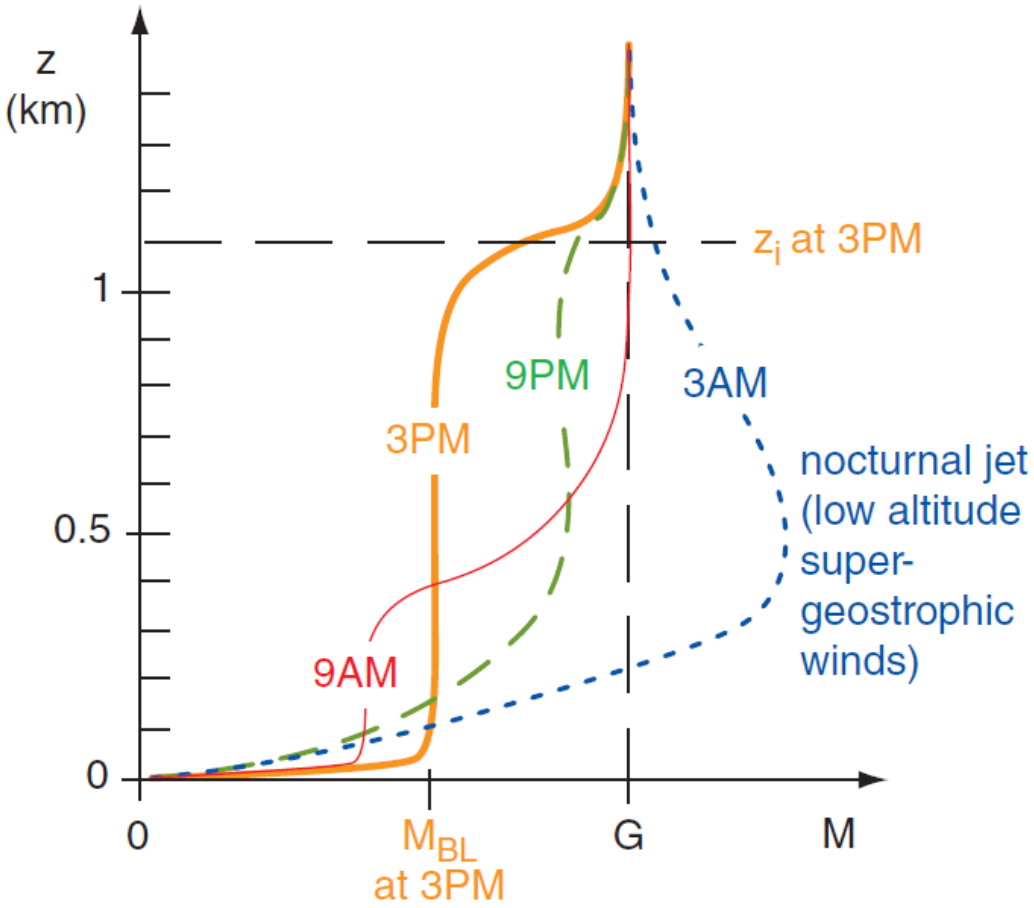
- Because stability evolves during the day, the wind profile also changes. Recall how stability changes throughout a cloudless, non-synoptically forced environment:
  - 3 AM
  - 9 AM
  - 3 PM
  - 9 PM

BL WIND EVOLUTION



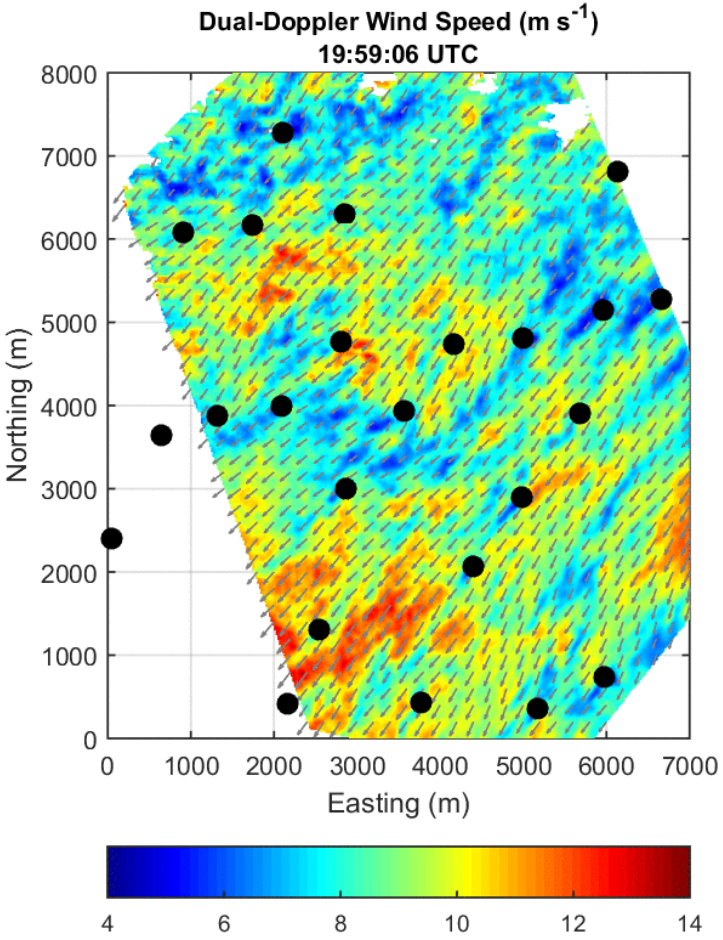
- Wind near the surface is slowed by friction (drag).
- That slower wind gets mixed with faster wind from above.
- Mixed layer deepens during the day.

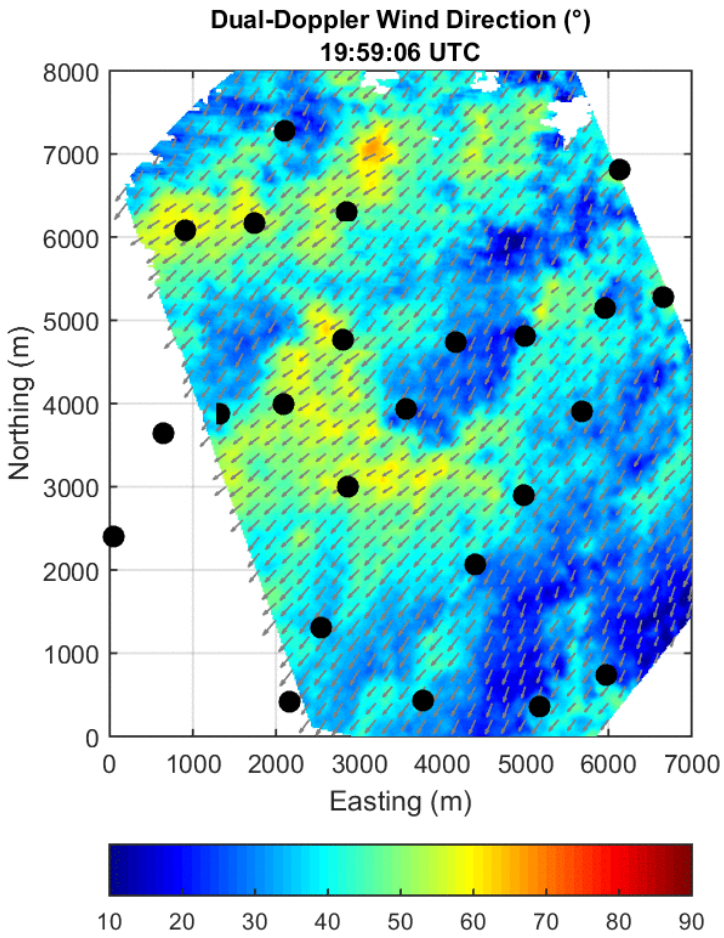
BL WIND EVOLUTION



- Turbulence ceases at night and the wind above the surface speeds up.
- Called a nocturnal jet.
- Can cause rapid transport of pollutants and moisture.

Stability Impacts in a Wind Plant Setting: Wind Speed and

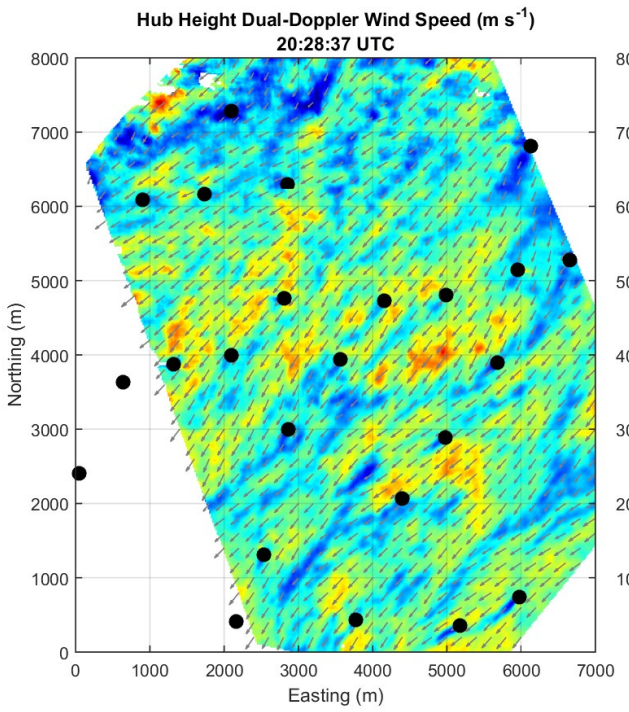




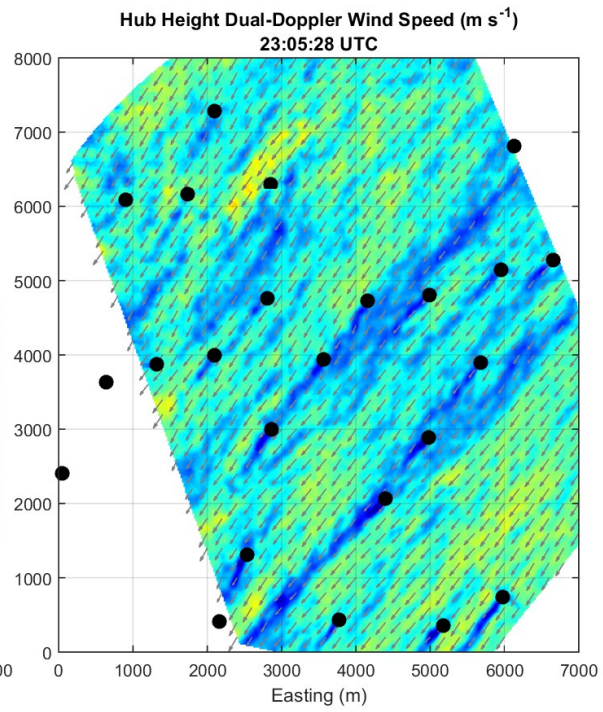
Smart Wind TECHNOLOGIES

Stability Impacts in a Wind Plant Setting: Wake Evolution

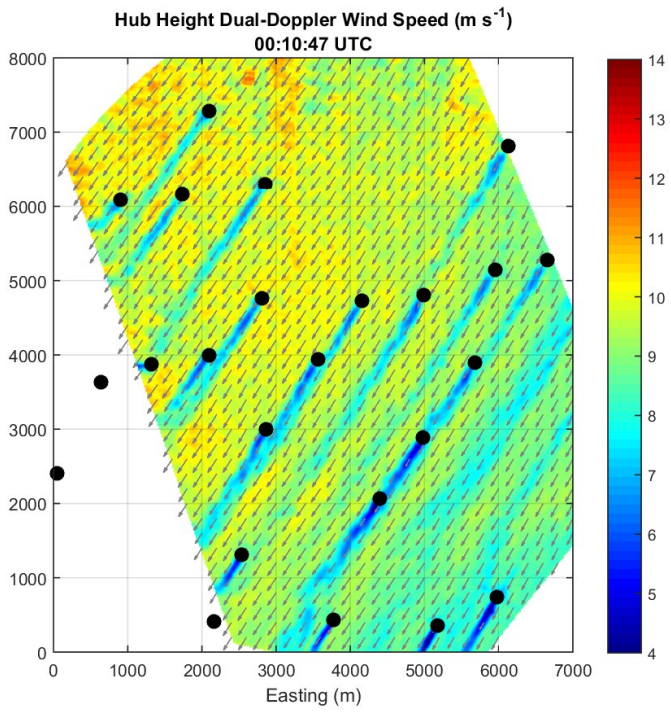
"Unstable"



"Transition"



"Stable"

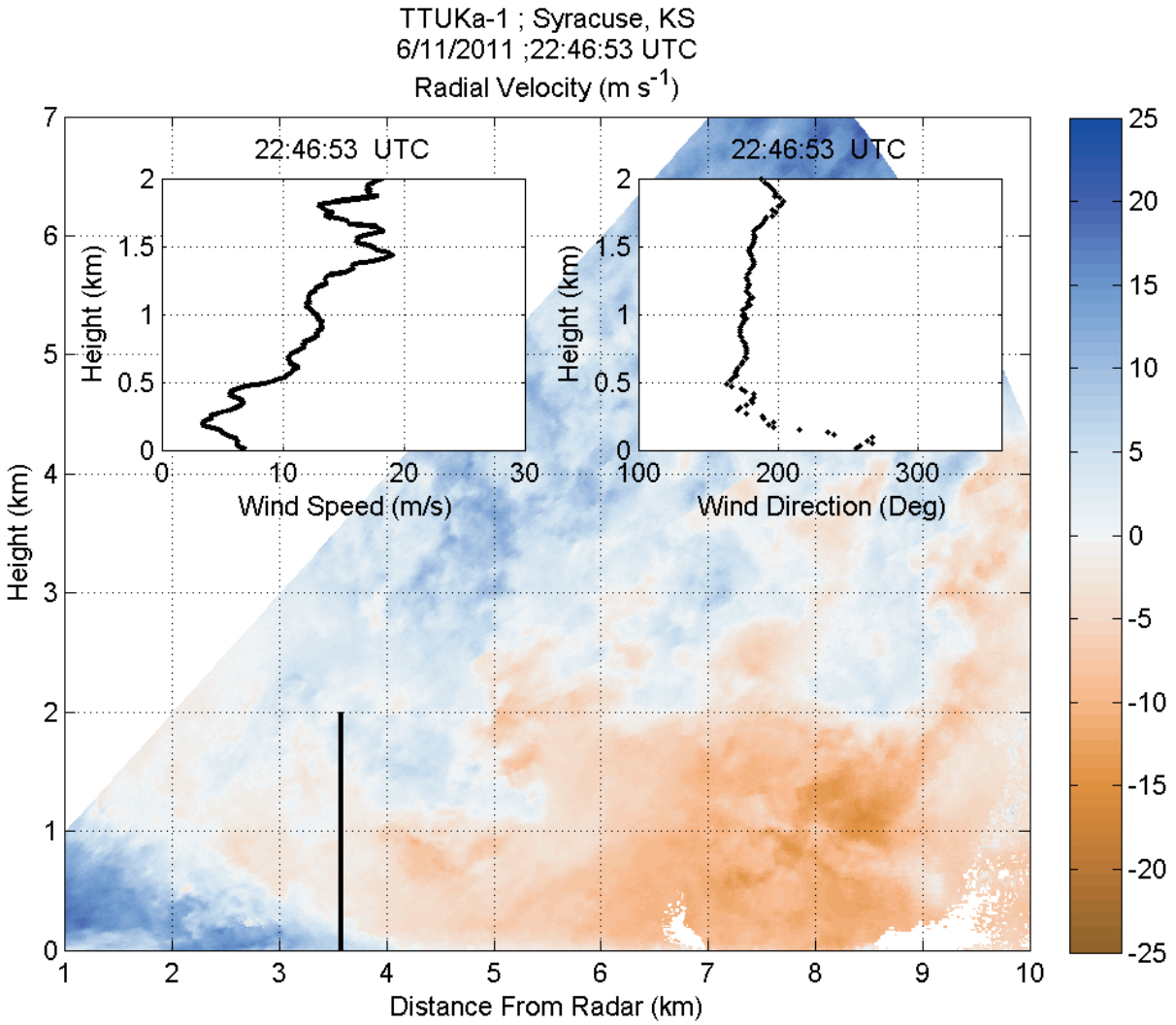


SmartWind TECHNOLOGIES

BL MODIFICATION

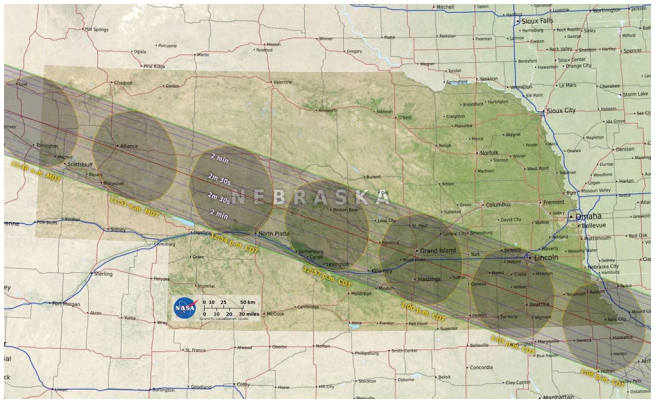
- Rapid changes in stability can lead to rapid changes in turbulence characteristics:
  - Thunderstorm winds / cold fronts
  - Solar Eclipses

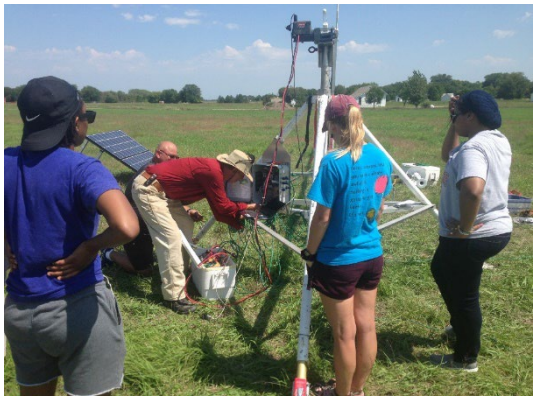
PROJECT SCOUT: THUNDERSTORM WINDS

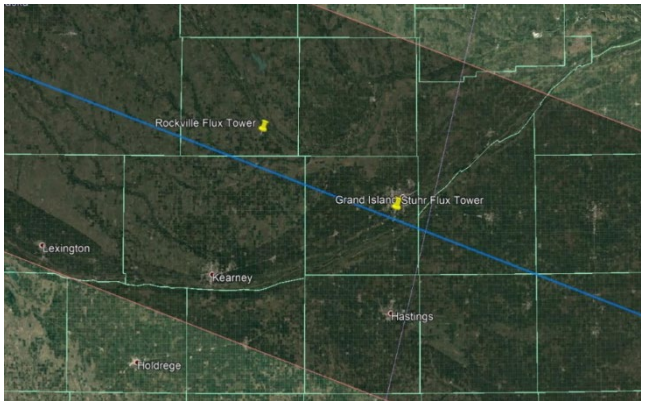


BL CASE STUDY: TOTAL SOLAR ECLIPSE

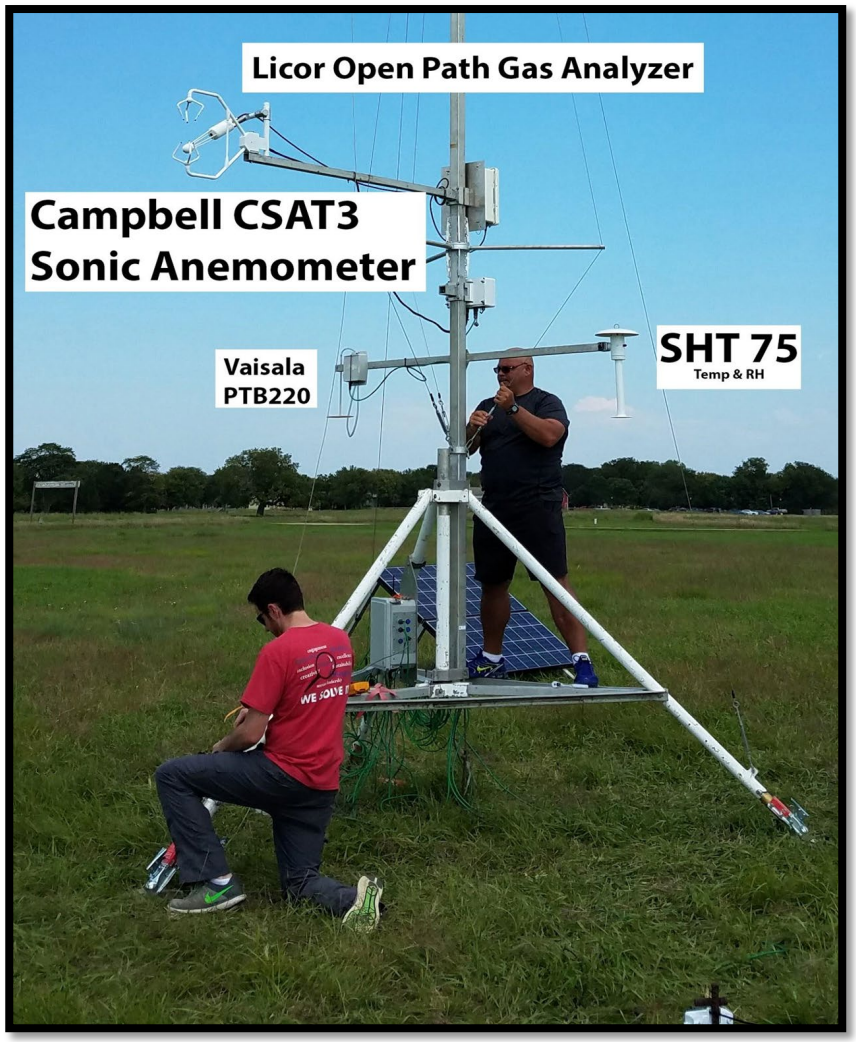
- Traveled to central Nebraska in August 2017 to measure changes in the ABL during a total solar eclipse.

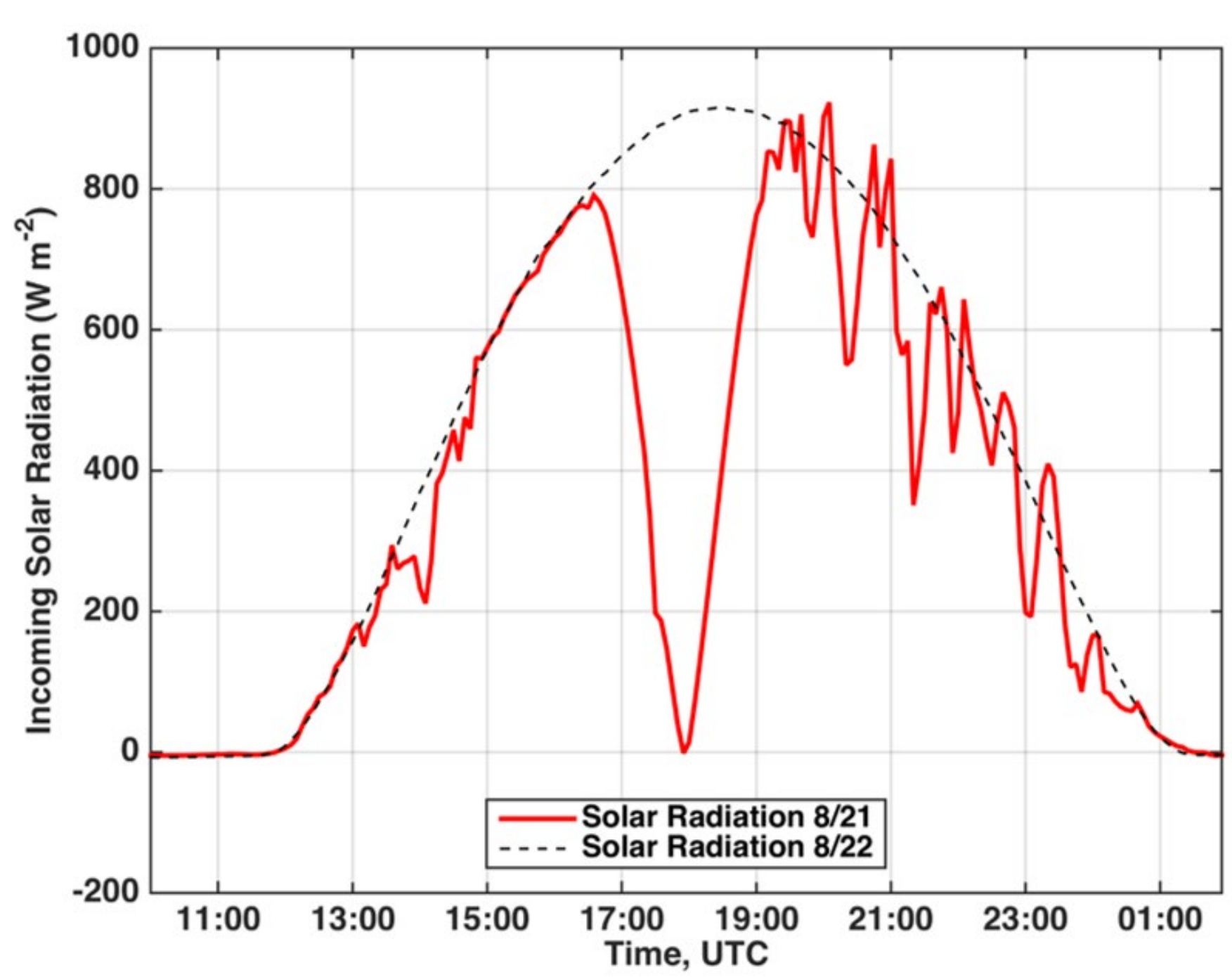


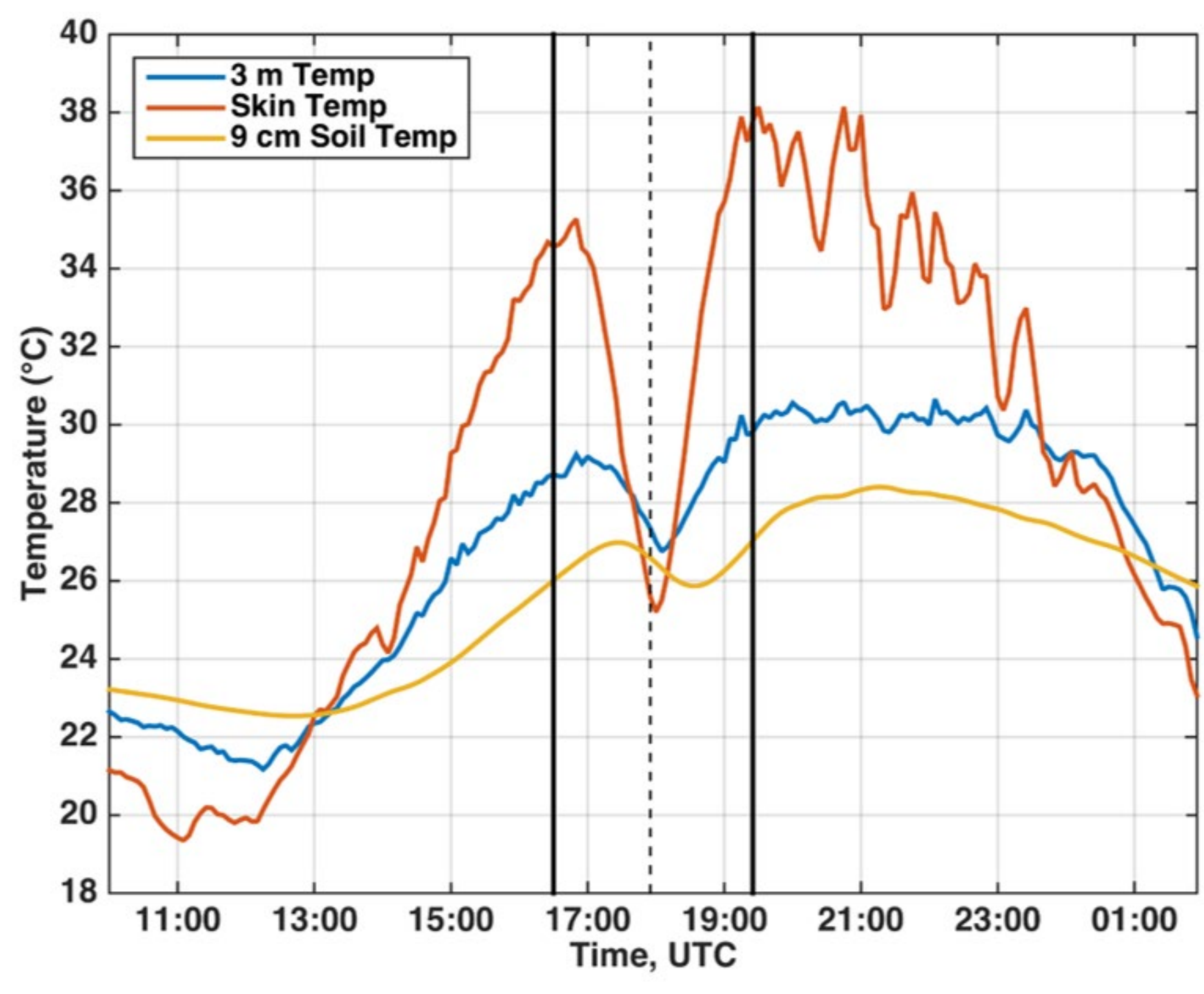


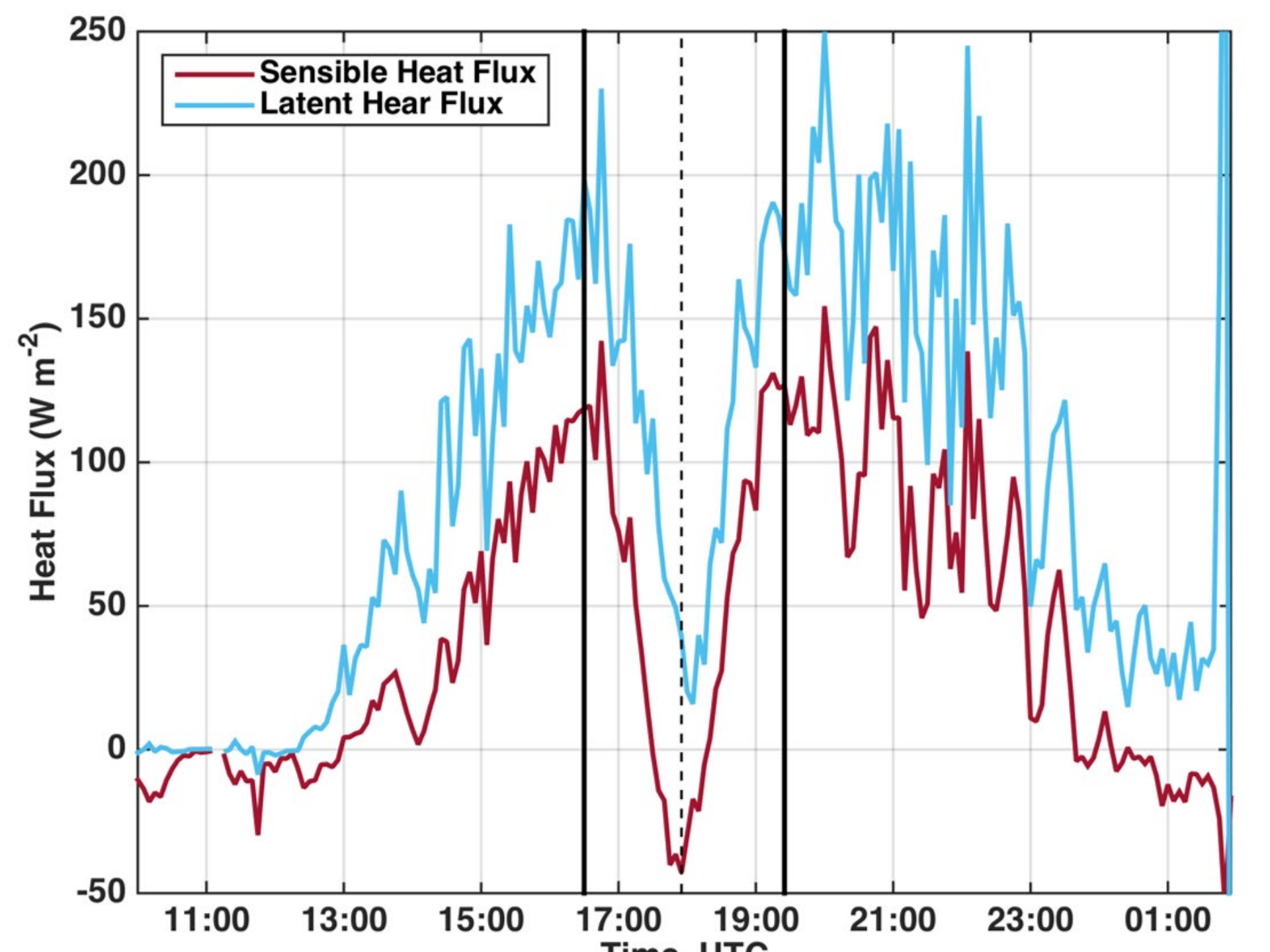


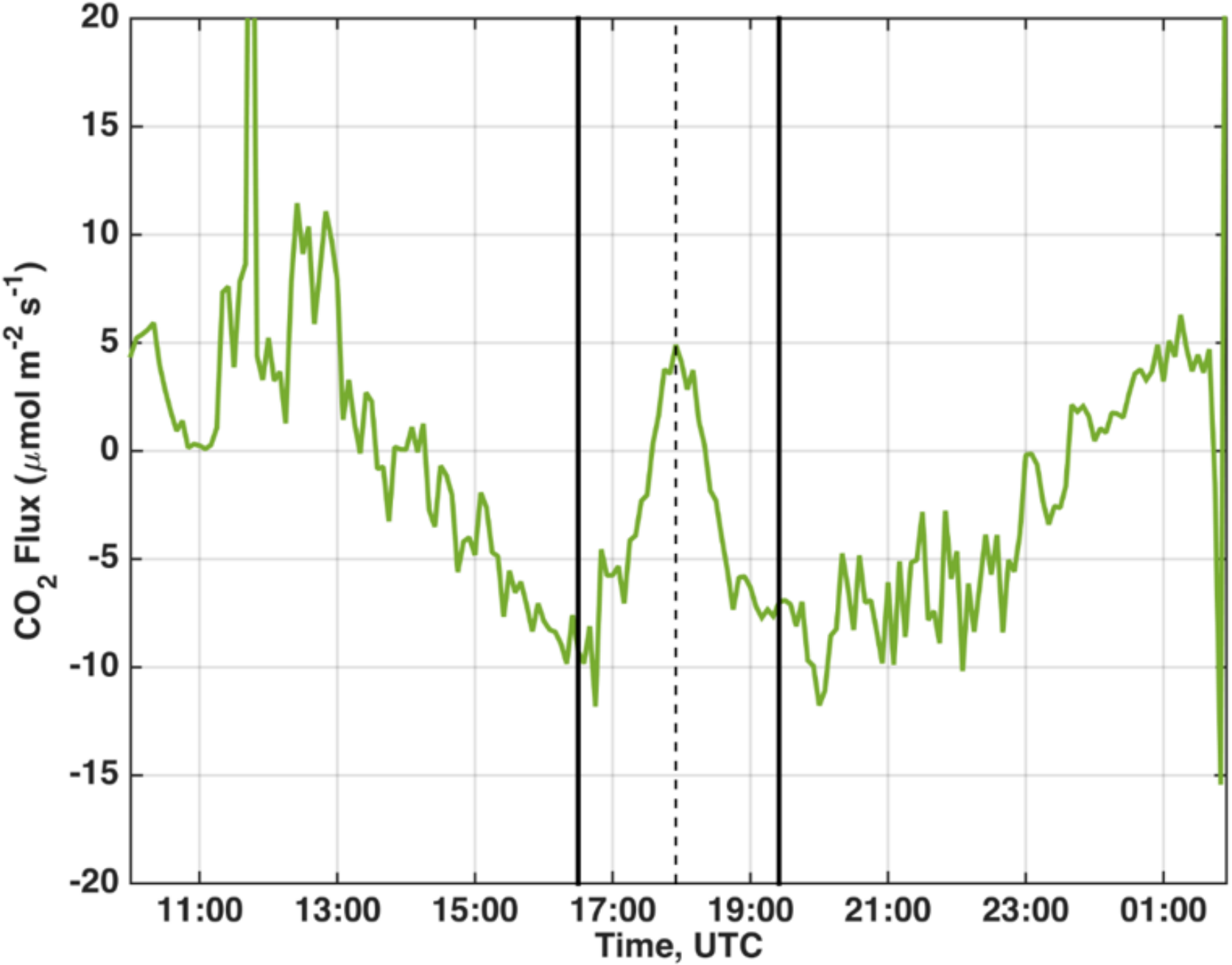
ECLIPSE DEPLOYMENT




1000
800
600
400
200
0
-200
Incoming Solar Radiation (W m-2)
11:00
13:00
15:00
17:00
19:00
21:00
23:00
01:00
Time, UTC
Solar Radiation 8/21
Solar Radiation 8/22

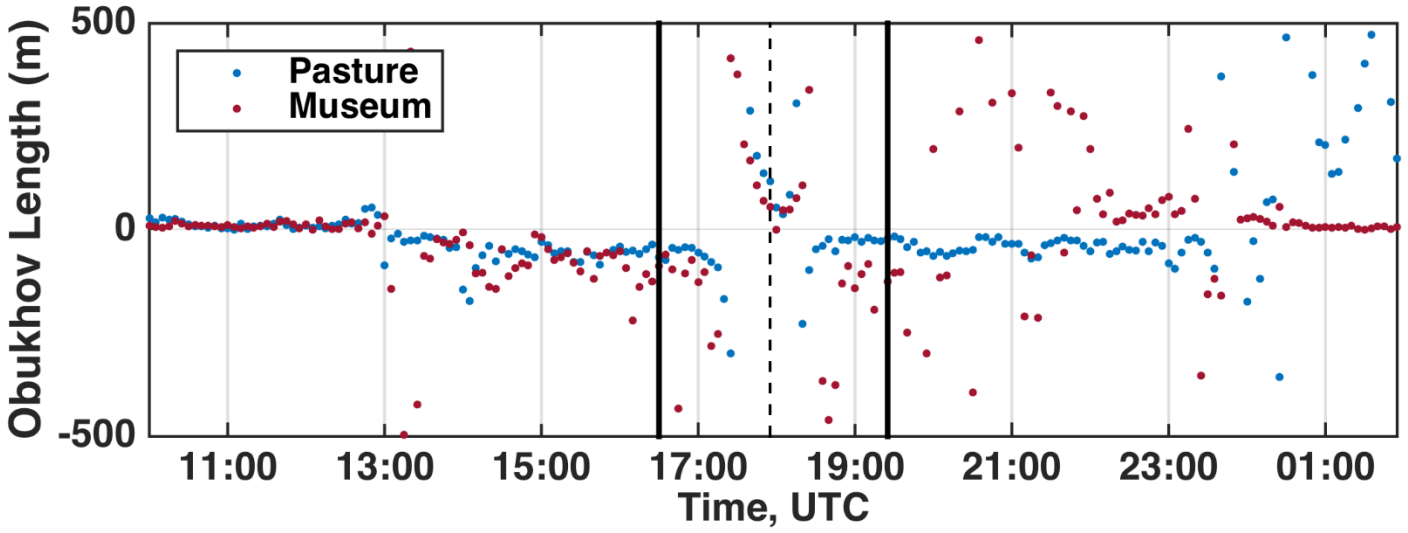

3 m Temp
Skin Temp
9 cm Soil Temp
Temperature (°C)
40
38
36
34
32
30
28
26
24
22
20
18
11:00
13:00
15:00
17:00
19:00
21:00
23:00
01:00
Time, UTC


Sensible Heat Flux
Latent Hear Flux
250
200
150
100
50
0
-50
Heat Flux (W m-2)
11:00
13:00
15:00
17:00
19:00
21:00
23:00
01:00

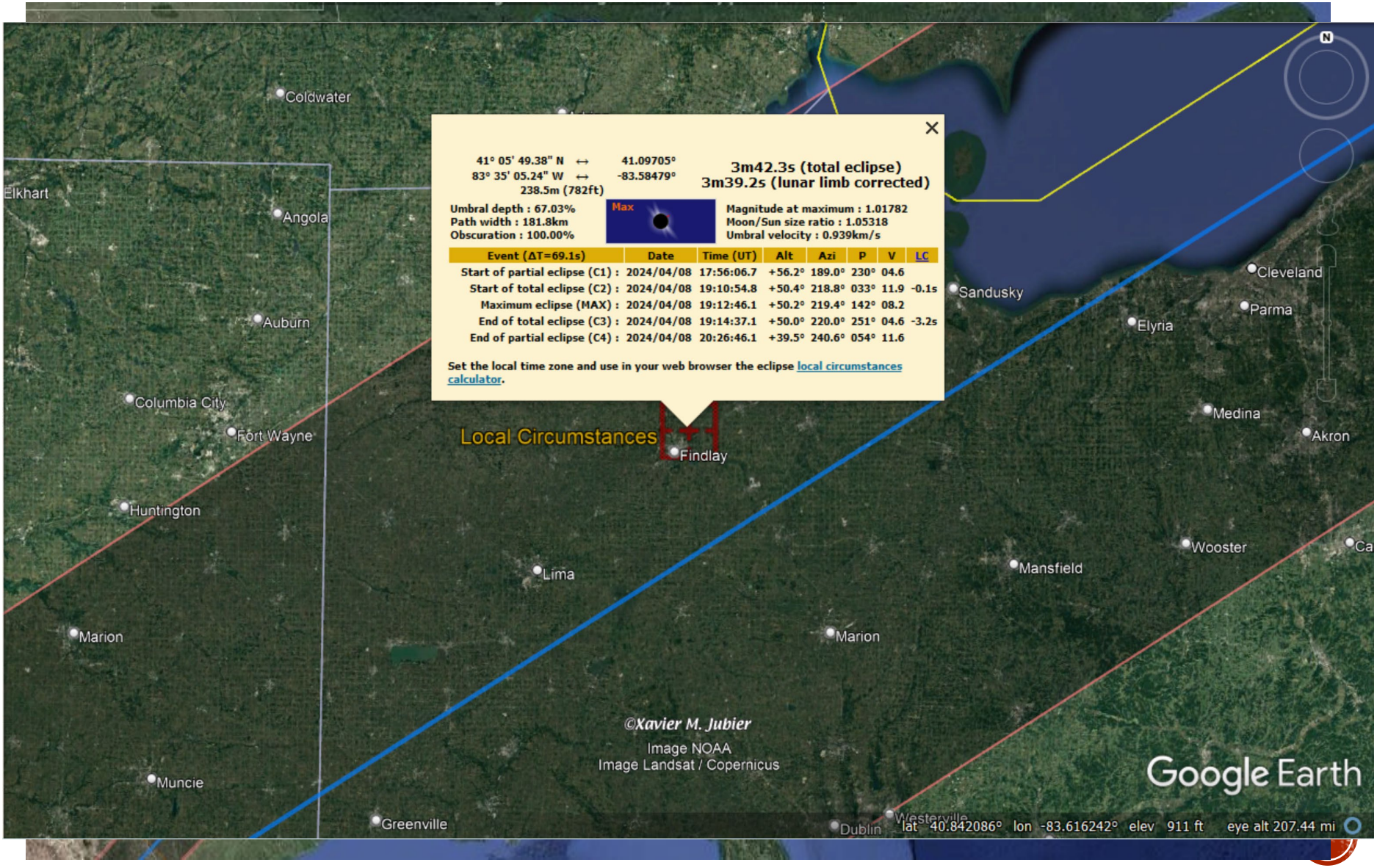

20
15
10
5
0
-5
-10
-15
-20
CO2 Flux (μmol m-2 s-1)
11:00
13:00
15:00
17:00
19:00
21:00
23:00
01:00
Time, UTC

21 AUGUST 2017 GREAT AMERICAN ECLIPSE

- As expected (based on the review of previous literature), eclipse totality corresponded to a brief period of atmospheric stability.



8 APRIL 2024...


41° 05' 49.38" N ↔ 41.09705°
83° 35' 05.24" W ↔ -83.58479°
238.5m (782ft)
3m42.3s (total eclipse)
3m39.2s (lunar limb corrected)
Umbral depth : 67.03%
Path width : 181.8km
Obscuration : 100.00%
Max
Magnitude at maximum : 1.01782
Moon/Sun size ratio : 1.05318
Umbral velocity : 0.939km/s
Event (ΔT=69.1s) | Date | Time (UT) | Alt | Azi | P | V | LC
Start of partial eclipse (C1) : 2024/04/08 17:56:06.7 +56.2° 189.0° 230° 04.6
Start of total eclipse (C2) : 2024/04/08 19:10:54.8 +50.4° 218.8° 033° 11.9 -0.1s
Maximum eclipse (MAX) : 2024/04/08 19:12:46.1 +50.2° 219.4° 142° 08.2
End of total eclipse (C3) : 2024/04/08 19:14:37.1 +50.0° 220.0° 251° 04.6 -3.2s
End of partial eclipse (C4) : 2024/04/08 20:26:46.1 +39.5° 240.6° 054° 11.6
Set the local time zone and use in your web browser the eclipse local circumstances calculator.
Local Circumstances
Coldwater
Elkhart
Angola
Auburn
Columbia City
Fort Wayne
Huntington
Marion
Muncie
Greenville
Lima
Findlay
Sandusky
Cleveland
Parma
Elyria
Medina
Akron
Wooster
Mansfield
Marion
Dublin
Westerville
©Xavier M. Jubier
Image NOAA
Image Landsat / Copernicus
Google Earth
lat 40.842086° lon -83.616242° elev 911 ft eye alt 207.44 mi