ATM505 Module 1: Atmospheric Boundary Layer (ABL) (Or the Planetary Boundary Layer—PBL)

Lecture Schedule

1. Monday, 23 January: Introduction to ABL (what's it all about?)
2. Wednesday, 25 January: Atmospheric Turbulence (big whorls and little whorls)
3. Monday, 30 January: Similarity Scaling (really all about stability)
4. Wednesday, 1 February: Parameterization of Surface Fluxes (what goes into those models)
5. Monday, 6 February: Marine ABL (offshore wind energy, air-sea interactions)

Homework #1: assigned 1/30; due 2/6; returned 2/13

Content: https://www.atmos.albany.edu/daes/atmclasses/atm505/content_2023/BOUNDARY_LAYERS/

Office hours: Mondays, 10 - 11:30 AM or when can be otherwise arranged.

Lecture 1: Introduction to Atmospheric Boundary Layer (ABL)

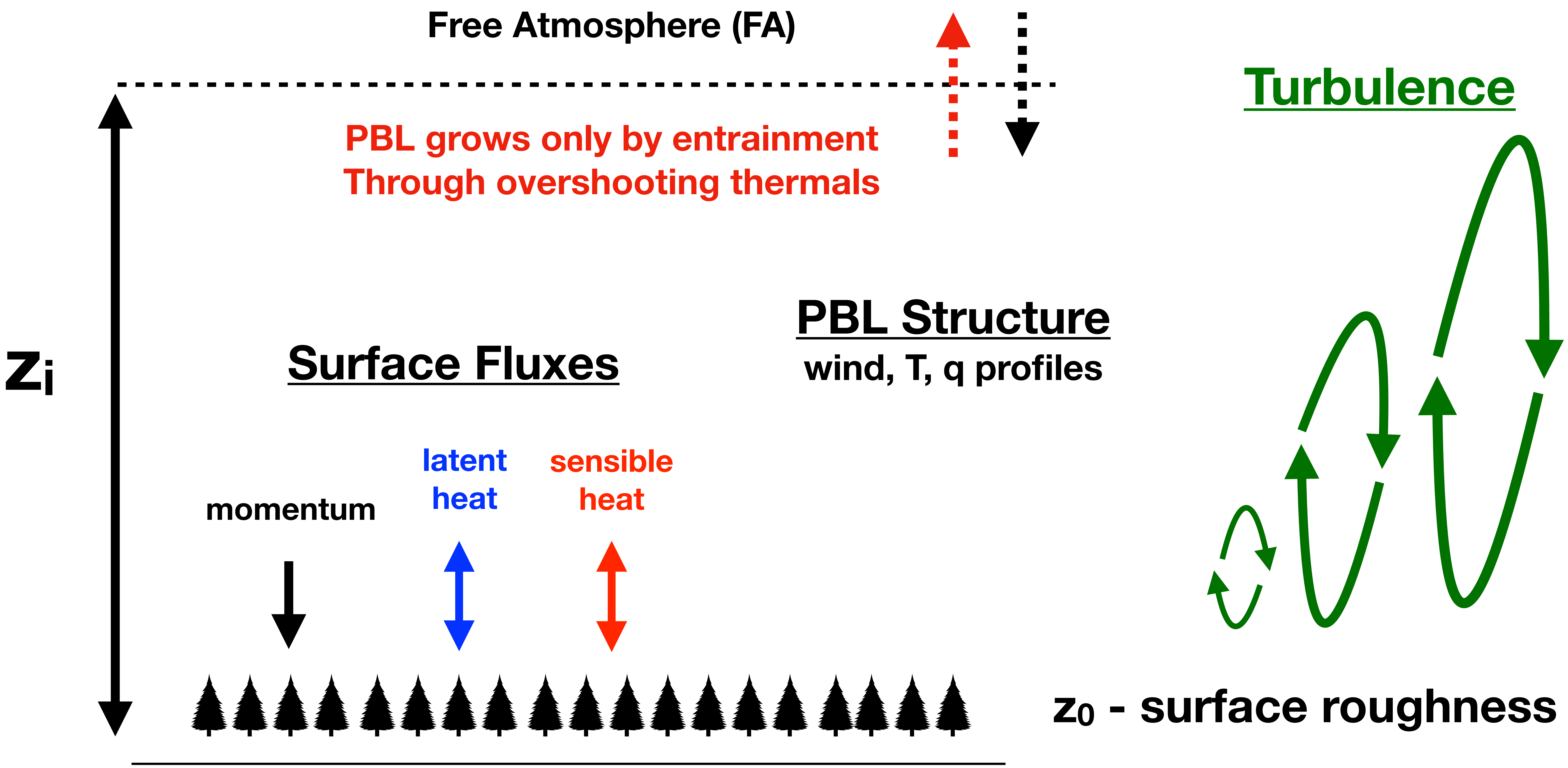
Announcements

- reading: ch 1, peruse ch 2 Stull (1988) - Boundary Layer Meteorology

Today's Lecture

1. Definition of ABL
2. Coupling between ABL and surface
3. Approach to understanding ABL
4. Observing the ABL
5. Introduction to (and using) the New York State Mesonet

Simple Schematic of the ABL (PBL)



horizontally homogeneous

Atmospheric Boundary Layer

The troposphere can be separated into the free atmosphere (above) and the **boundary layer**, which is:

- directly influenced by earth surface
- order 1 km vertical scale (but ranges from 1 - 3 km eastern US up to 5+ km over deserts)
- responds on short (~1 hr) timescales
- typically turbulent flow

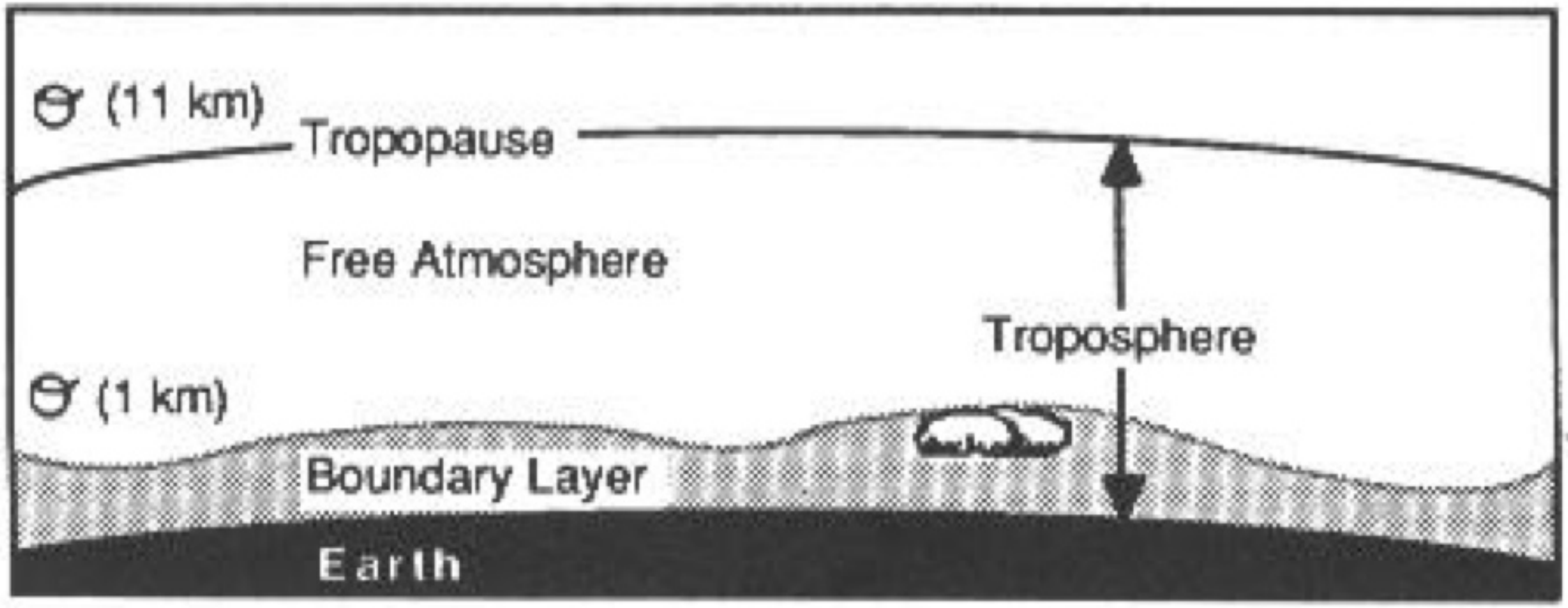
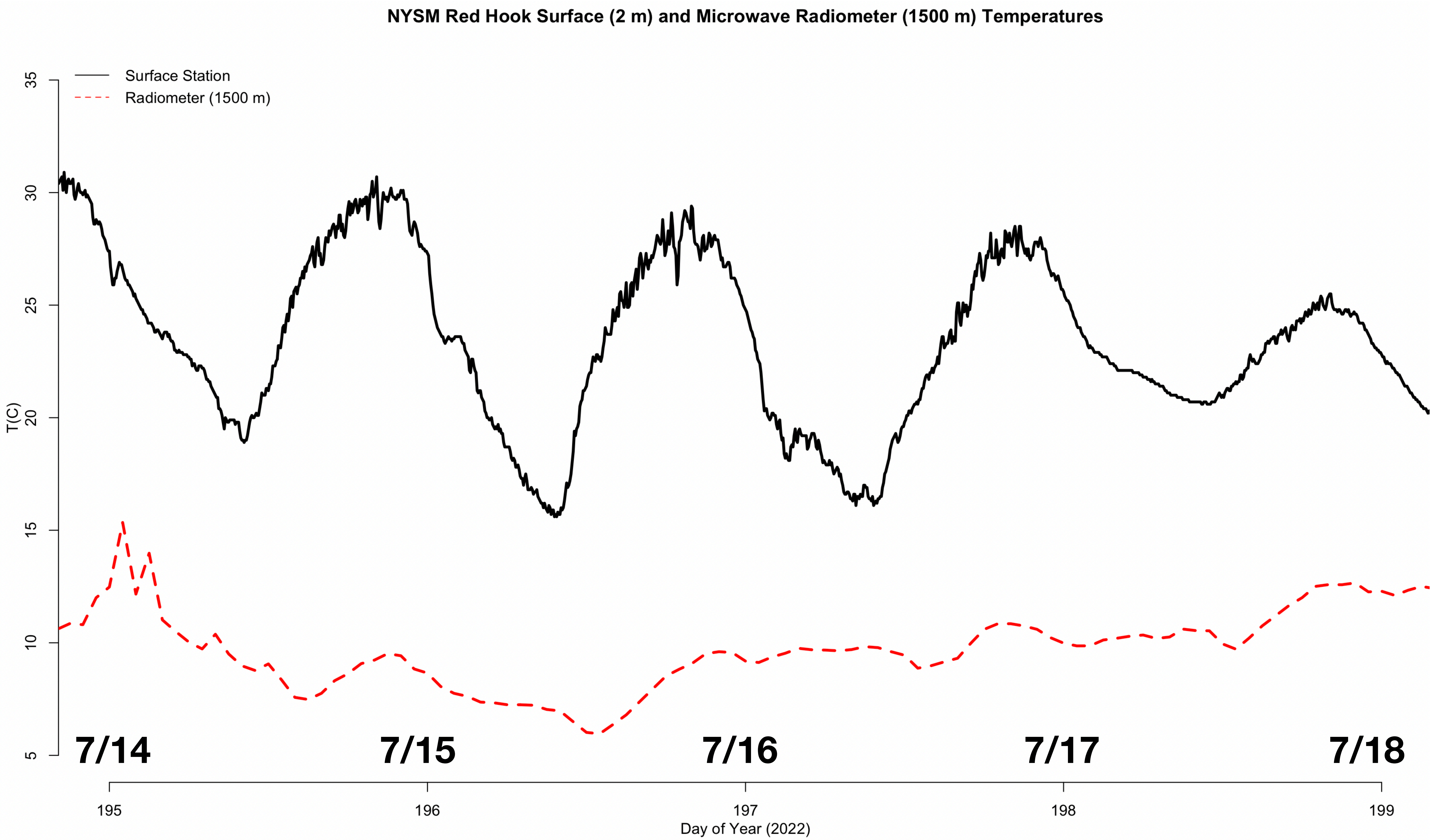


Fig. 1.1 The troposphere can be divided into two parts: a boundary layer (shaded) near the surface and the free atmosphere above it.

Stull 1998

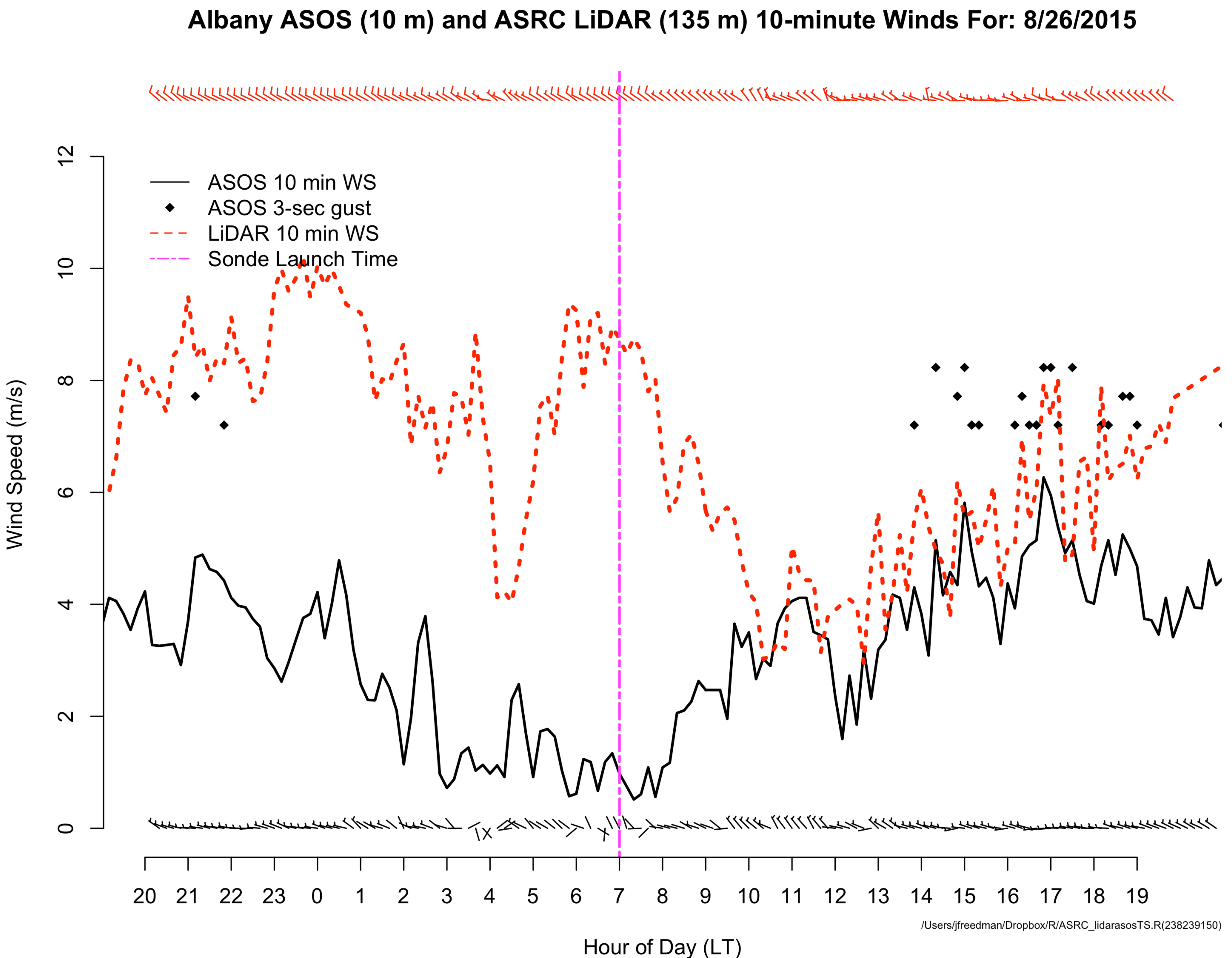
Boundary layer vs free atmosphere response to surface forcing: Temperature



- surface temperatures warmer (15C during daytime, 5C at night)
- surface - strong diurnal variations not seen above ABL
- solar heating of the surface drives upward heat flux lead to afternoon peaks

Stull 1998

Surface layer vs atmosphere above and response to surface forcing



ASRC Leosphere 100S Scanning Lidar

Diurnal cycle of the Atmospheric Boundary Layer (ABL)

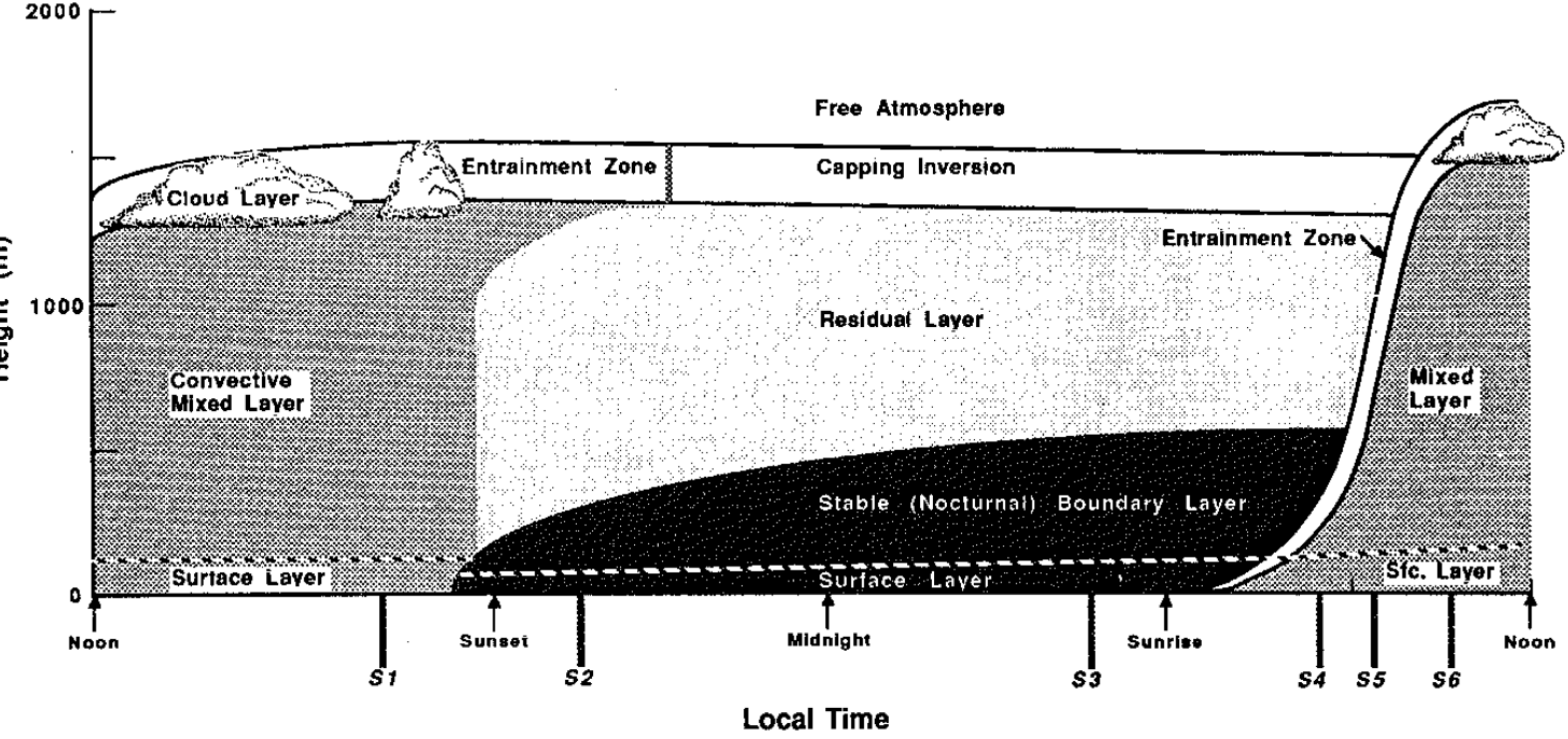


Figure from Still (1988) Chapter 1

Diurnal cycle of the Atmospheric Boundary Layer (ABL)

Dealing mostly with the fair weather ("boring", quiescent) atmospheric boundary layer—which happens ⅔ of the time around here over land [but we'll touch upon other boundary layers—over the ocean].

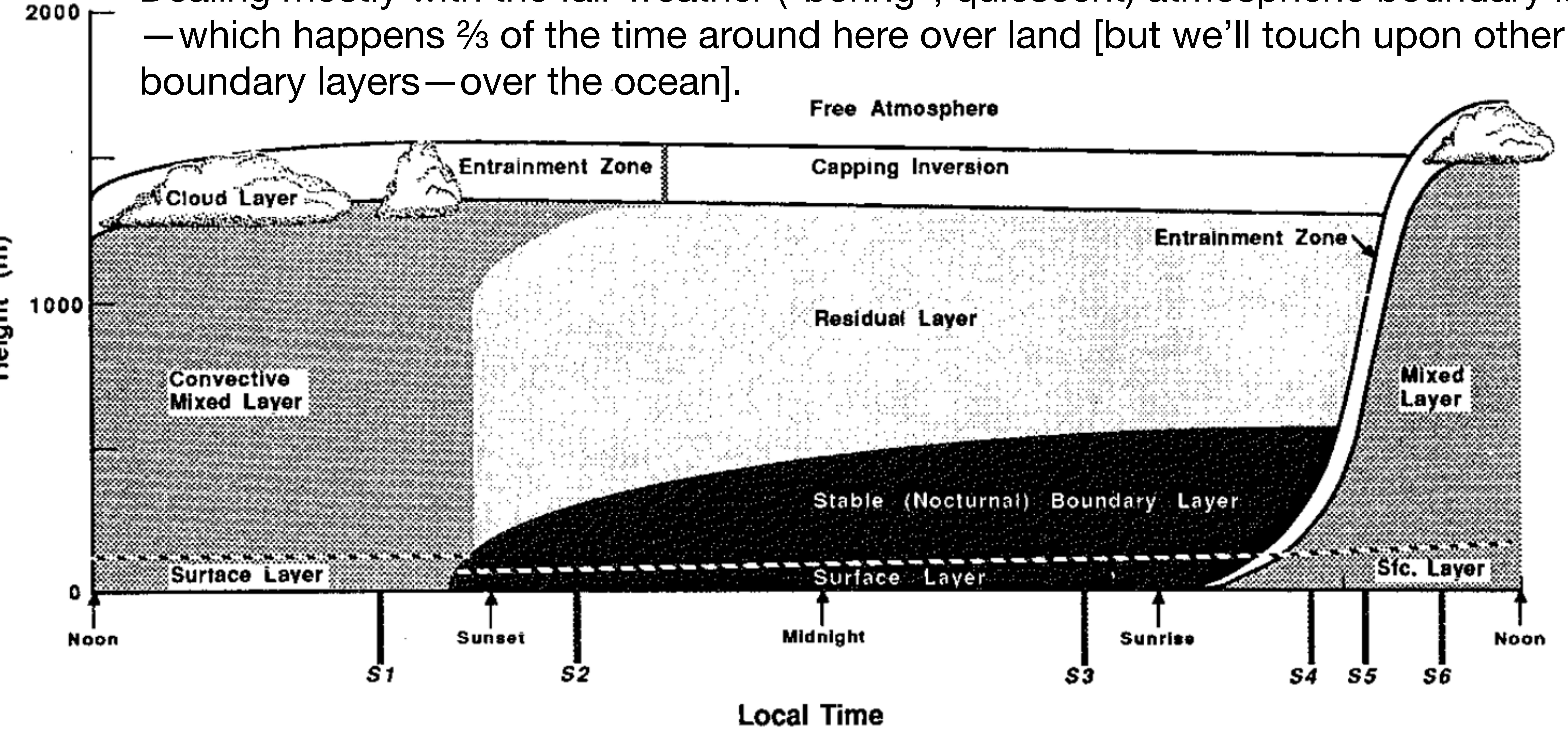
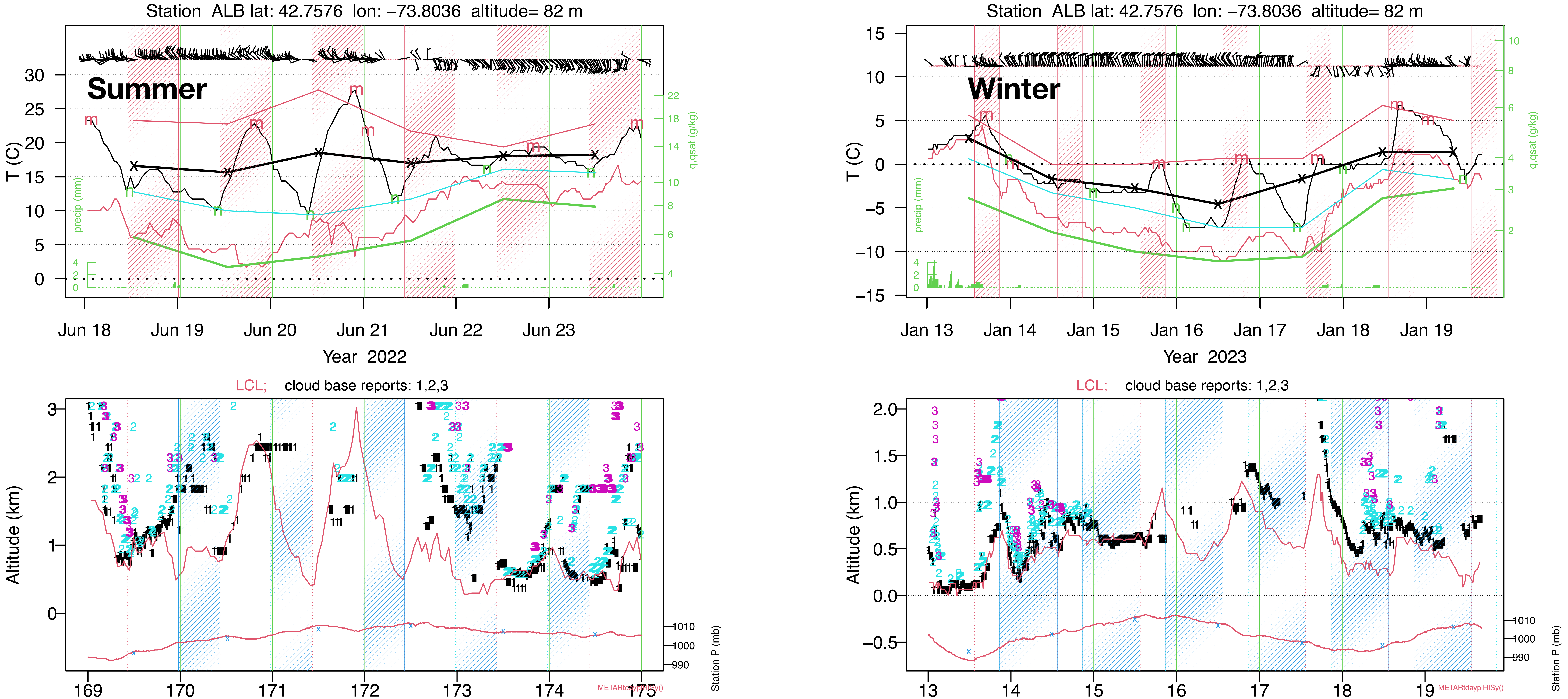
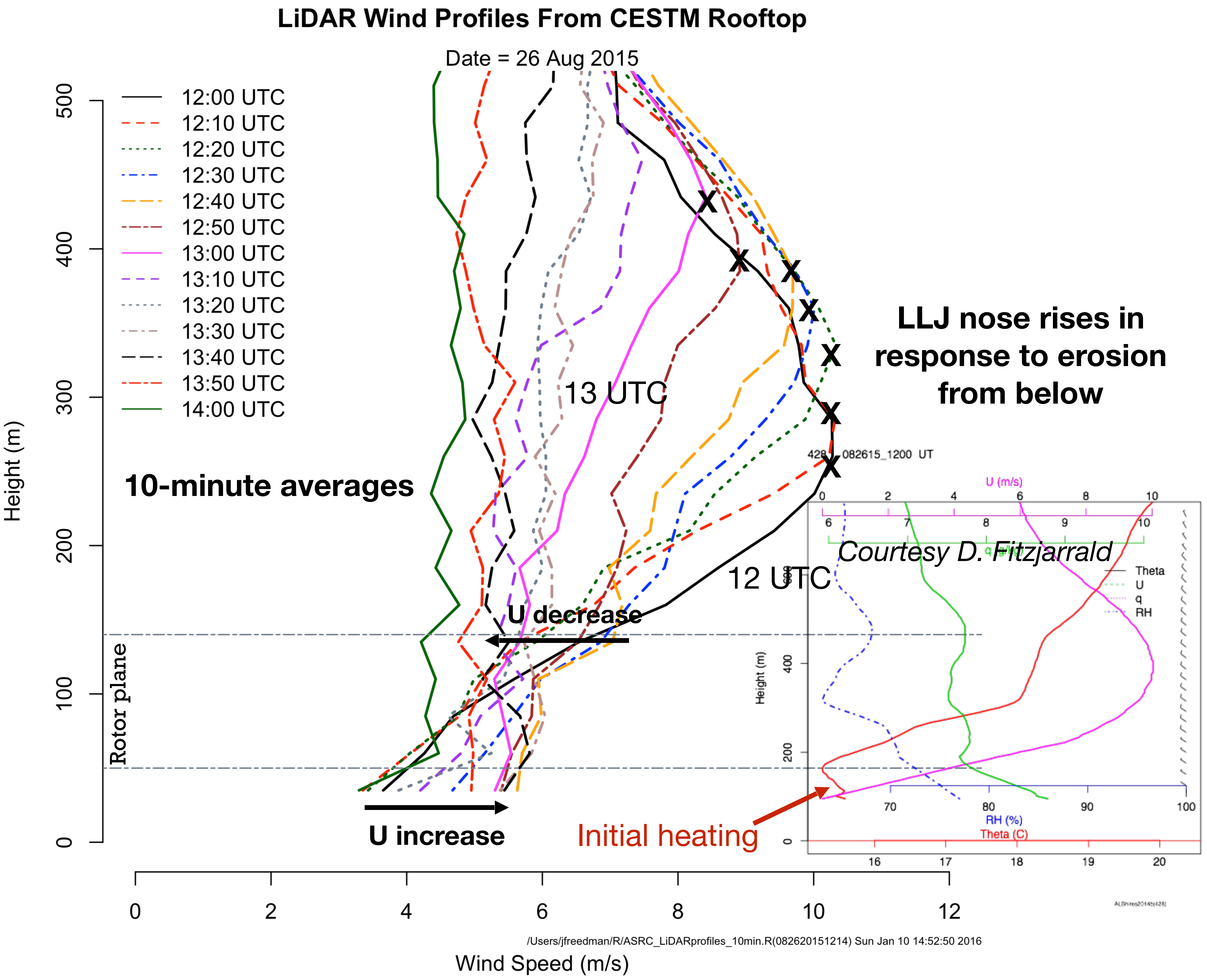


Figure from Still (1988) Chapter 1

All relates to season at our latitude and “continentality”



Boundary layer wind profile response to surface heating—later we'll link to fluxes

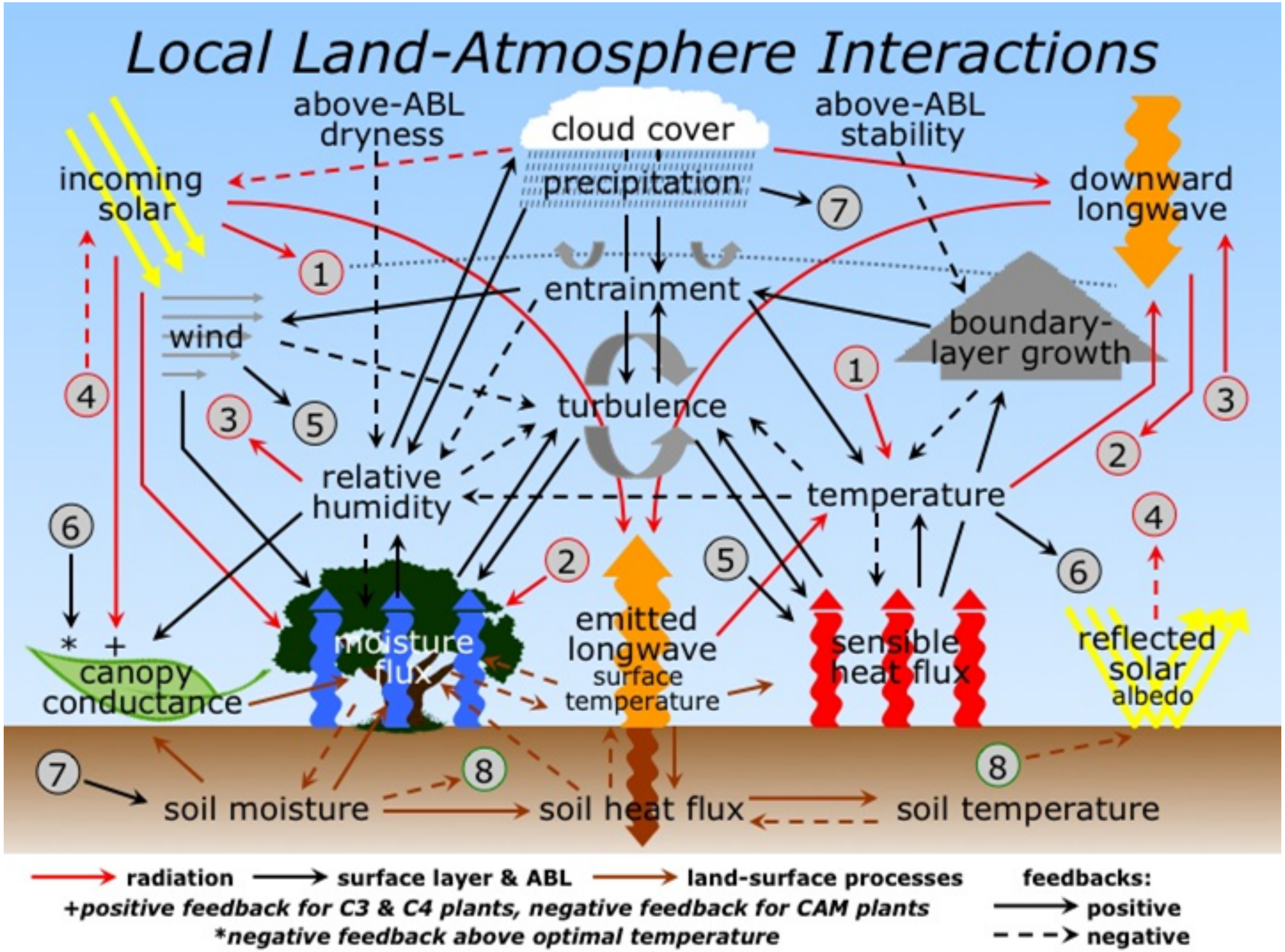


Comparison of boundary layer and free atmosphere

Table 1-1. Comparison of boundary layer and free atmosphere characteristics.

Property	Boundary Layer	Free Atmosphere
Turbulence	• Almost continuously turbulent over its whole depth.	• Turbulence in convective clouds, and sporadic CAT in thin layers of large horizontal extent.
Friction	• Strong drag against the earth's surface. Large energy dissipation.	• Small viscous dissipation.
Dispersion	• Rapid turbulent mixing in the vertical and horizontal.	• Small molecular diffusion. Often rapid horizontal transport by mean wind.
Winds	• Near logarithmic wind speed profile in the surface layer. Subgeostrophic, cross-isobaric flow common.	• Winds nearly geostrophic.
Vertical Transport	• Turbulence dominates.	• Mean wind and cumulus-scale dominate
Thickness	• Varies between 100 m to 3 km in time and space. Diurnal oscillations over land.	• Less variable. 8-18 km. Slow time variations.

Stull 1998



Quite a lot going on here!

We'll touch upon some of this in subsequent lectures.

Think of this in the context of your research: e.g., climate change, storm genesis, air quality, renewable energy, teleconnections, etc.

Image credit: Mike Ek

Air-Sea Interaction

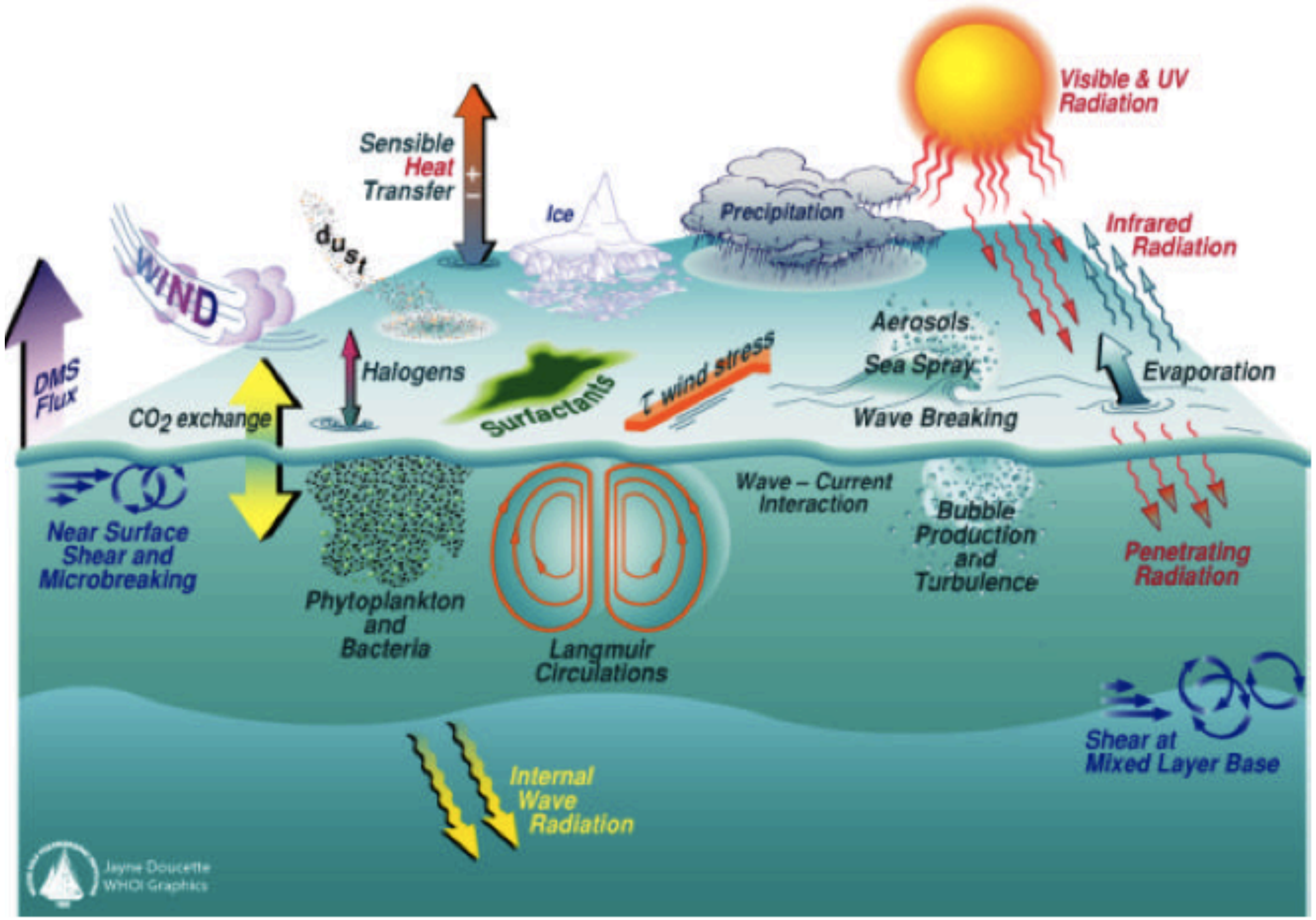
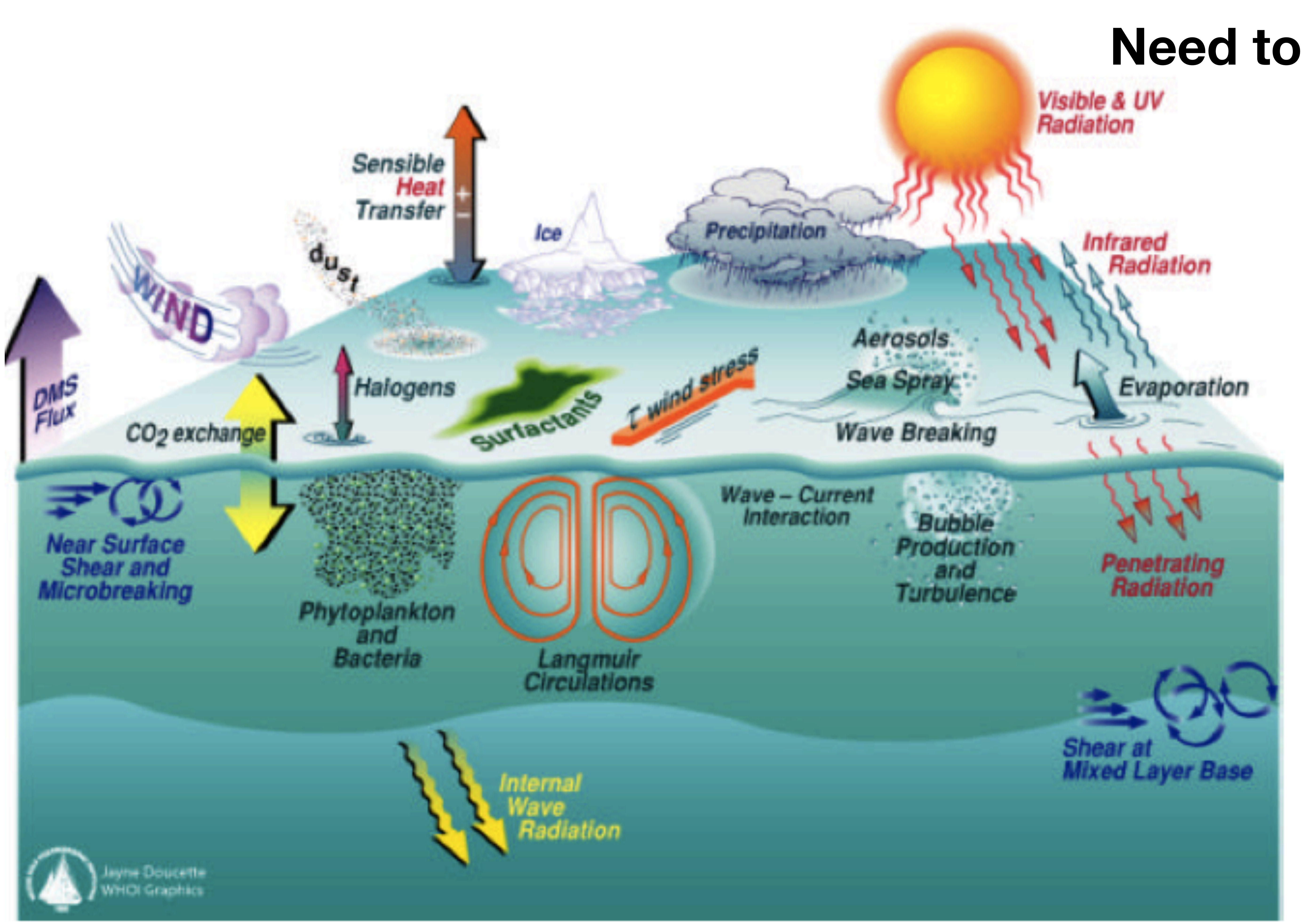


Image credit: SOLAS

Air-Sea Interaction

Need to measure all this!



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Air-Sea Interaction

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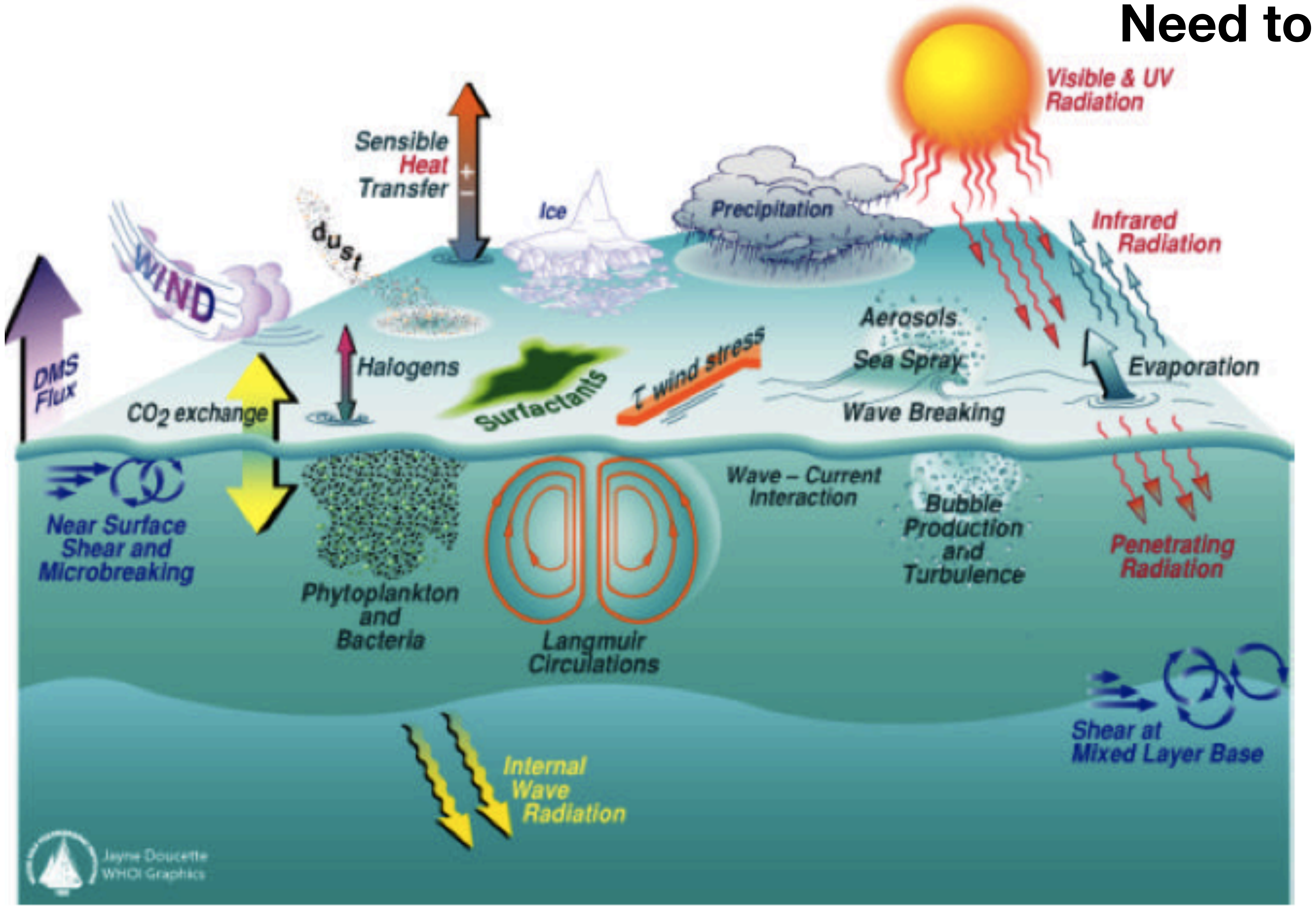


Image credit: SOLAS

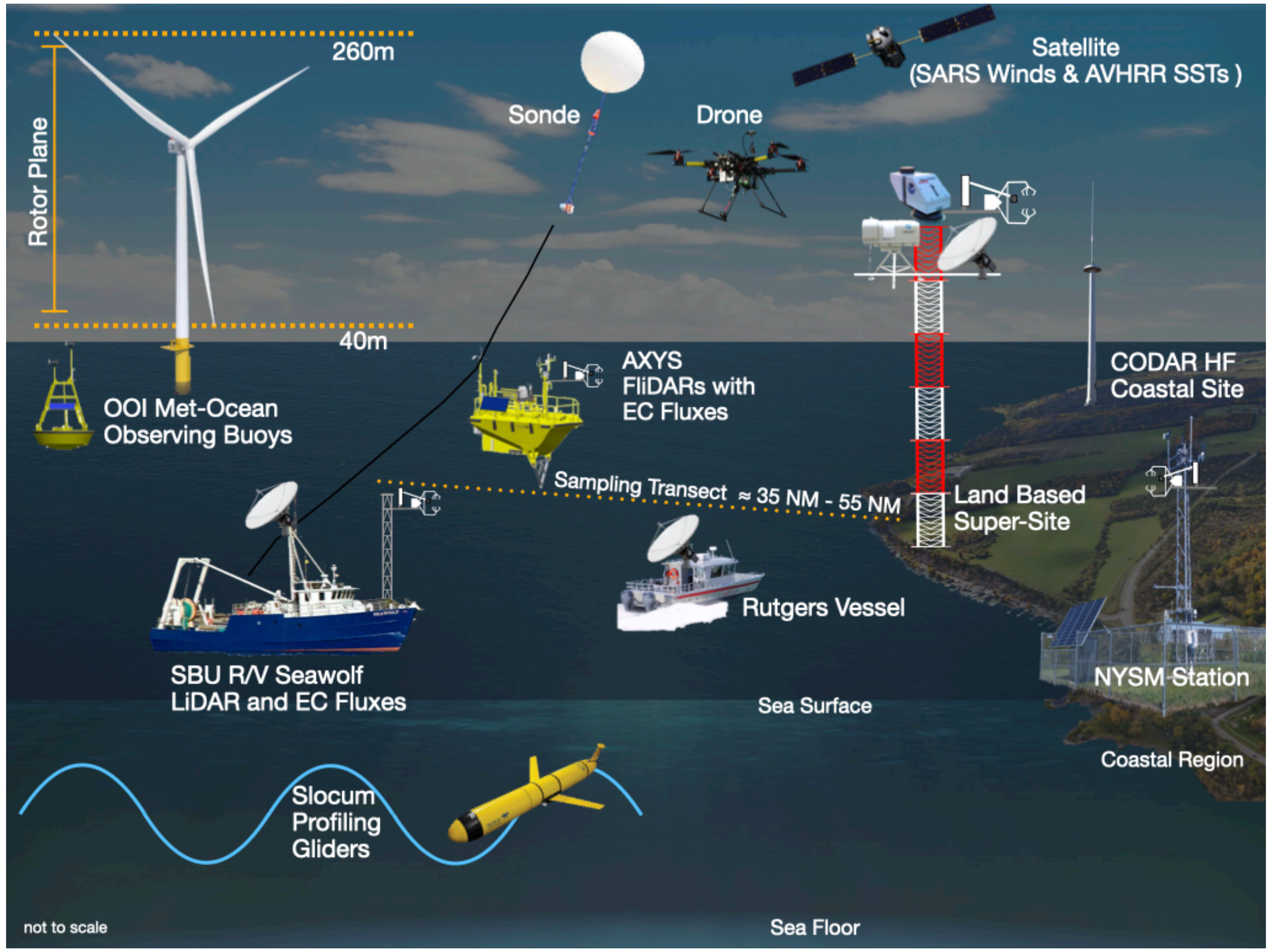
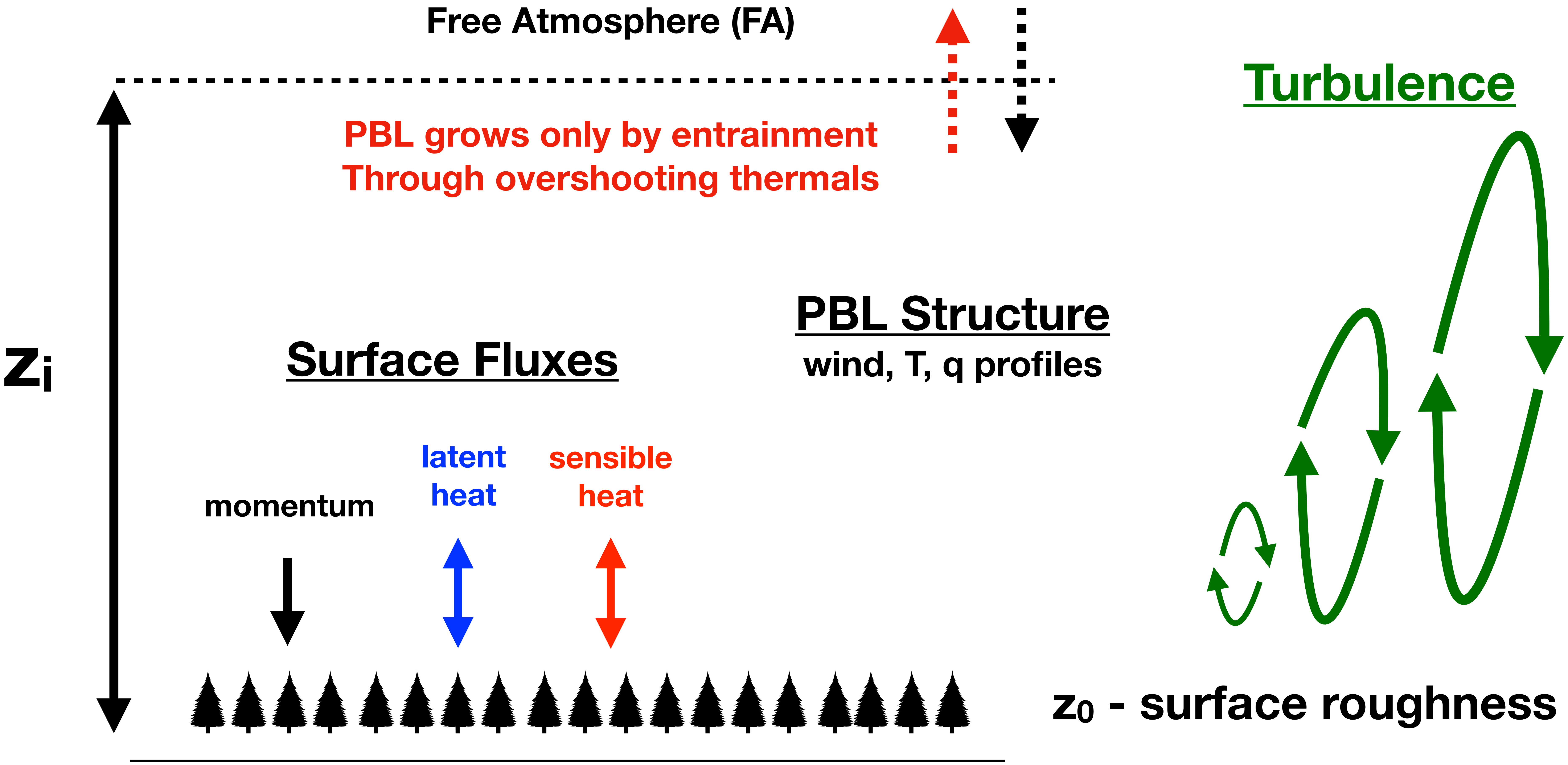


Figure: Elizabeth McCabe

Simple Schematic of the ABL (PBL)



horizontally homogeneous

Diurnal Profile evolution

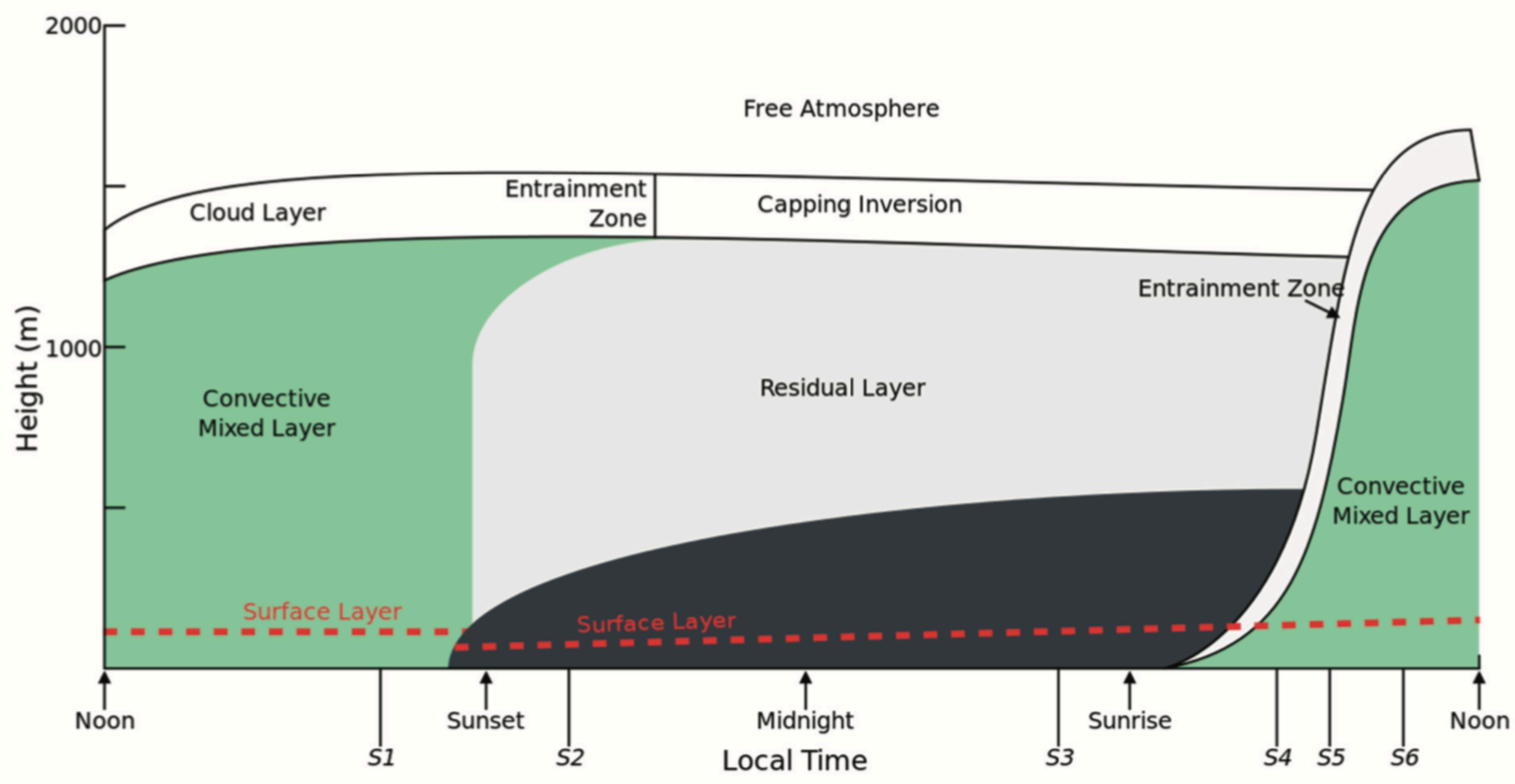
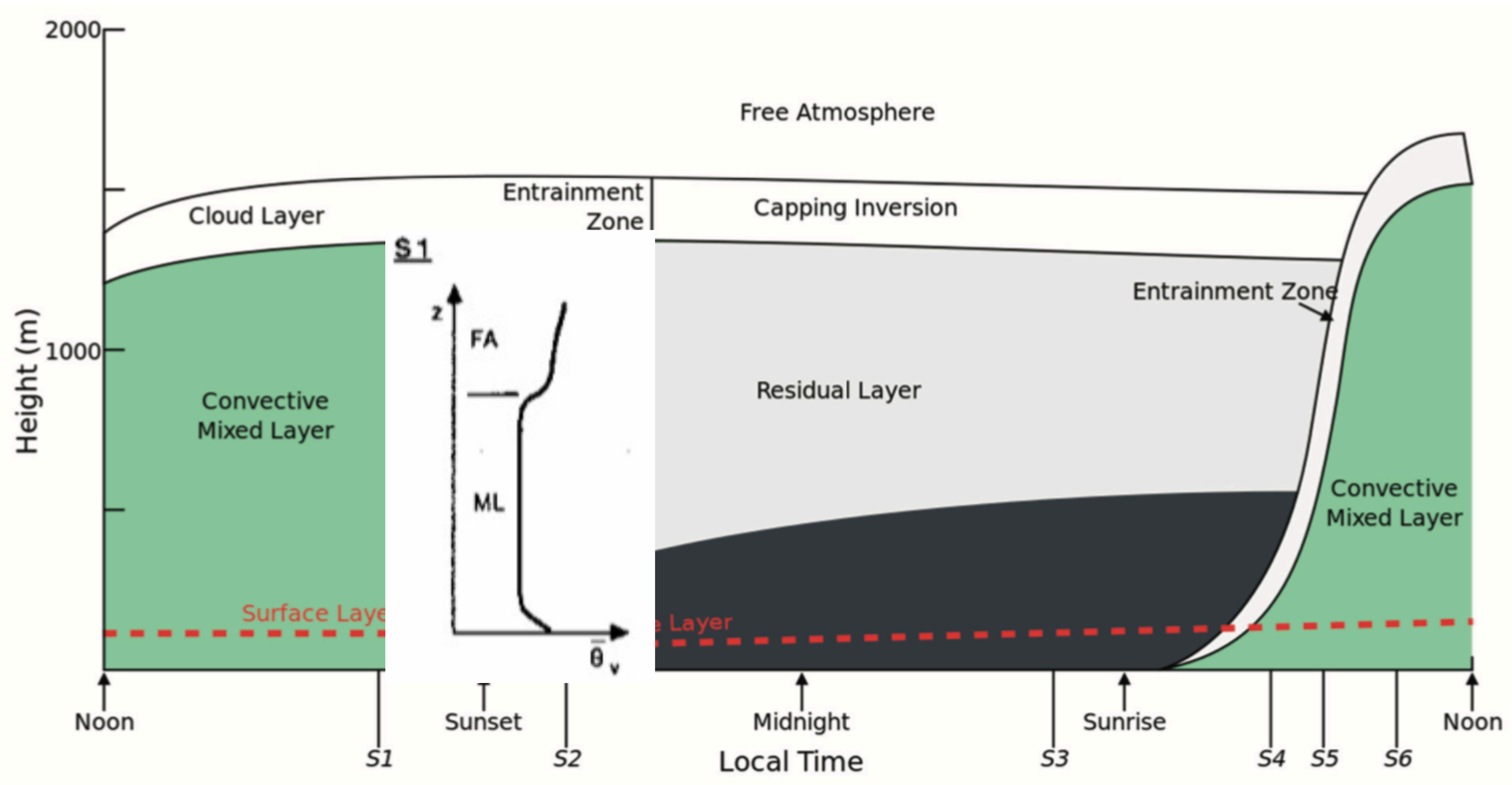


FIGURE 1. Schematic of the structure of the atmospheric boundary layer in high pressure regions over land, showing daily variations. SOURCE: Wikimedia Commons.

Stull 1998

Diurnal Profile evolution



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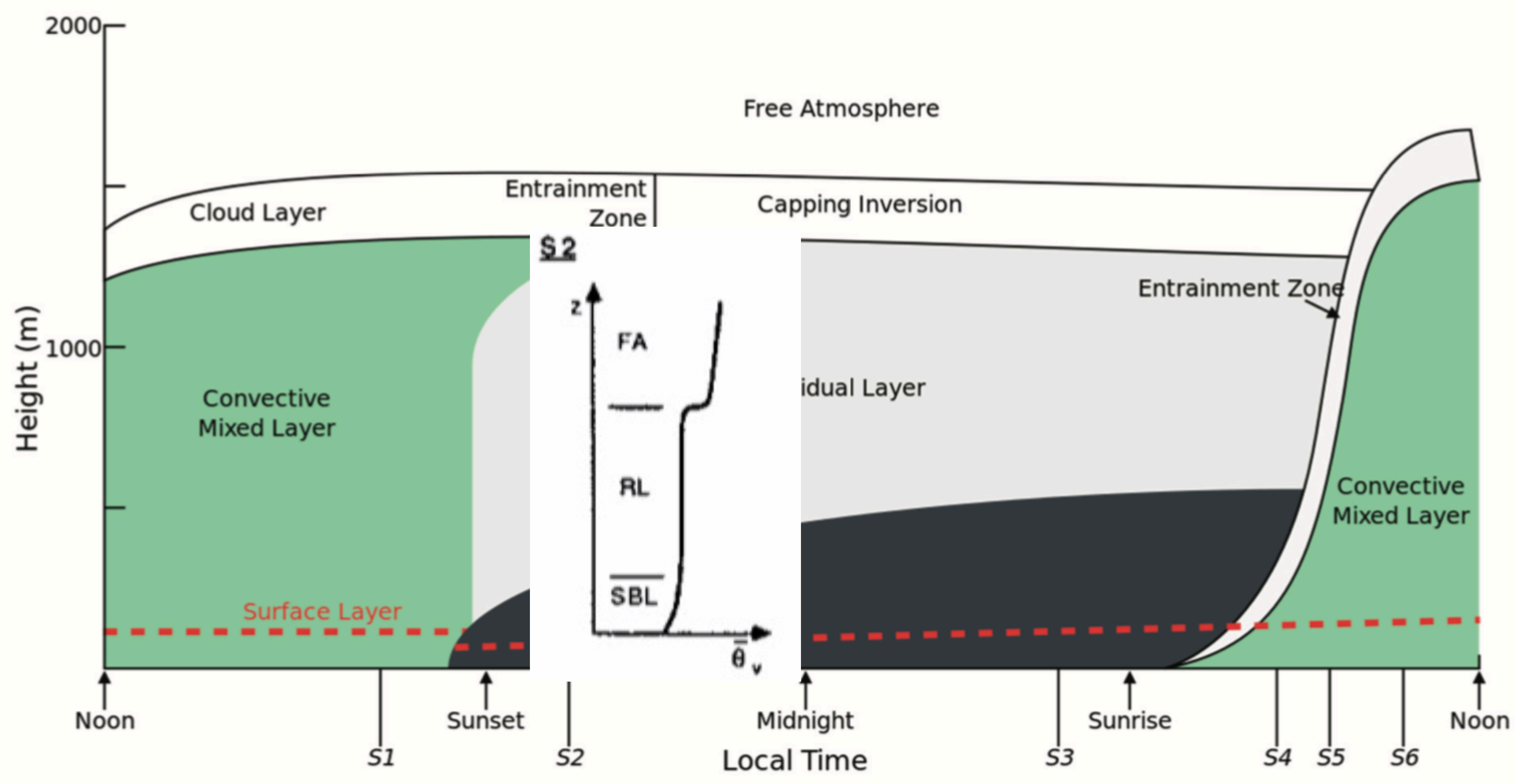
Stull 1998

Diurnal Profile evolution



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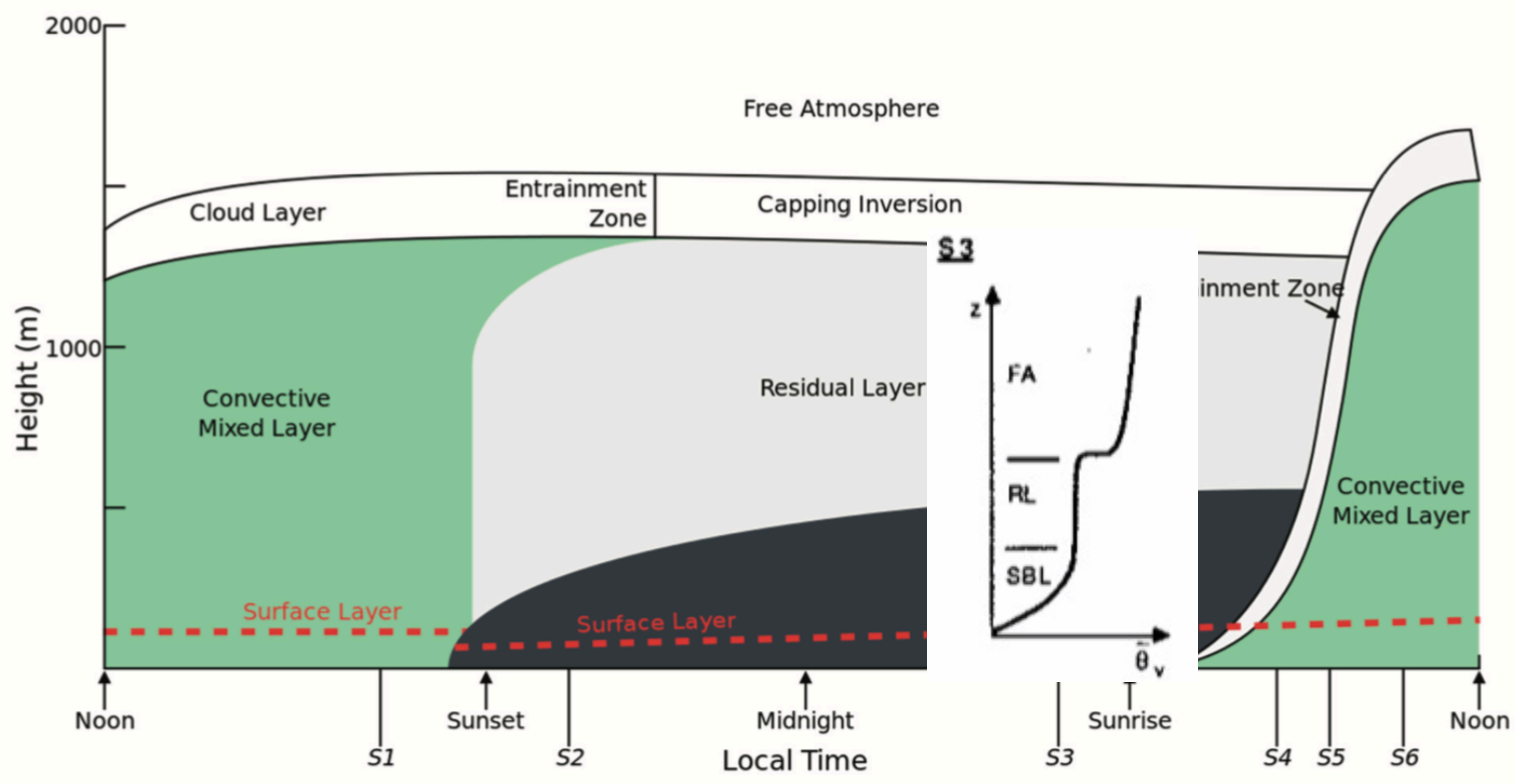

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Stull 1998

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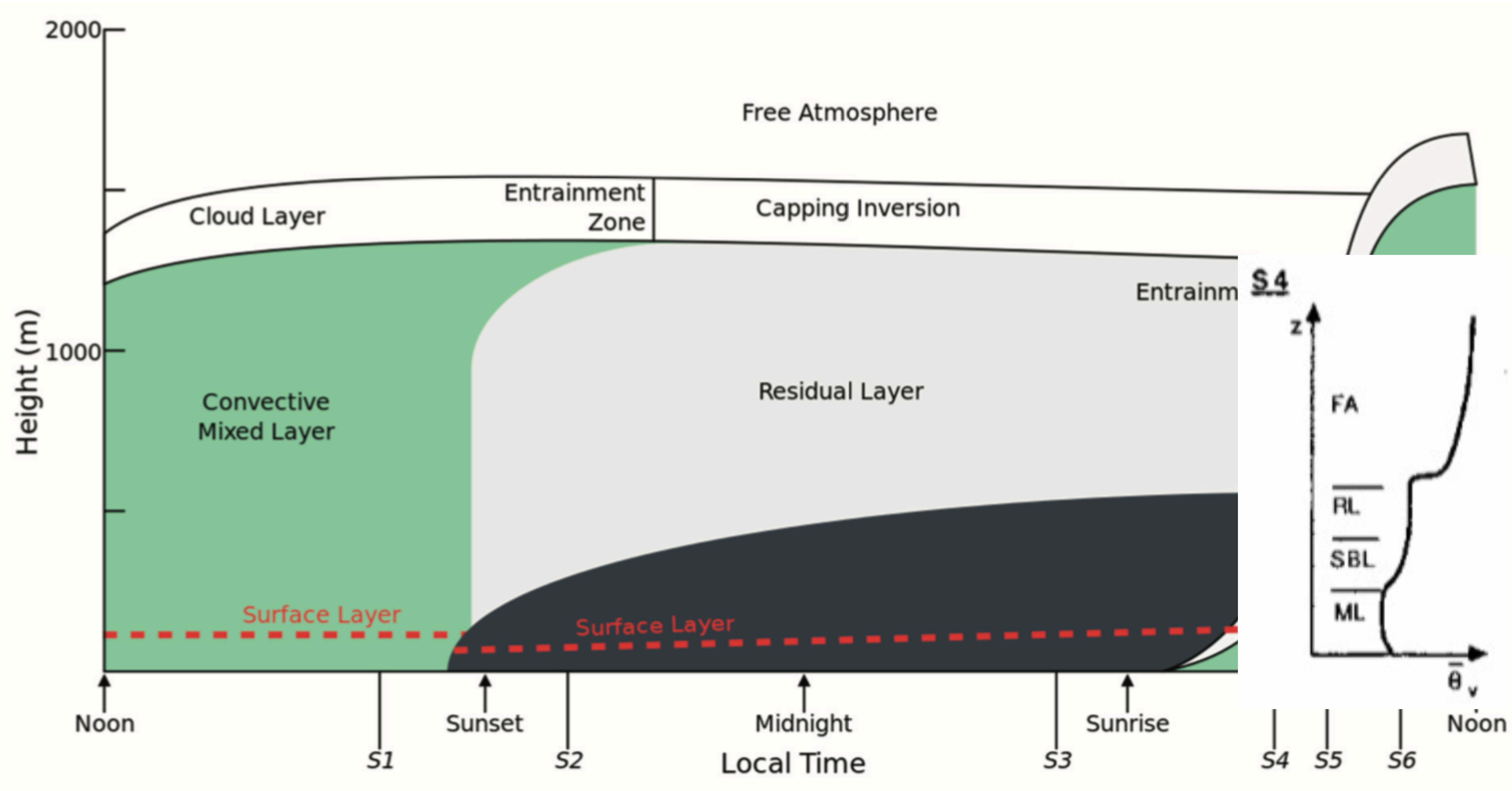

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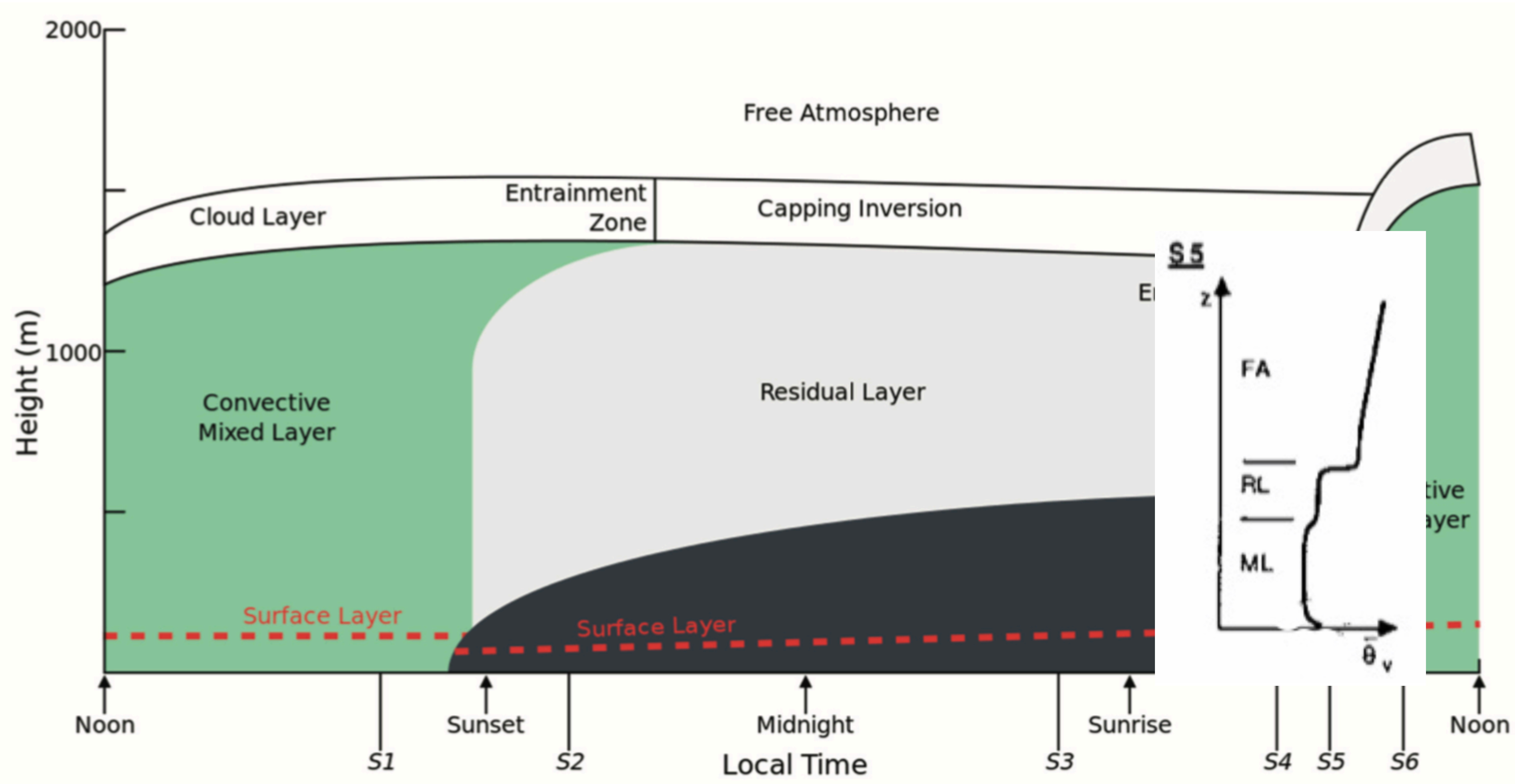
Stull 1998

Diurnal Profile evolution



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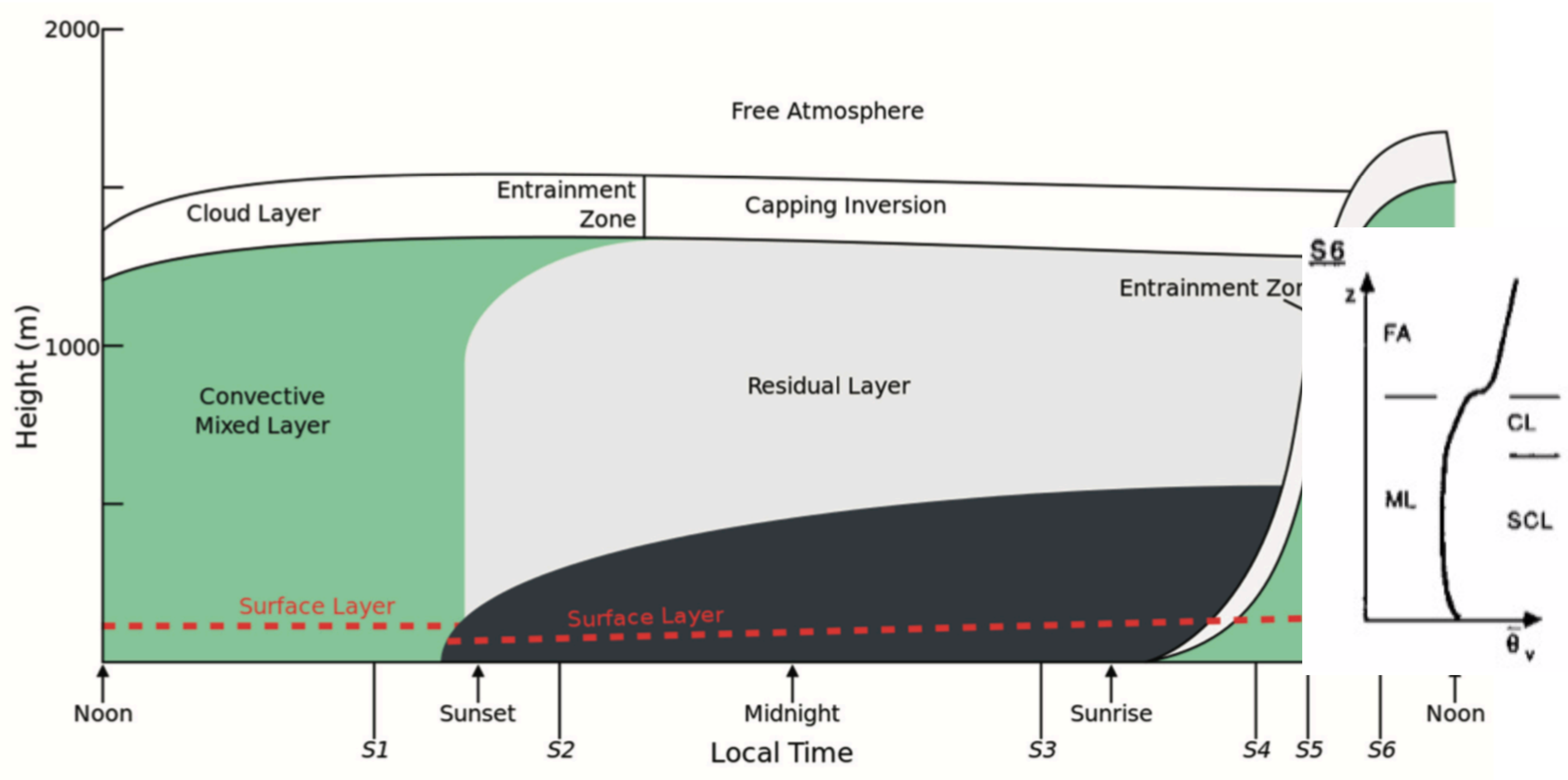
Diurnal Profile evolution



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Stull 1998

Diurnal Profile evolution

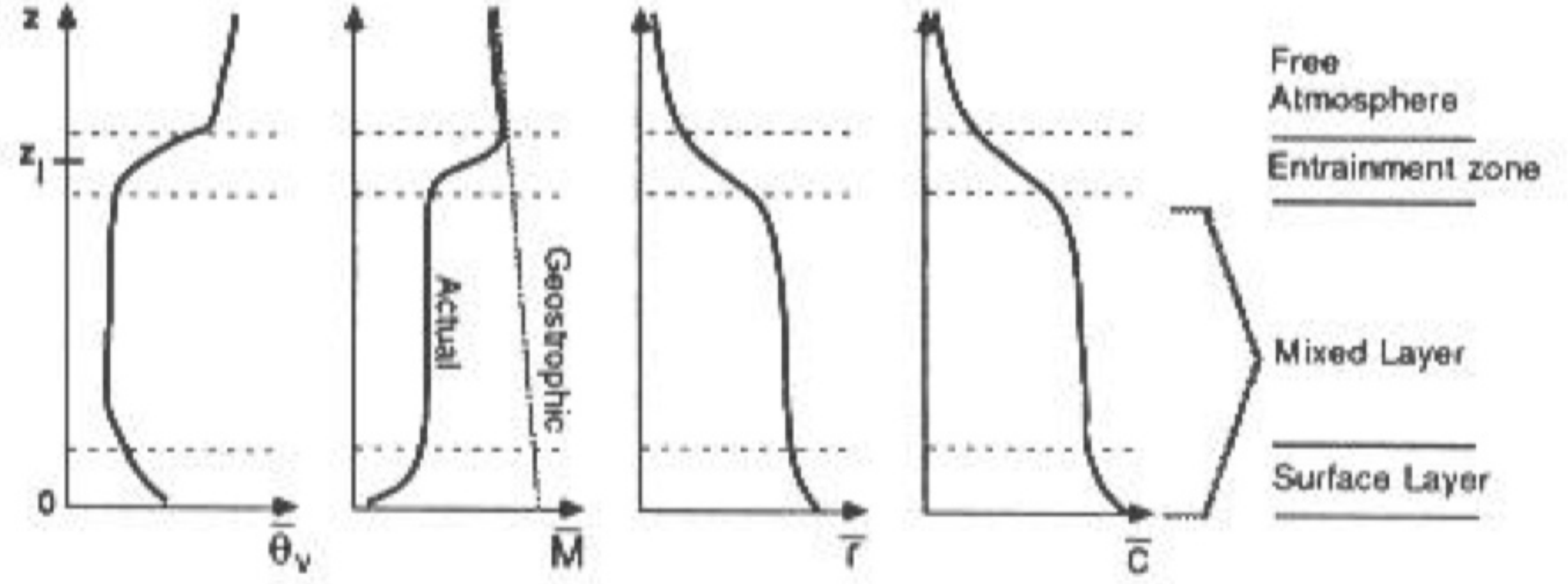
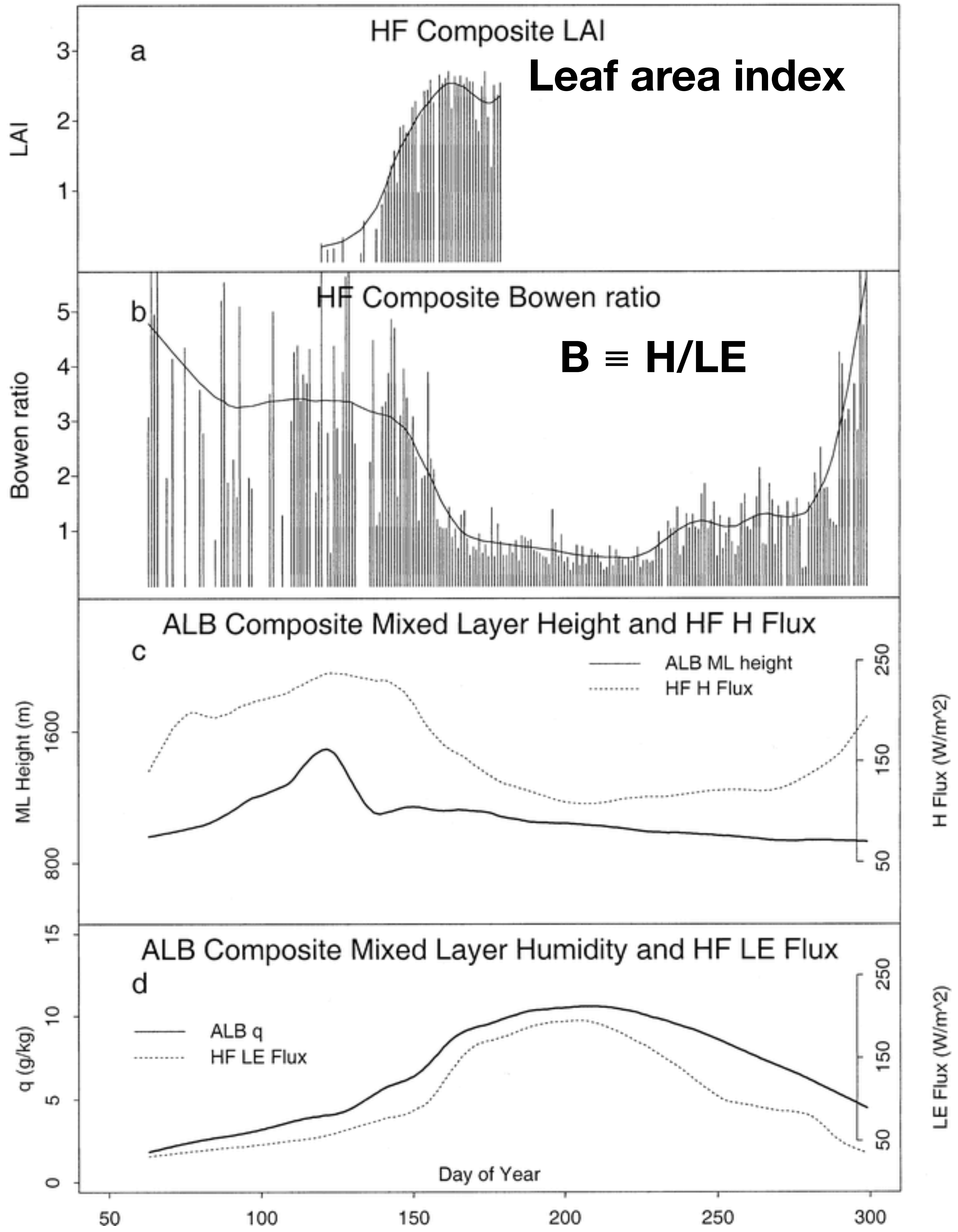


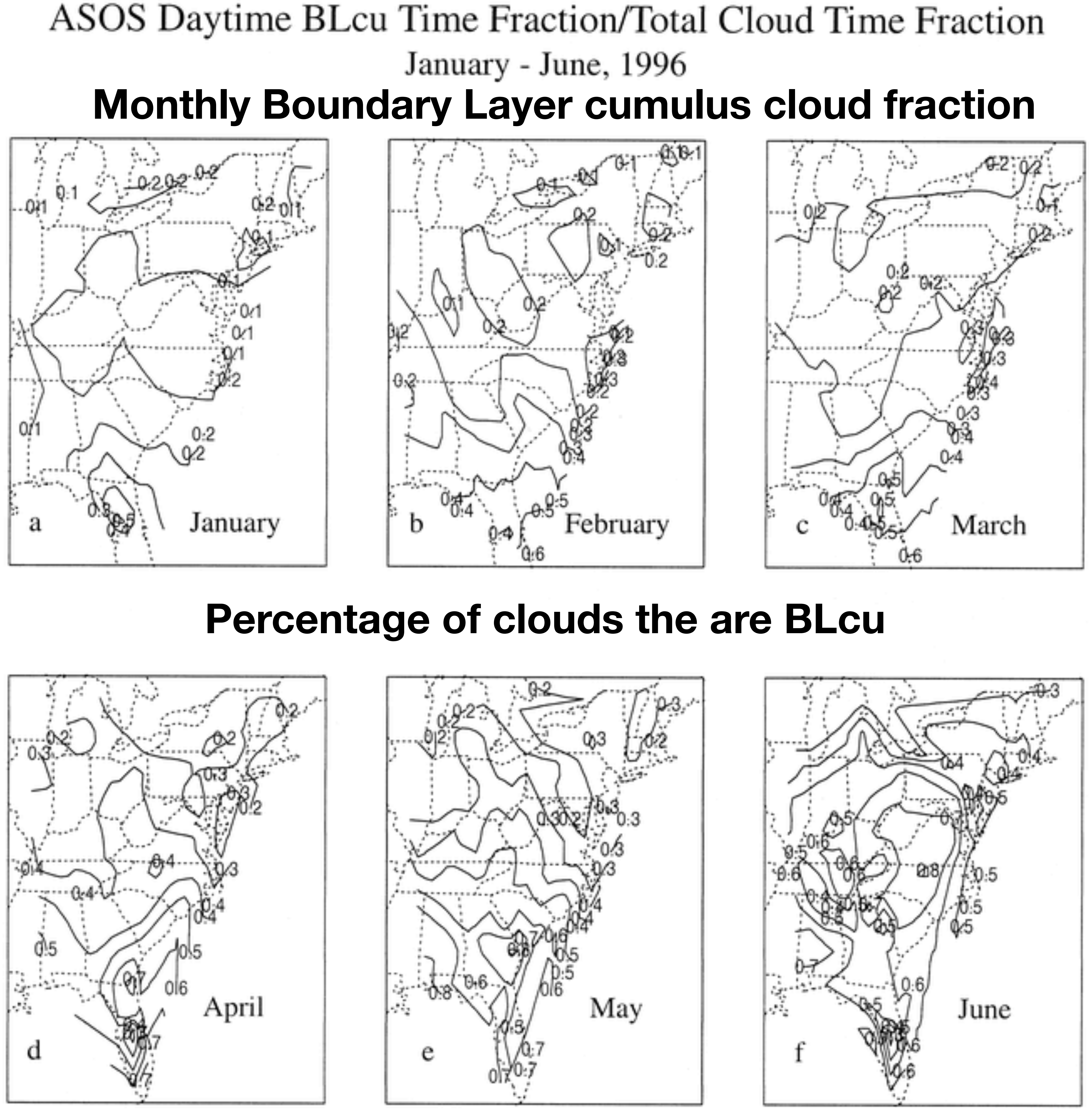
Fig. 1.9 Typical daytime profiles of mean virtual potential temperature $\overline{\theta_v}$, wind speed $\overline{M}$ (where $\overline{M}^2 = \overline{u}^2 + \overline{v}^2$), water vapor mixing ratio $\overline{r}$, and pollutant concentration $\overline{c}$.

Stull 1998

Seasonal aspects of the ABL—eastern US

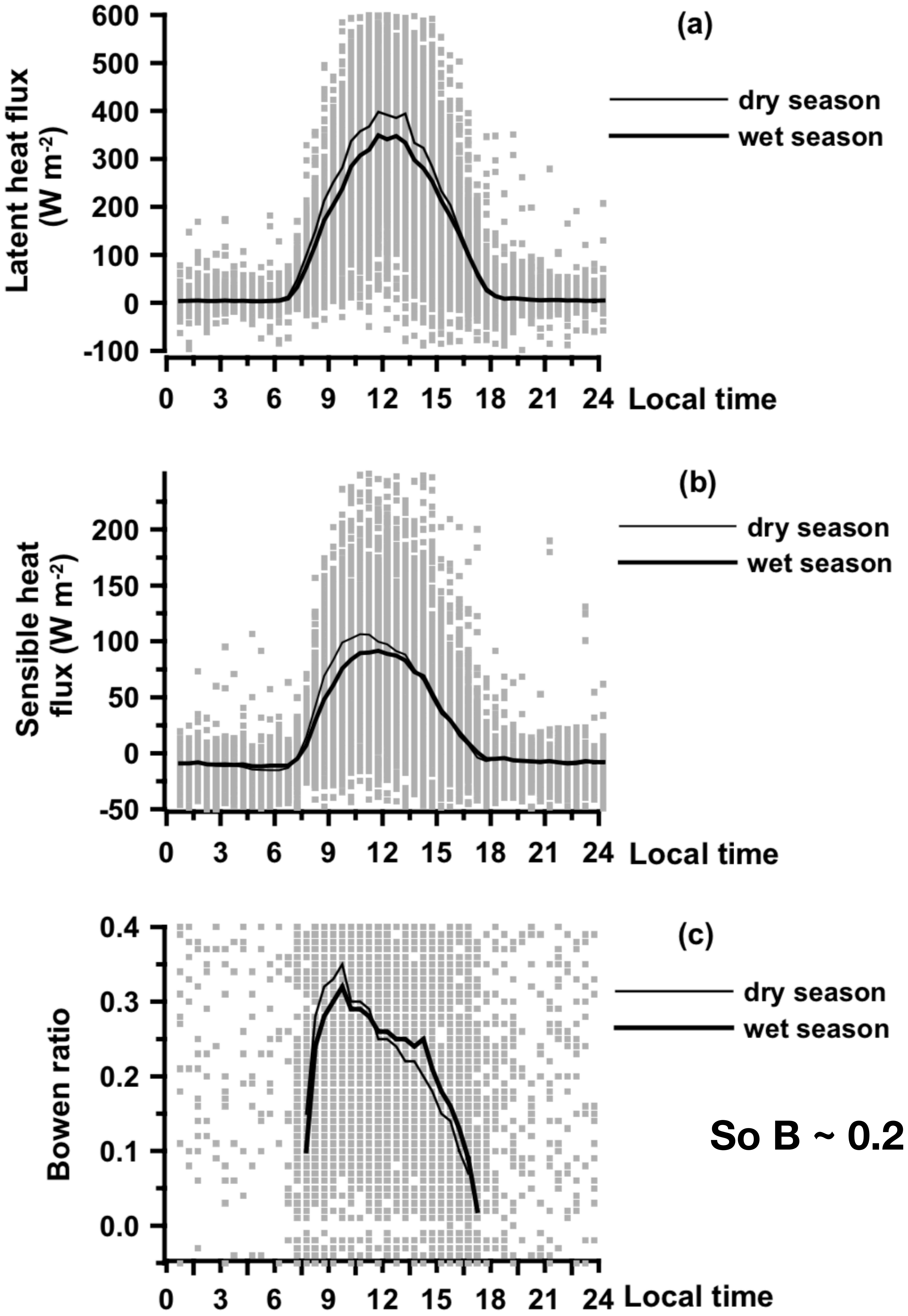


From Freedman et al. (2001)



Amazon Rainforest Surface Heat and Moisture Fluxes

65 m flux tower

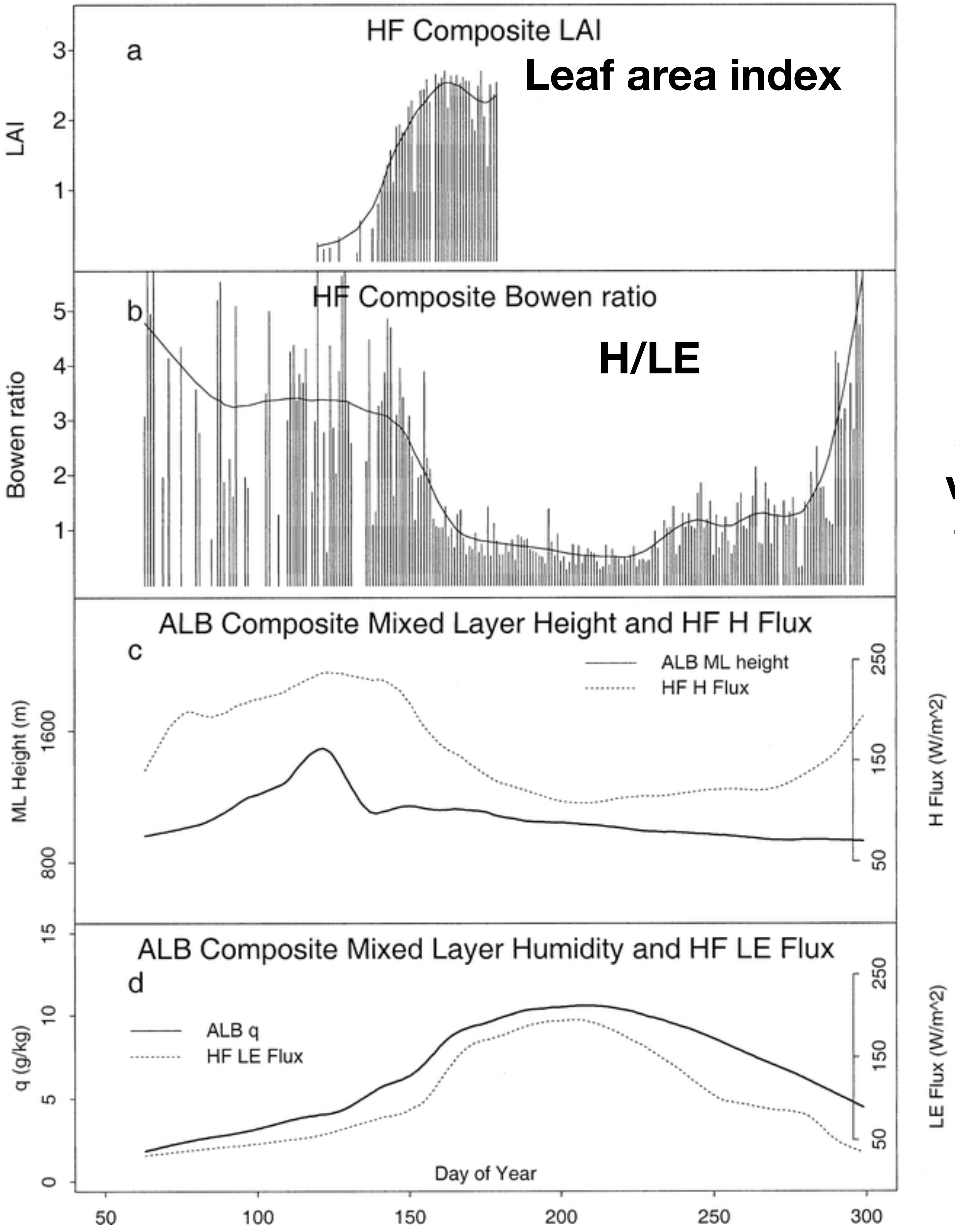


So B ~ 0.2

3)

Harvard Forest (Petersham MA) Surface Heat and Moisture Fluxes)

33 m flux tower Environmental Monitoring Site



So B can approach Amazon-like values during the summer!

BOREAS—Old Jack Pine (Thompson MB) Surface Heat and Moisture Fluxes)

30 m flux tower

From Moore et al. 2000

Different story in this part of the world

Table 2. Meteorological Comparison of Years 1994 and 1996, Days 150 to 250

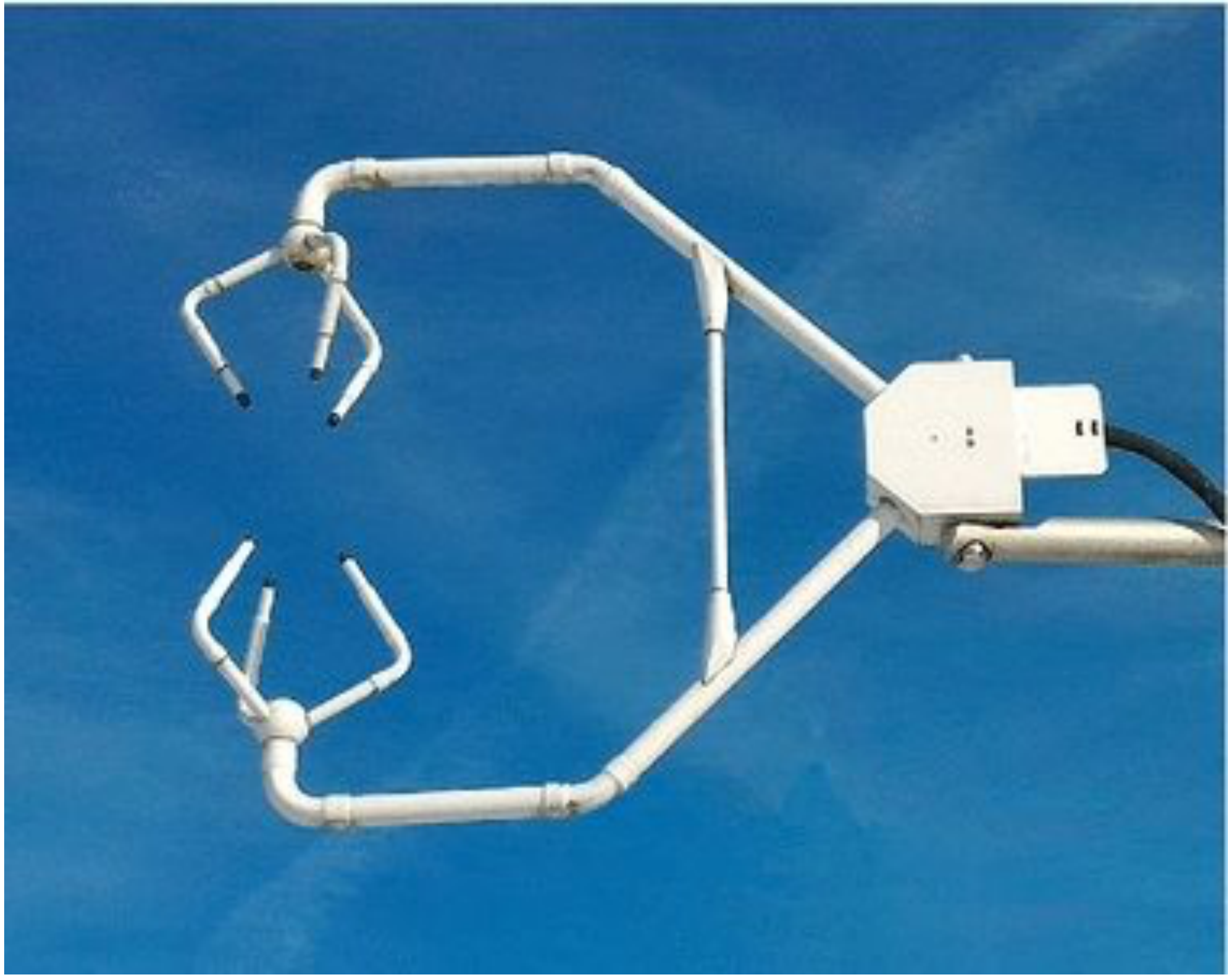
		Year			
		1994		1996	
Variable	Climate Normal	Mean	Standard Deviation	Mean	Standard Deviation
Bowen ratio		2.14	1.44	2.82	2.62
AFM* q, g/kg		5.67	1.5	7.45	1.9
VPD,† kPa		2.0	0.66	2.2	0.73
Temperature, °C	12.3	16.6	5.6	18.0	6.0
Precipitation,‡ mm	242	176		202	
Q_E, Krypton		82.5	49.1	72.8	23.0
Q_E, Licor		78.6	46.3	60.0	37.5

*Specific humidity (q) data from automatic weather station tower at the site.
†Vapor pressure deficit.
‡Total precipitation for the period.

Understanding the ABL - History

1900-1910	• laminar boundary layer theory (aerodynamics) - Prandtl • Ekman layer (pressure gradient, Coriolis, friction important)
1910-1940	• Taylor - methods for understanding turb mixing • mixing length theory, eddy diffusivity • contributions from von Karman, Prandtl, Lettau
1940-1950	Kolmogorov turbulence similarity theory
1950-1960	• buoyancy effects (Monin Obukhov similarity) • early field experiments w/direct flux measurements (Great Plains Experiment)
1960-1970	• Golden Age of Boundary Layer Meteorology • Fast response instrumentation (e.g. sonic anemometry) enabled accurate BL observations • verification/calibration of similarity theory • Kansas 1968, Minnesota 1971 (flat sites) • surface layer spectra and cospectra
1970-1980	• tropical marine boundary layer experiment (GATE 1974) • introduction of Large Eddy Simulation - 3D modeling of BL turbulence
1980-	• new technology and tools (eg., lidar) • extensive space-based coverage • coupled ocean atmosphere models • major air/sea field campaigns (TOGA COARE)

Understanding the ABL - History



Understanding the ABL - History

1900-1910	• laminar boundary layer theory (aerodynamics) - Prandtl • Ekman layer (pressure gradient, Coriolis, friction important)
1910-1940	• Taylor - methods for understanding turb mixing • mixing length theory, eddy diffusivity • contributions from von Karman, Prandtl, Lettau
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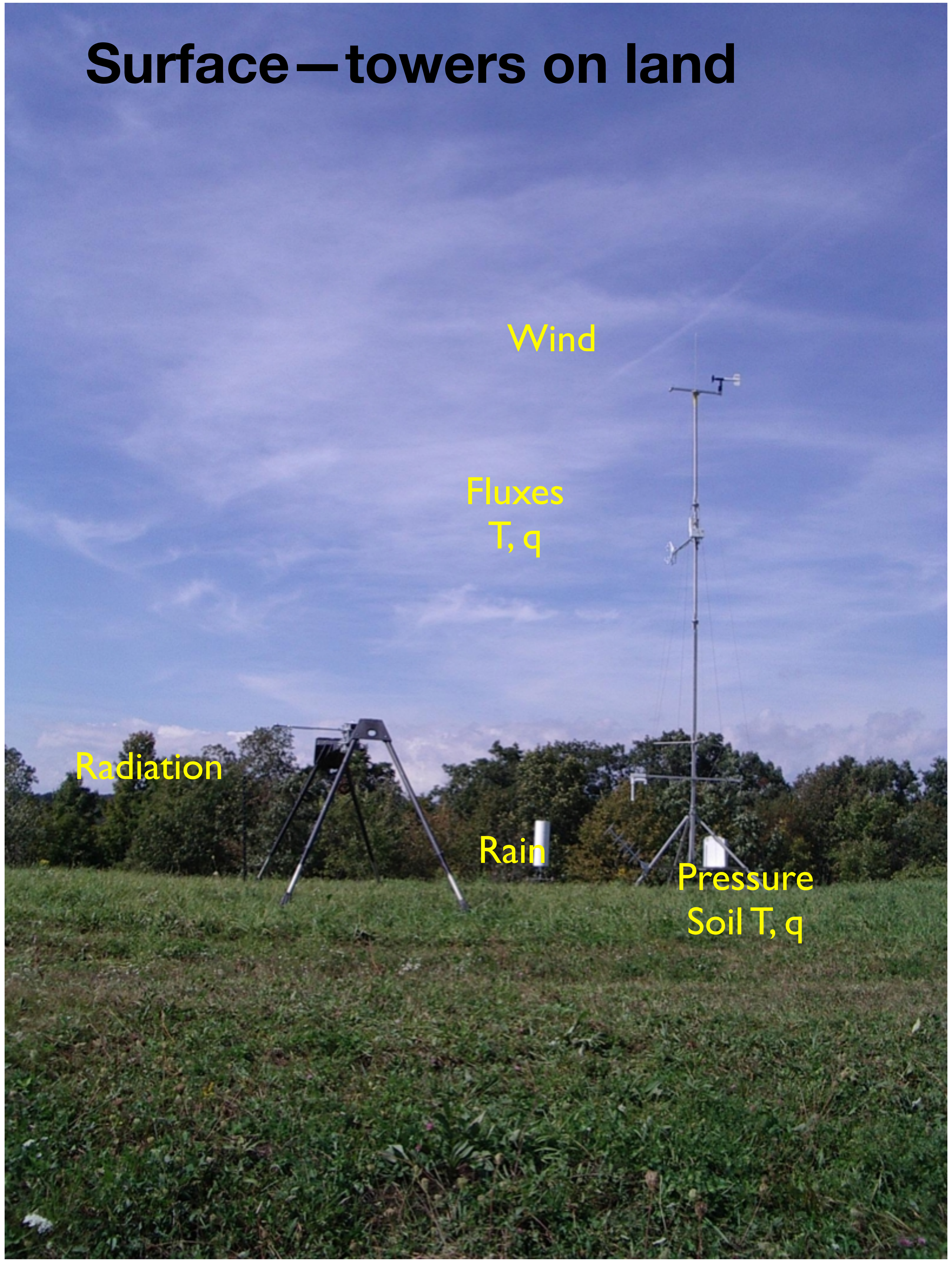
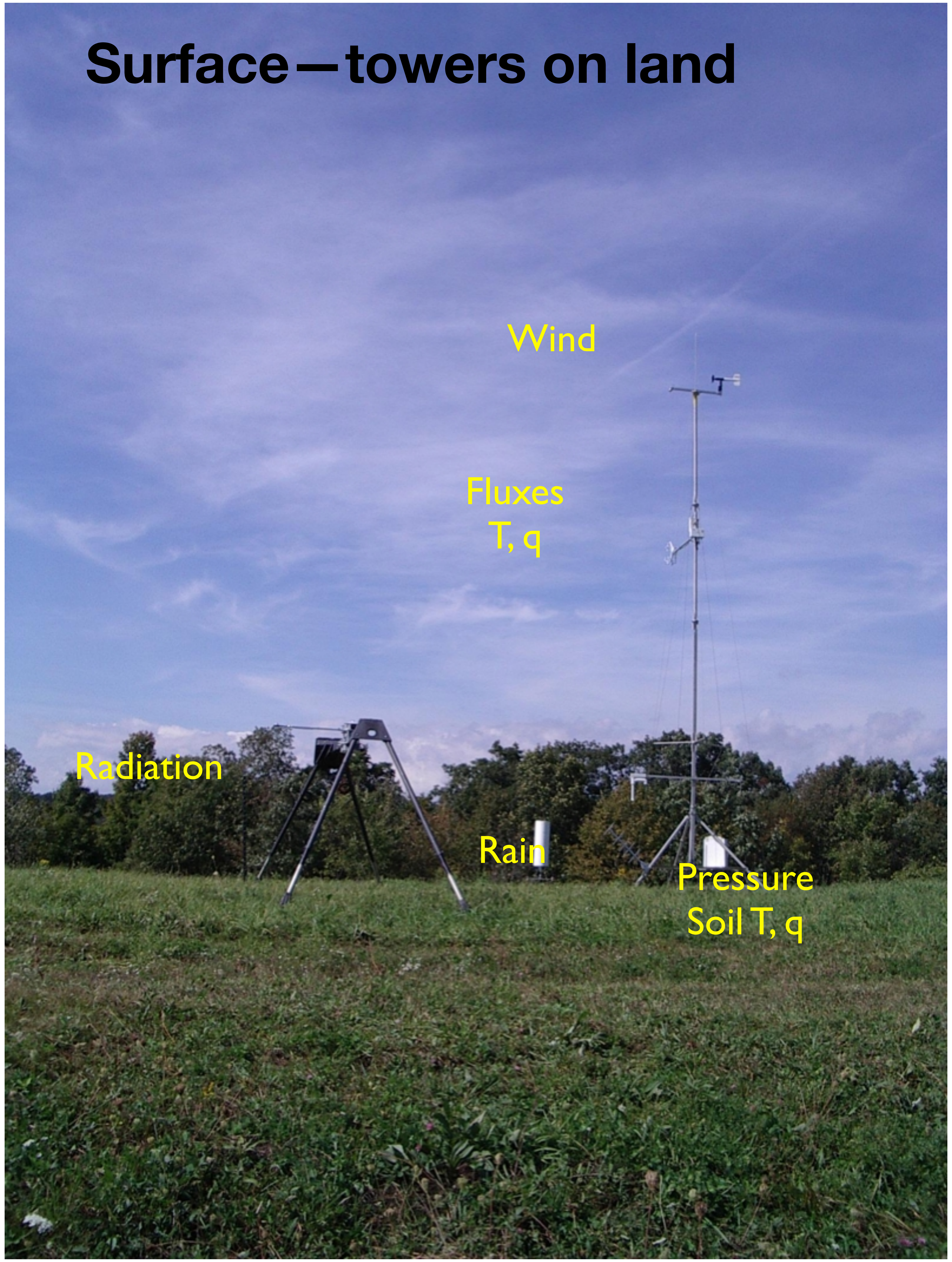
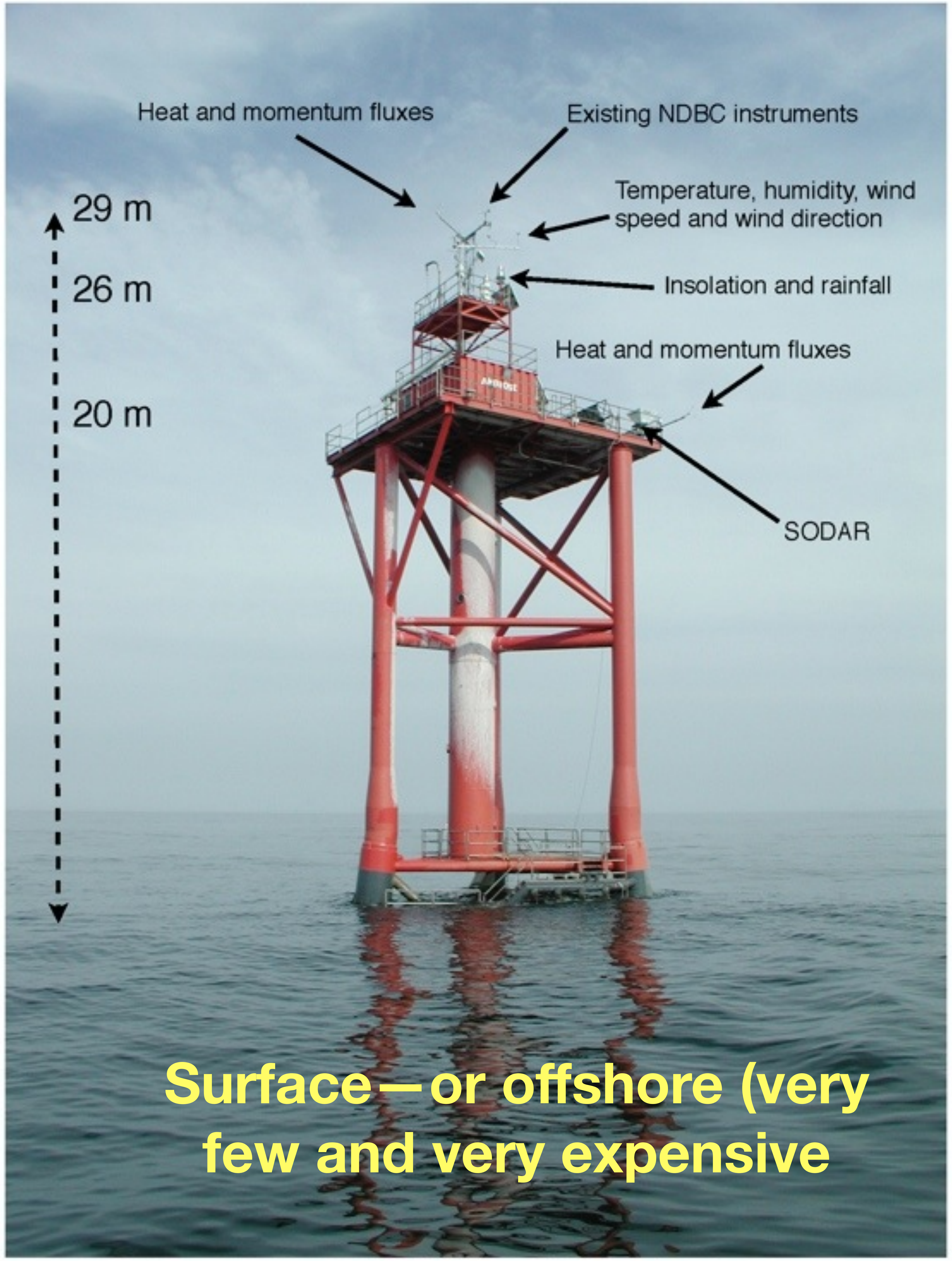
Ways we measure the ABL

(We'll explore what the measurements actually tell us about the ABL in lecture 5)

Surface—towers on land

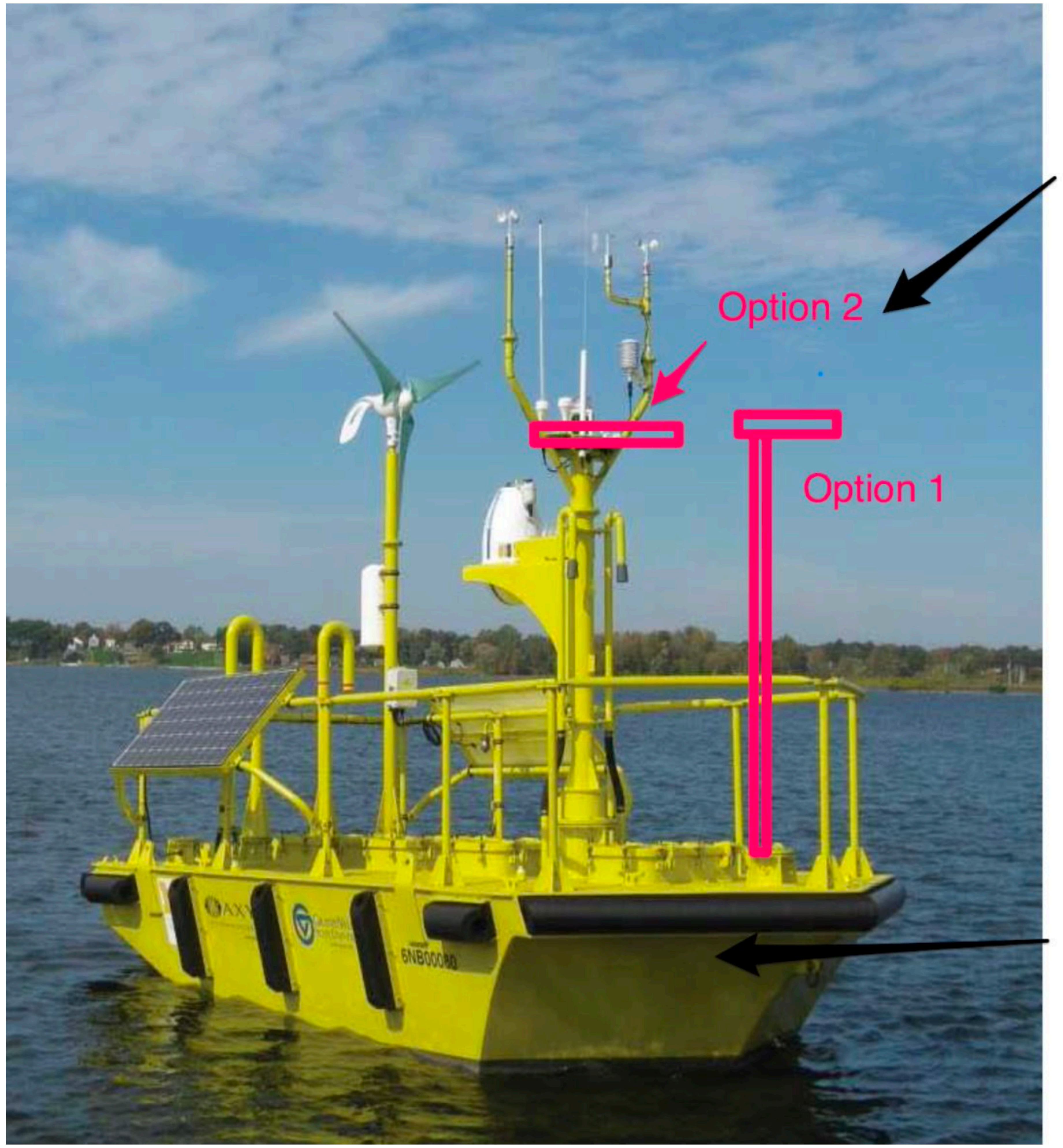



Surface—towers on land
Wind
Fluxes
T, q
Radiation
Rain
Pressure
Soil T, q


Heat and momentum fluxes
Existing NDBC instruments
29 m
Temperature, humidity, wind speed and wind direction
26 m
Insolation and rainfall
Heat and momentum fluxes
20 m
SODAR
Surface—or offshore (very few and very expensive

We (ASRC Miller and Freedman) are working with DOE on this:

Buoy-based flux-LiDAR system



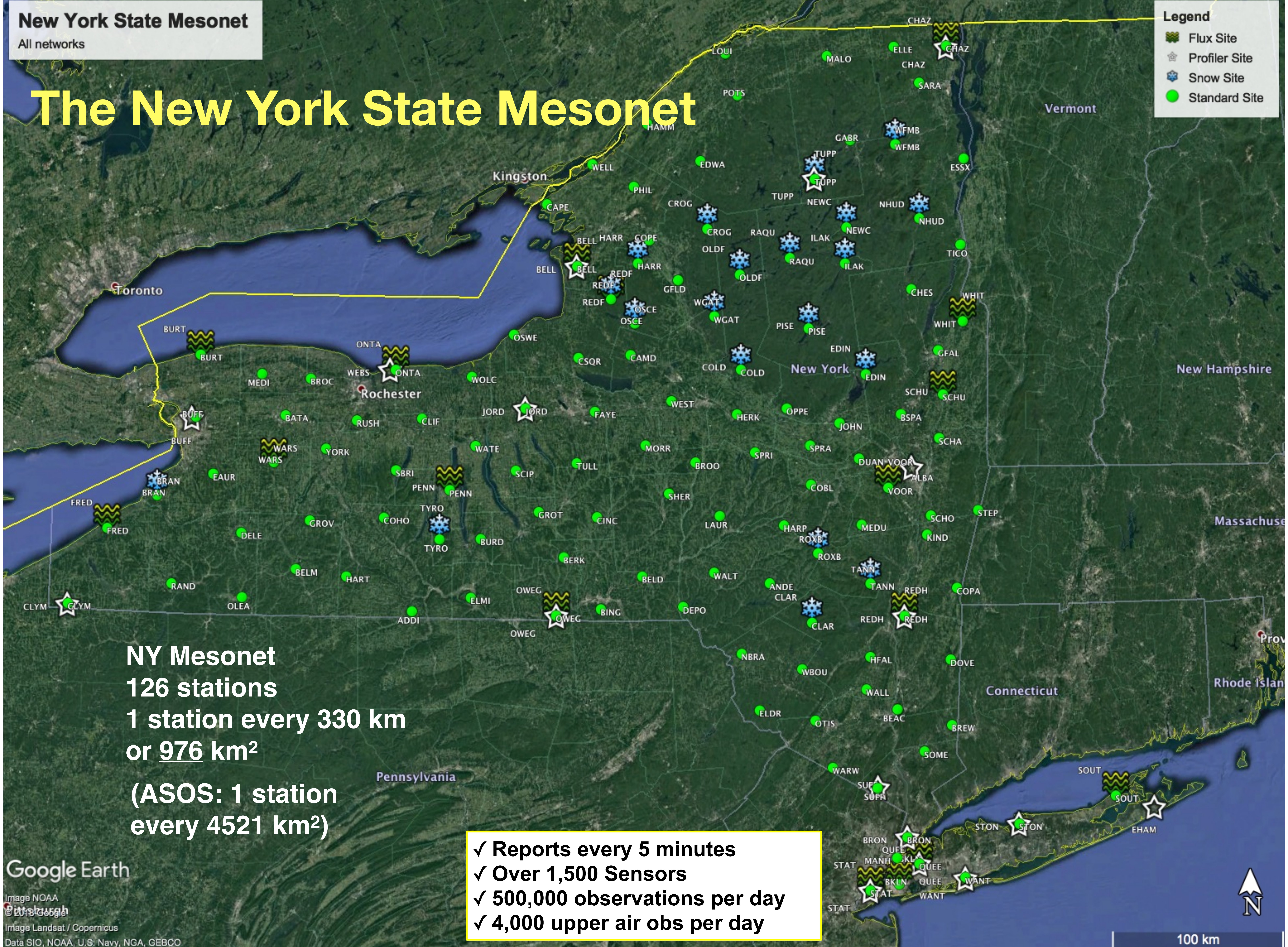
Above Deck
sonics
motion sensor
gas analyzers
Net radiometer
T/RH sensor
Skin temperature sensor
Antennas

Below Deck
power connections
pumps
datalogger
compressor

Sometimes it helps to get in the air….

UWyoming King Air—HVAMS 2003 (with Kathy Moore)

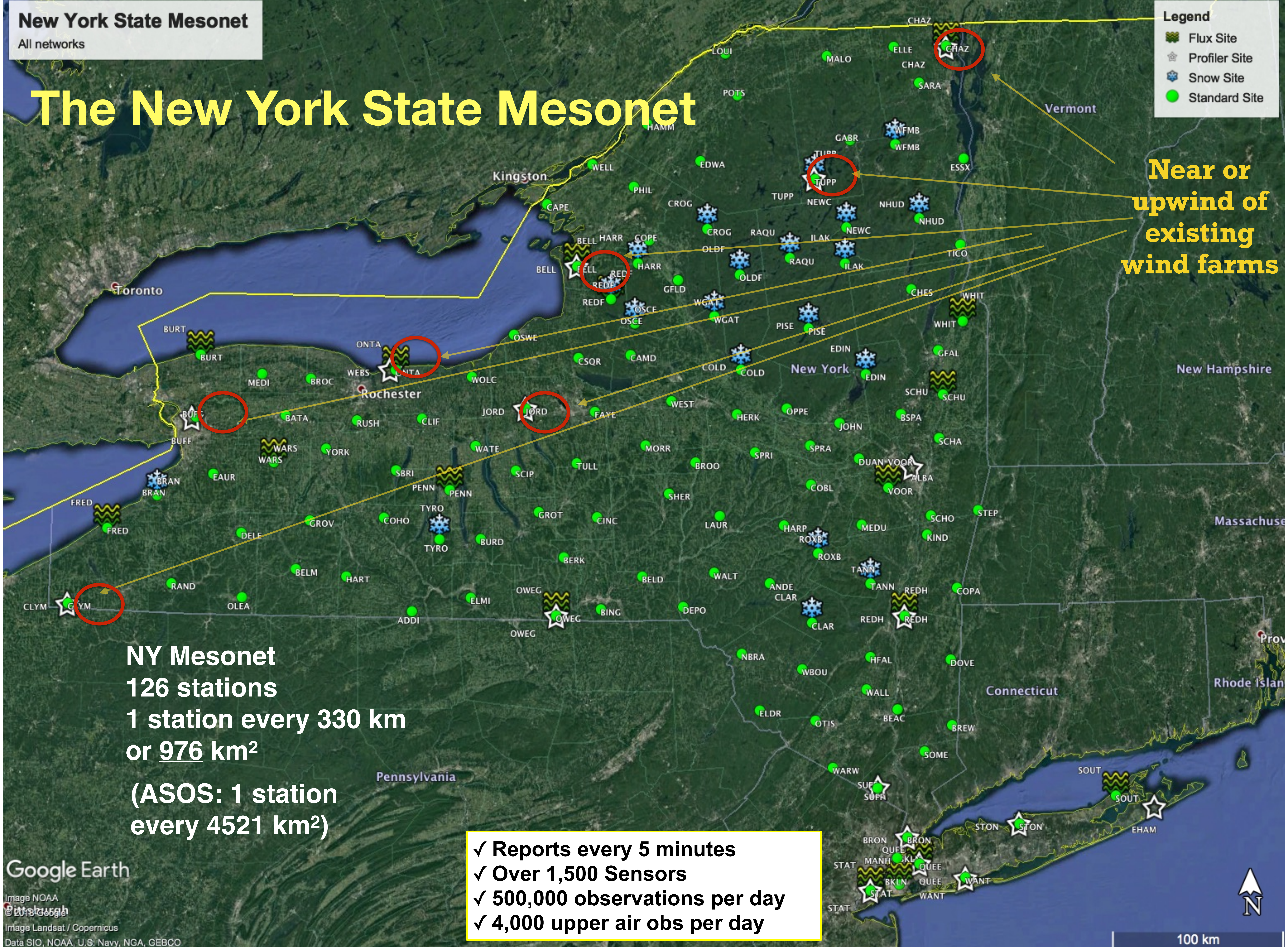
The New York State Mesonet

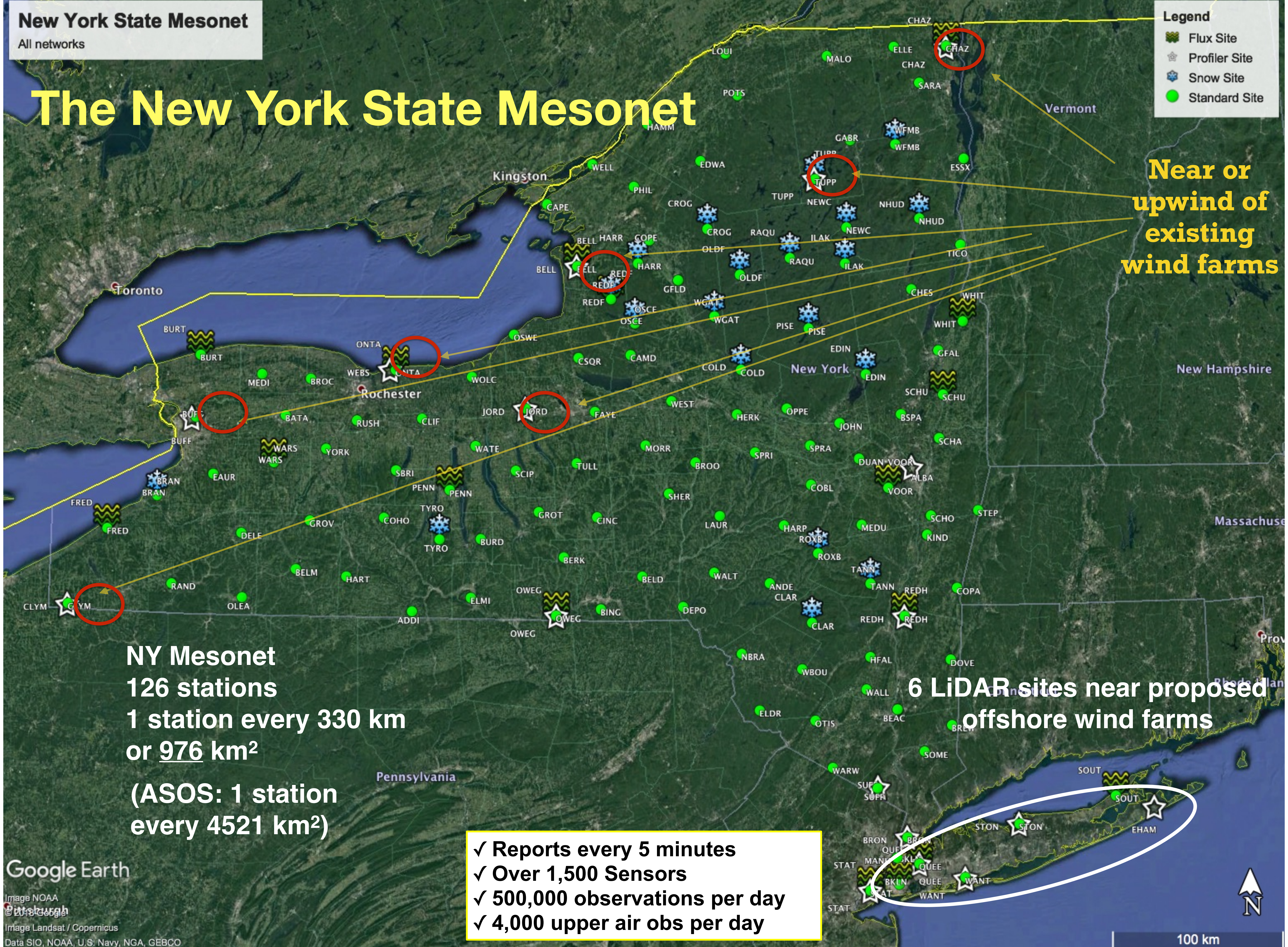


NY Mesonet
126 stations
1 station every 330 km
or 976 km²

(ASOS: 1 station every 4521 km²)

- ✓ Reports every 5 minutes
- ✓ Over 1,500 Sensors
- ✓ 500,000 observations per day
- ✓ 4,000 upper air obs per day


New York State Mesonet
All networks
The New York State Mesonet
Legend
Flux Site
Profiler Site
Snow Site
Standard Site
Near or upwind of existing wind farms
NY Mesonet
126 stations
1 station every 330 km
or 976 km²
(ASOS: 1 station every 4521 km²)
✓ Reports every 5 minutes
✓ Over 1,500 Sensors
✓ 500,000 observations per day
✓ 4,000 upper air obs per day
Kingston
Toronto
Rochester
New York
Vermont
New Hampshire
Massachusetts
Connecticut
Rhode Island
Pennsylvania
Google Earth
Image NOAA
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
100 km
N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126 stations
1 station every 330 km
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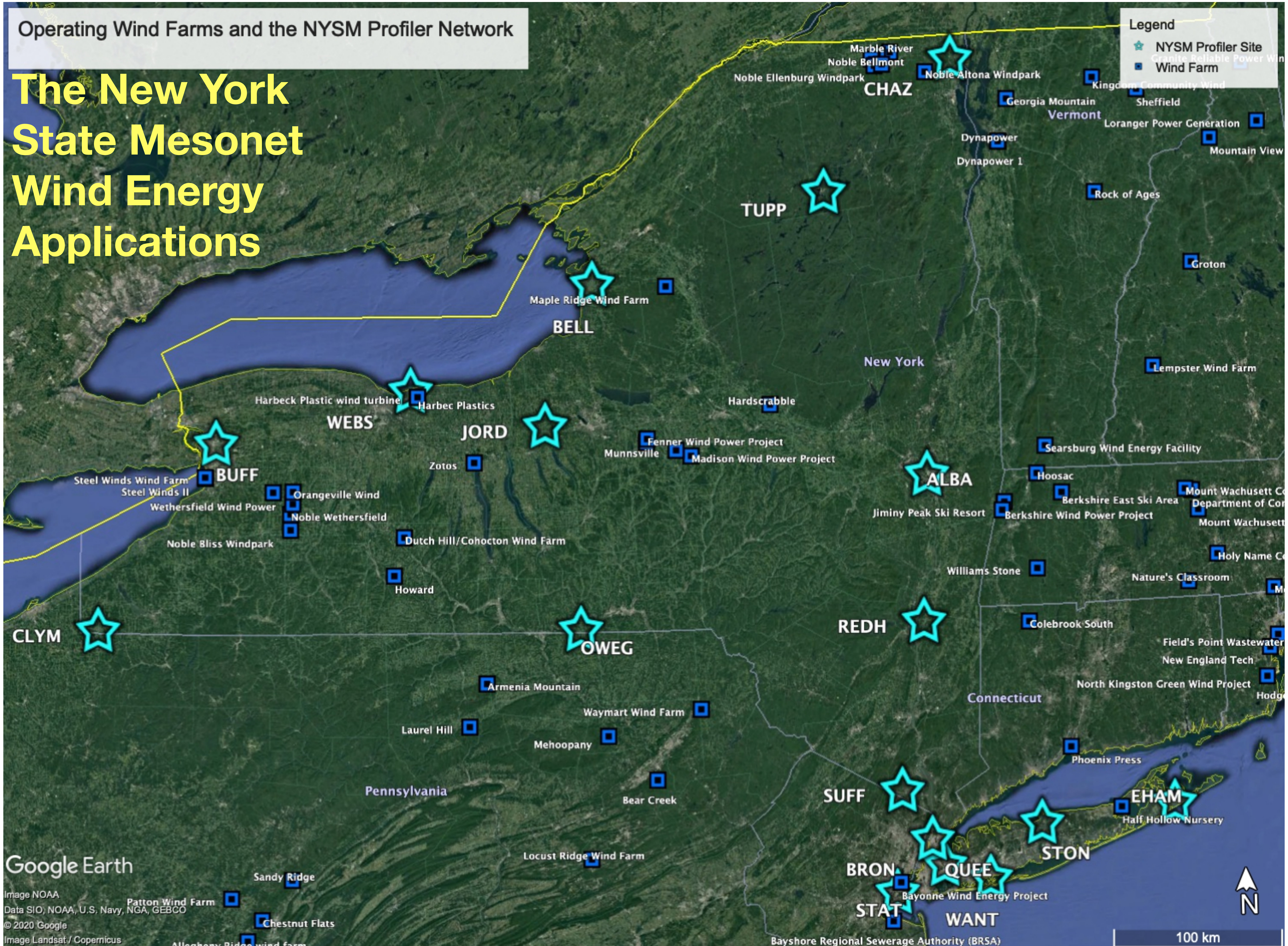
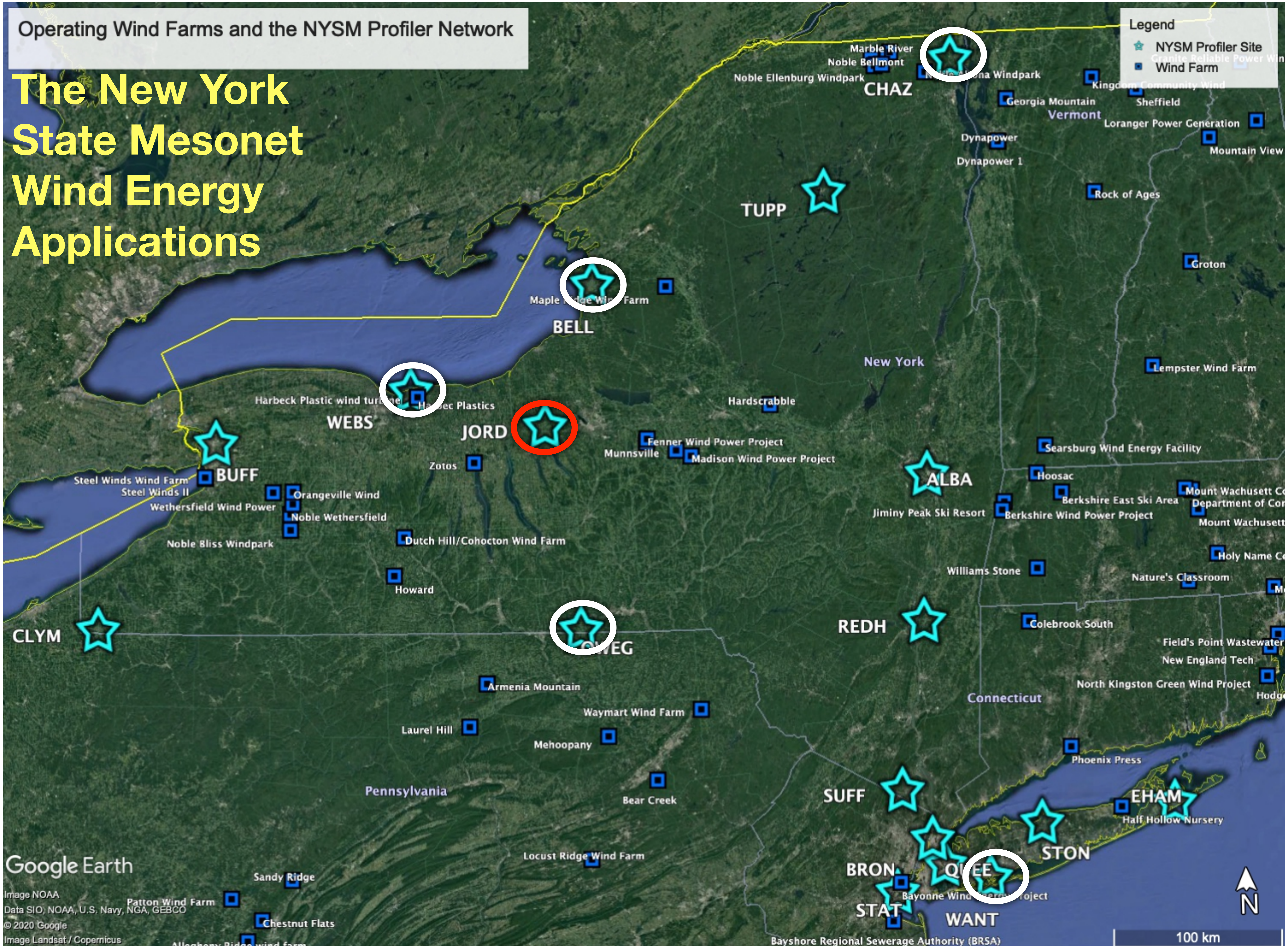
(ASOS: 1 station every 4521 km²)
6 LiDAR sites near proposed offshore wind farms
✓ Reports every 5 minutes
✓ Over 1,500 Sensors
✓ 500,000 observations per day
✓ 4,000 upper air obs per day
Toronto
Kingston
Rochester
New York
Vermont
New Hampshire
Massachusetts
Pennsylvania
Google Earth
Image NOAA
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
100 km
N

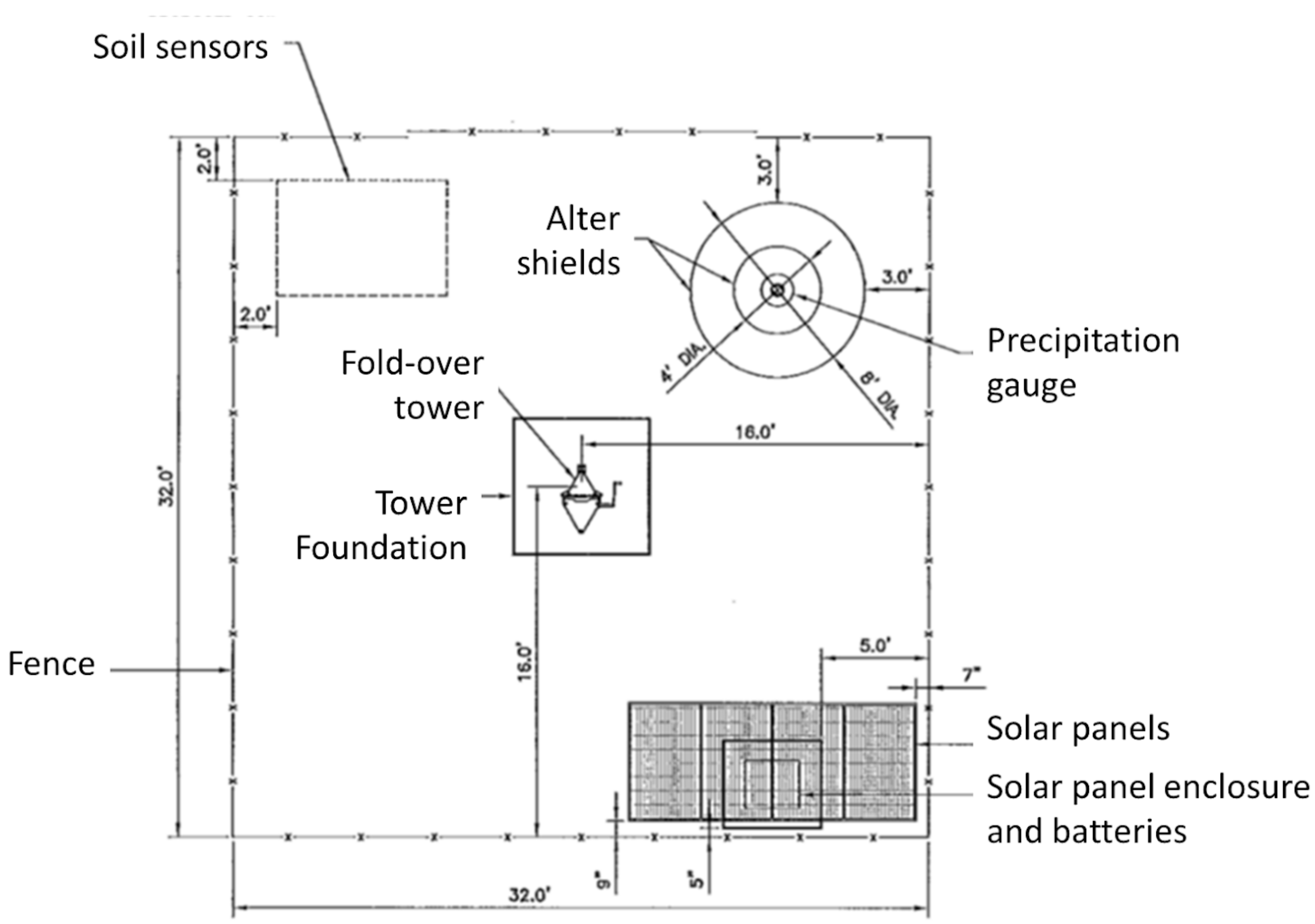
The New York State Mesonet Wind Energy Applications

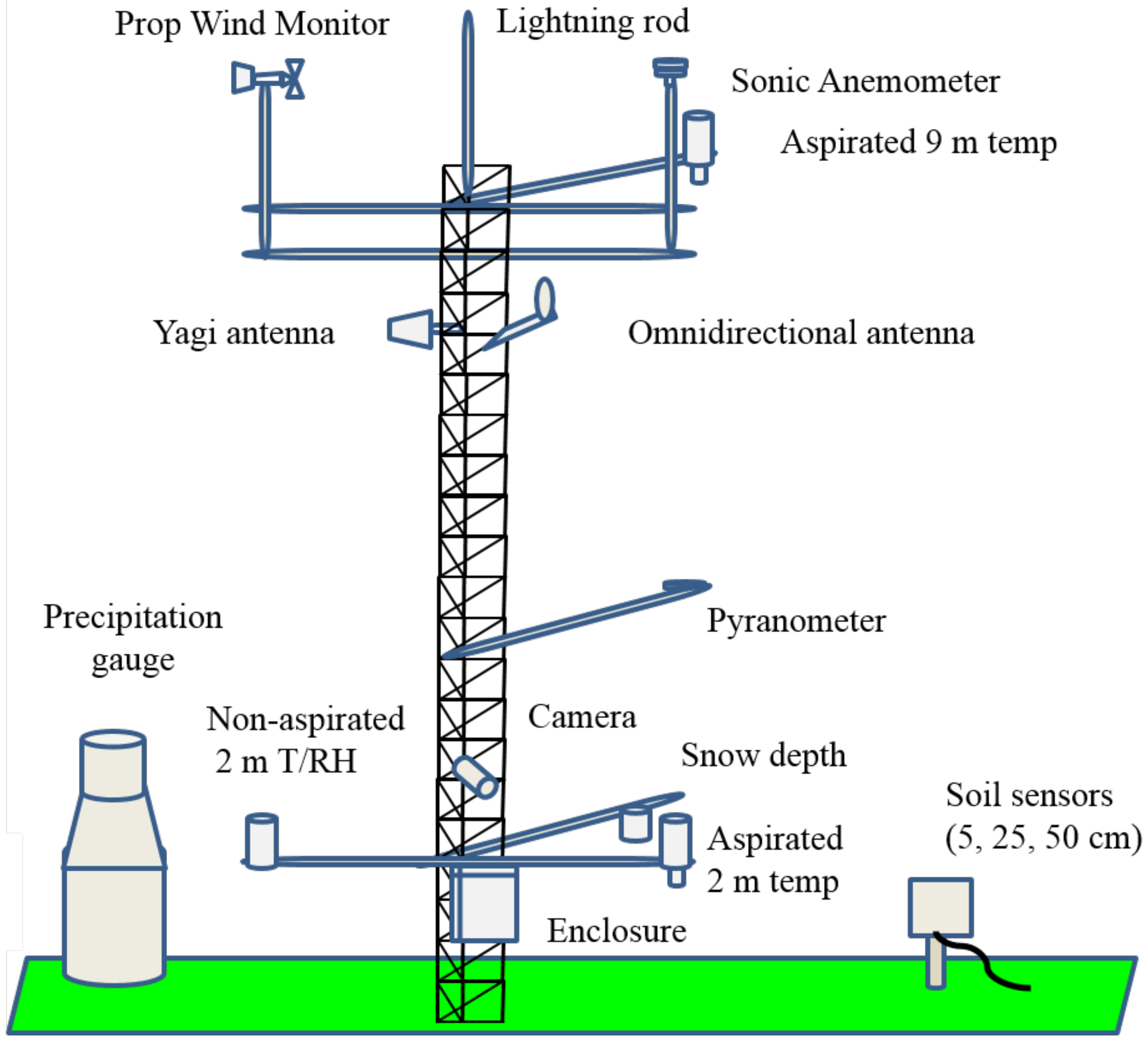


The New York State Mesonet Wind Energy Applications

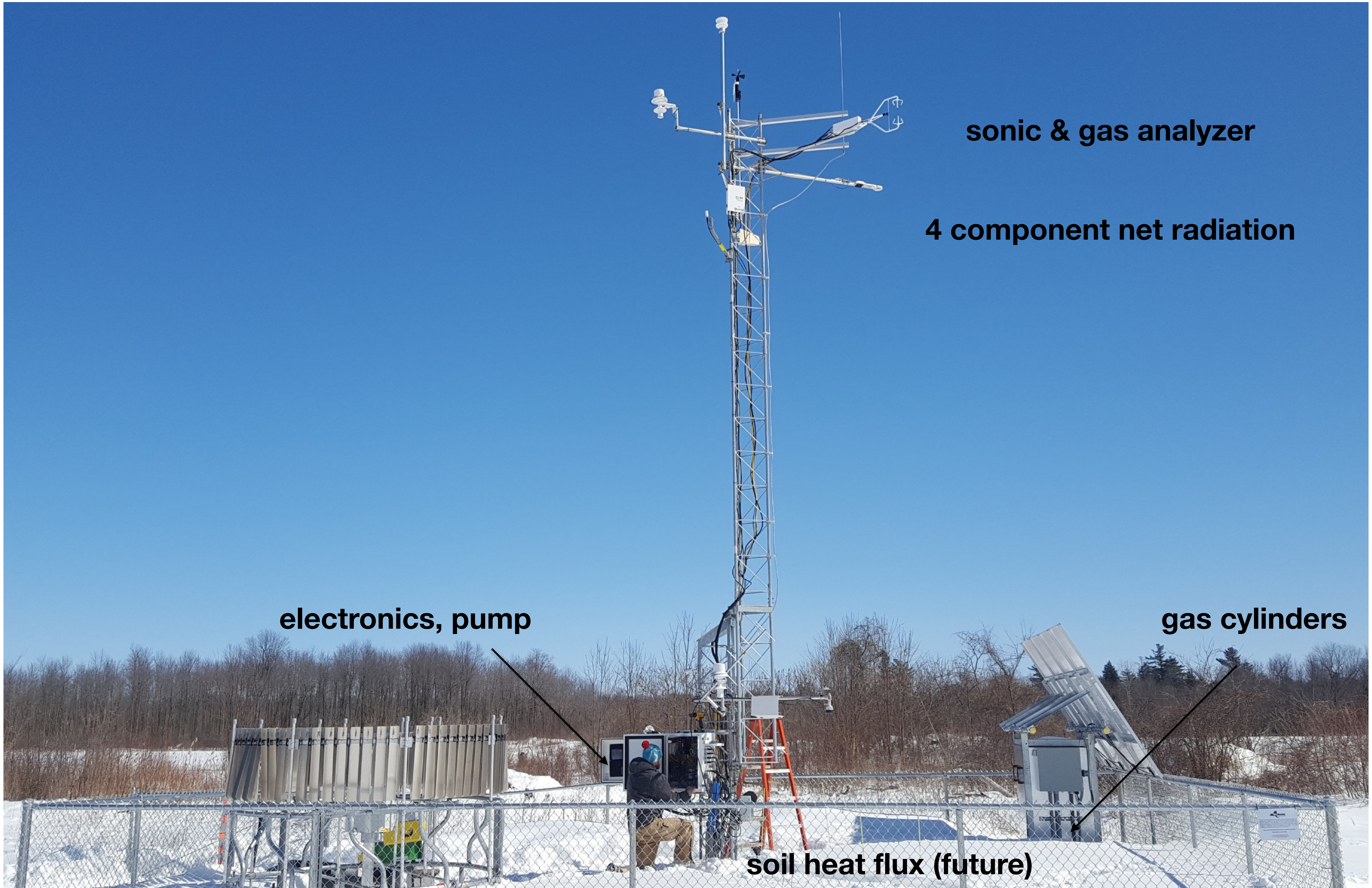


The New York State Mesonet—standard site





NYS Mesonet surface flux station



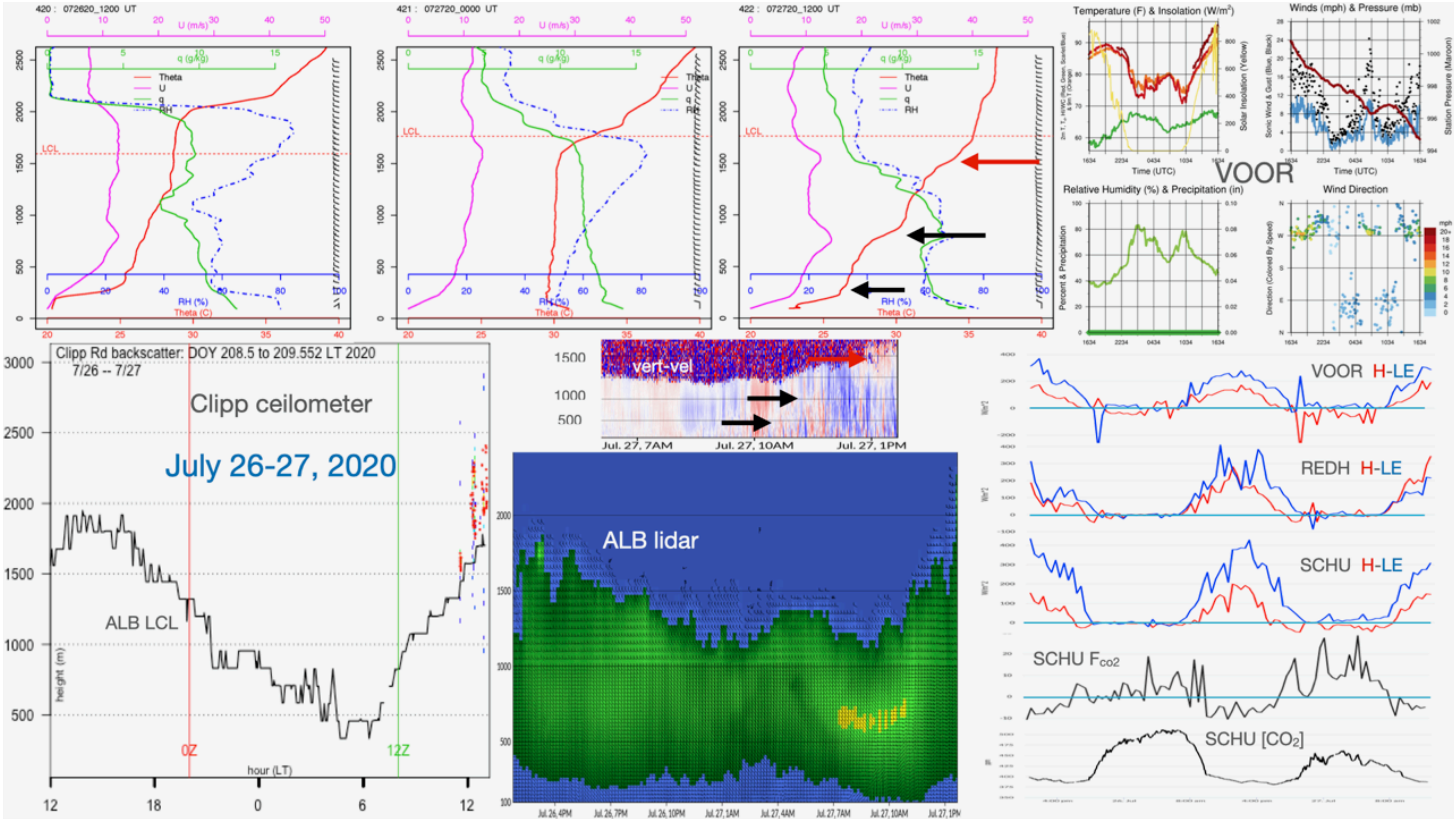
The New York State Mesonet—profiler site

Radiometrics MP-3000 series microwave radiometer. This is a passive instrument that measures the downwelling microwave radiation to estimate vertical profiles of temperature, humidity, and liquid up to 10 km above ground level.

Leosphere WindCube WLS-100 series Doppler LiDAR (Light Detection and Ranging). The LiDAR uses a vertically-pointing eye-safe laser to estimate wind velocities in the vertical. The LiDAR measures the speed and direction of aerosols moving towards and away from the beam, and the reflected energy is analyzed to determine 3-D wind speed and direction.

A hint of things to come…putting it all together

Courtesy of Dave Fitzjarrald (from 26 July 2020)



A 'stair-step' theta profile this morning (12Z, black and red arrows), but today, we reached the LCL and the small clouds appeared. At the end of the day yesterday, a well-defined convective boundary layer with its 'lid' at about the LCL was there, but there was not enough time for the clouds to form. The dew points all around the state just after noon were in the 70's F, or just about there in the high 60's except for the higher altitude places. For reference, the dew point in the eastern Amazon, along the Tapajós River at Santarém is currently 75F (24C). Tough times.

From AMS Annual Meeting
24th Symposium on
Boundary Layers and
Turbulence—a link to the
real world

Attributes and distribution of extreme wind gusts as related to distinct weather regimes in New York State

Jeffrey M. Freedman, Atmospheric Sciences Research Center, University at Albany, State University of New York
John Zack, MESO, Inc.
Bhupal Shrestha, New York State Mesonet
Michael Berlinger

Work presented sponsored in part by the New York State Energy Research and Development Authority, in collaboration with the Consolidated Edison Company of New York

Brooklyn, NY 5 August 2020; Photo by Todd Maisel. From amNY

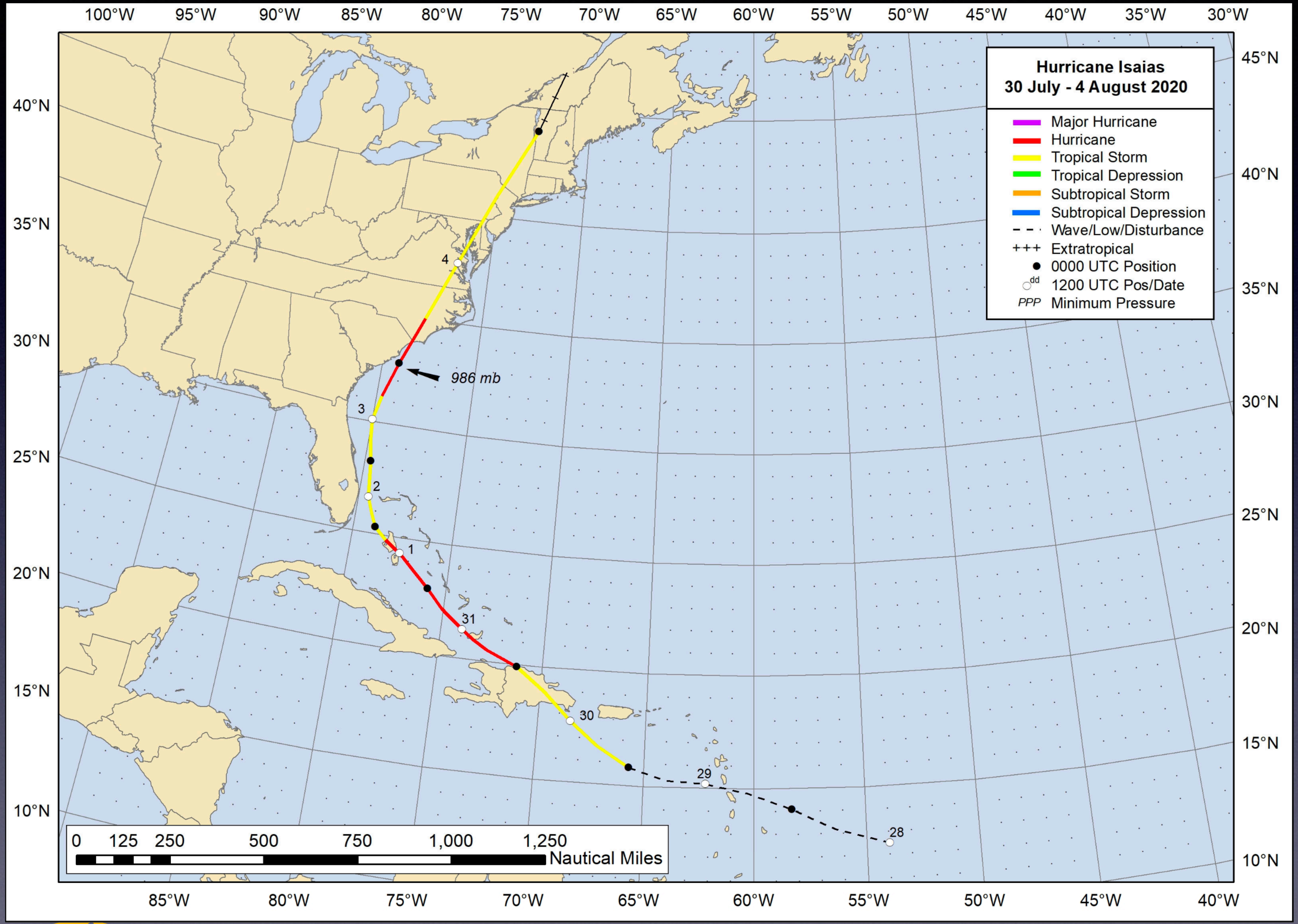
Case Study: Tropical Storm Isaias

4 August 2020

Case Study: Tropical Storm Isaias

NHC Track

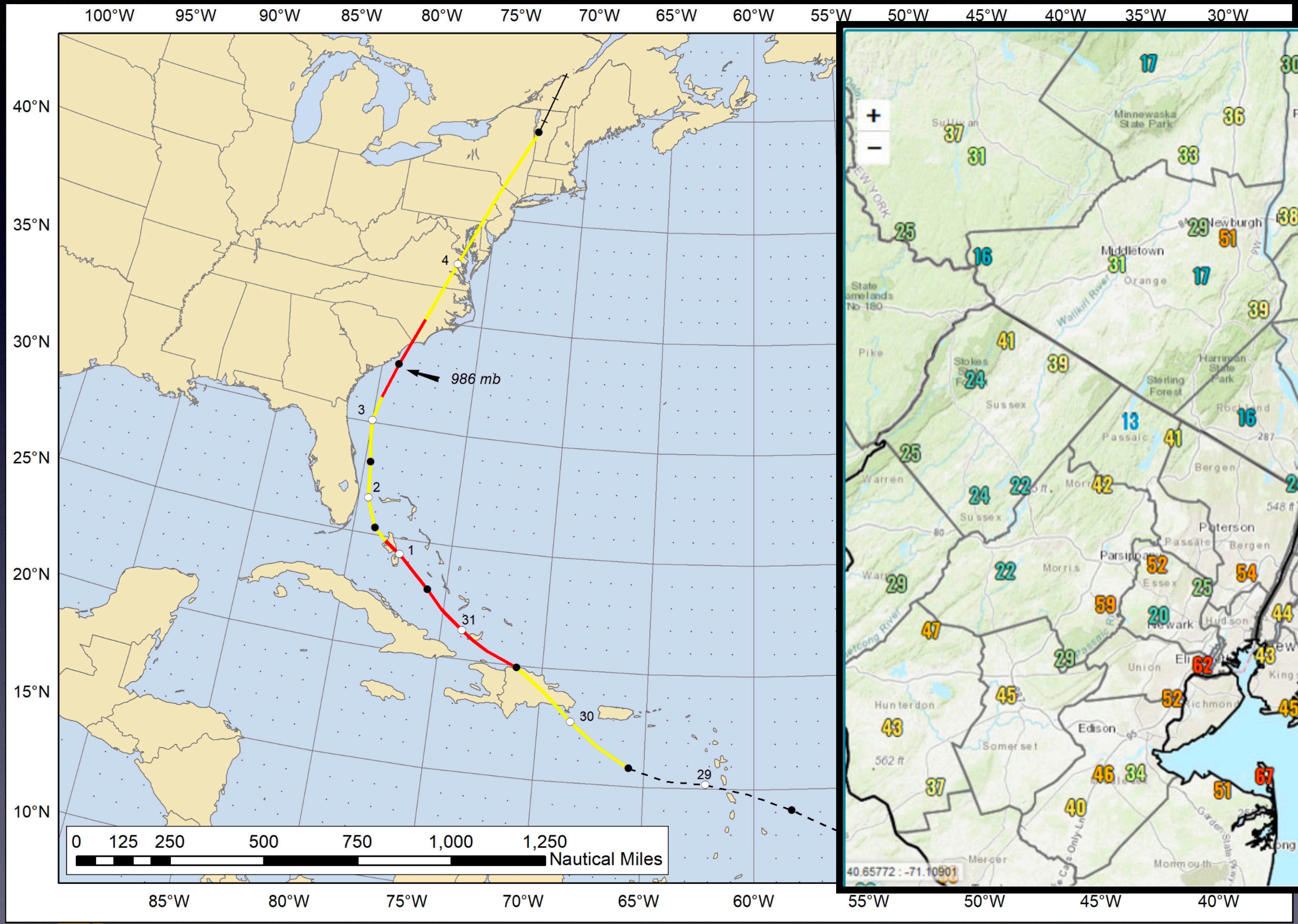
4 August 2020



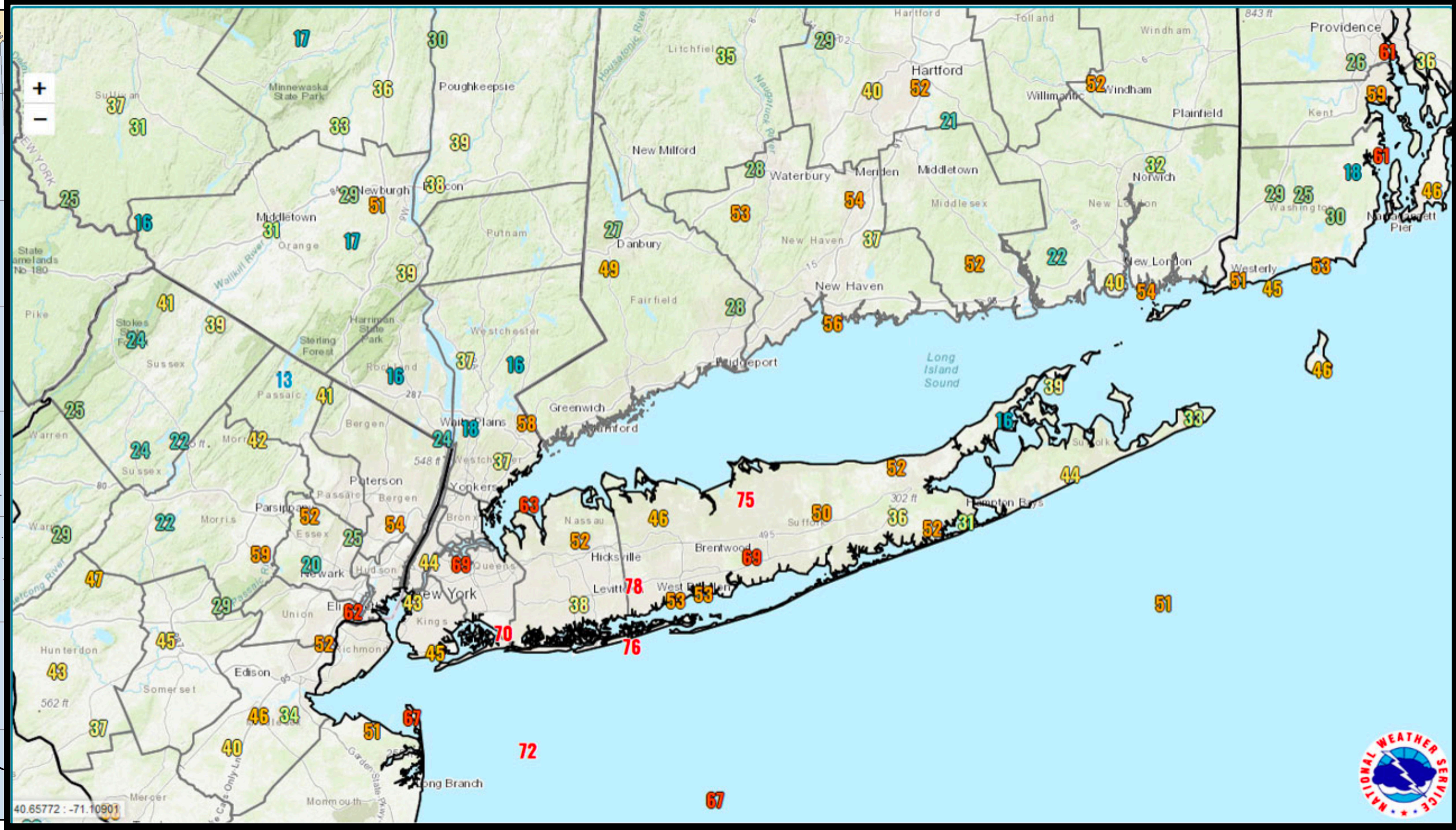
Case Study: Tropical Storm Isaias

4 August 2020

NHC Track



Maximum Wind Gusts MPH (NYC WFO)

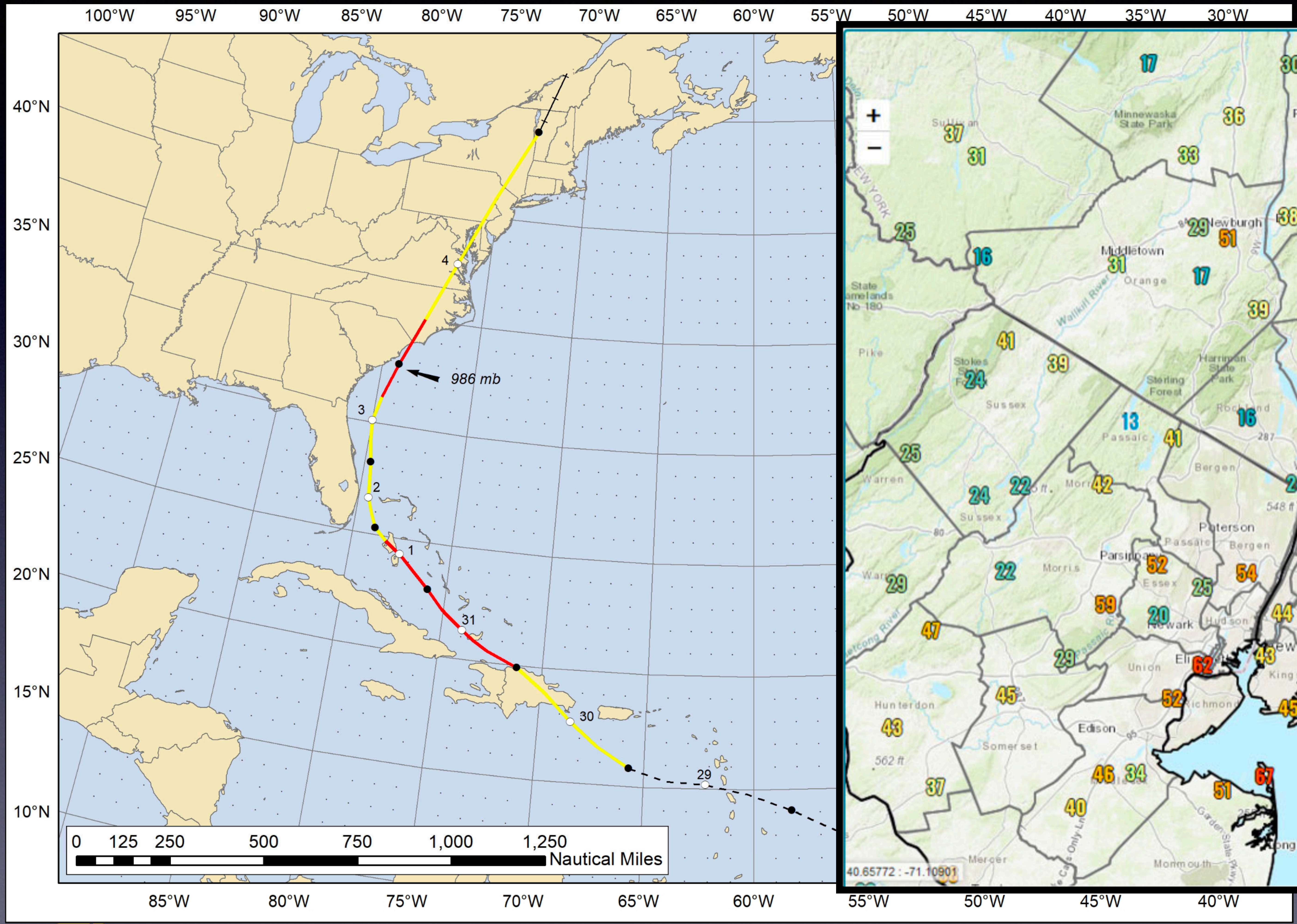


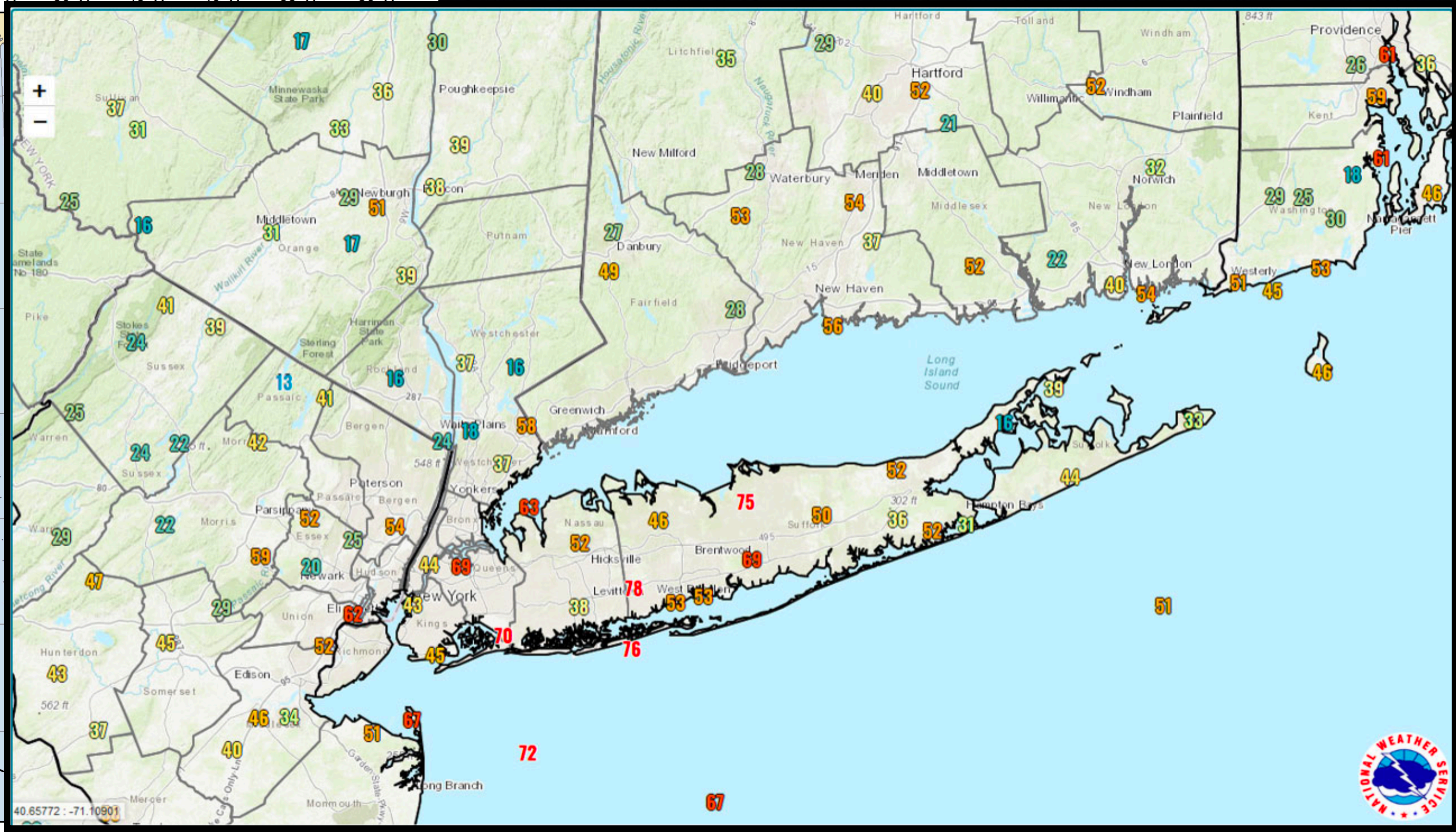
Case Study: Tropical Storm Isaias

NHC Track

4 August 2020

Maximum Wind Gusts MPH (NYC WFO)





Does NOT include NYSM!

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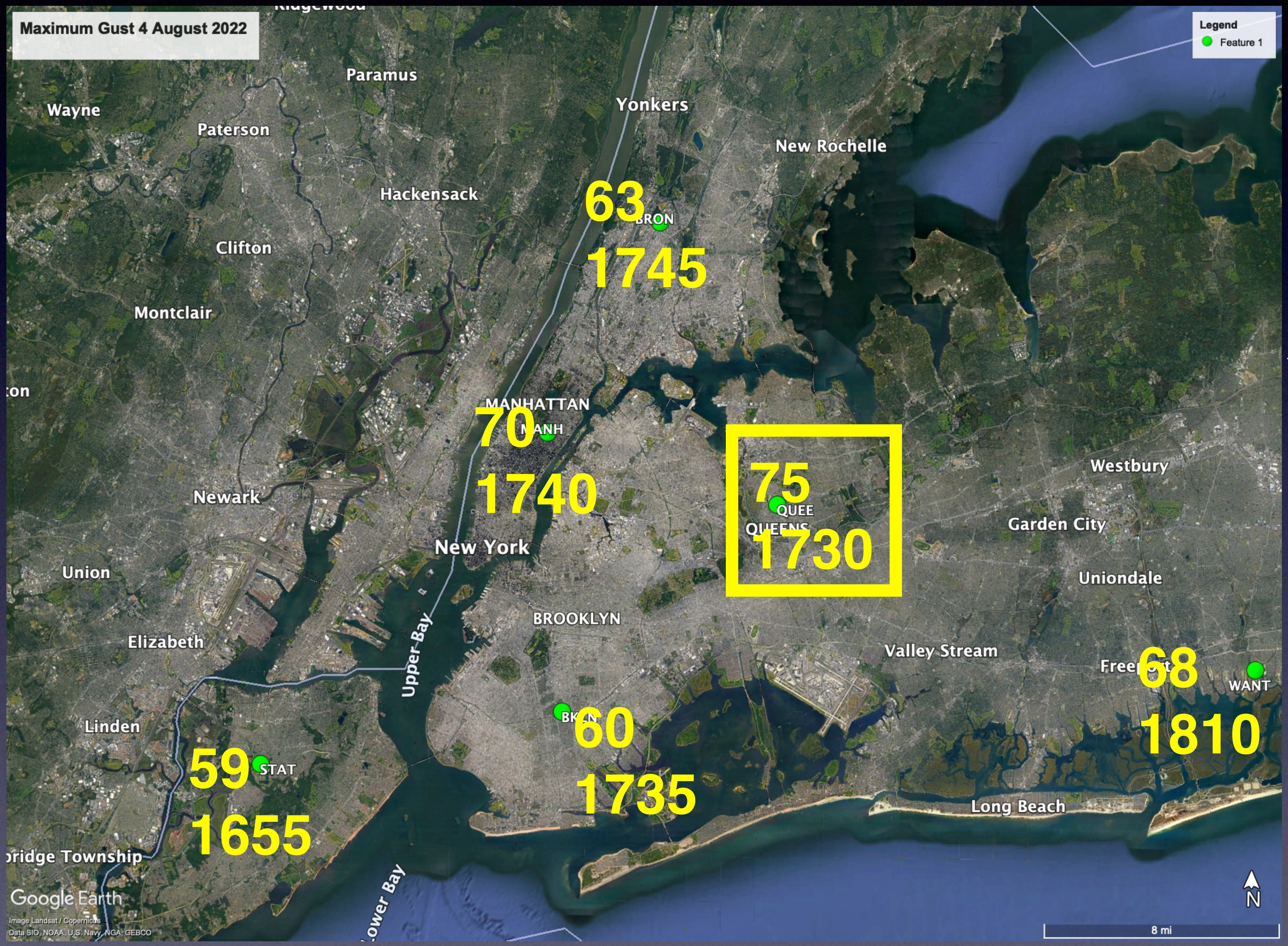
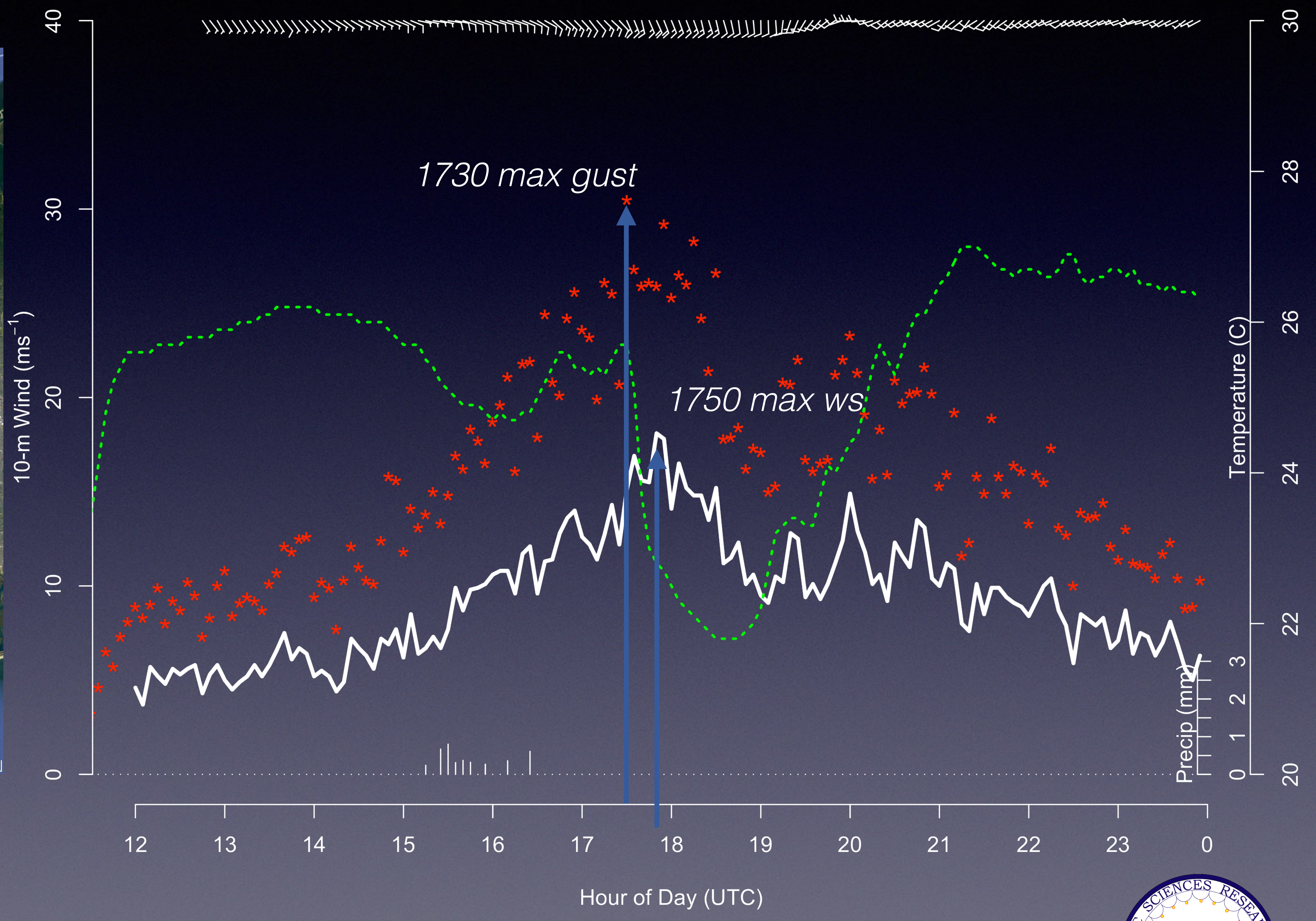
Case Study: Tropical Storm Isaias

4 August 2020

Max. Gust (MPH) NYSM Stations



NYSM Standard Site (QUEE) Winds, Temperature, and Precipitation 4 August 2020



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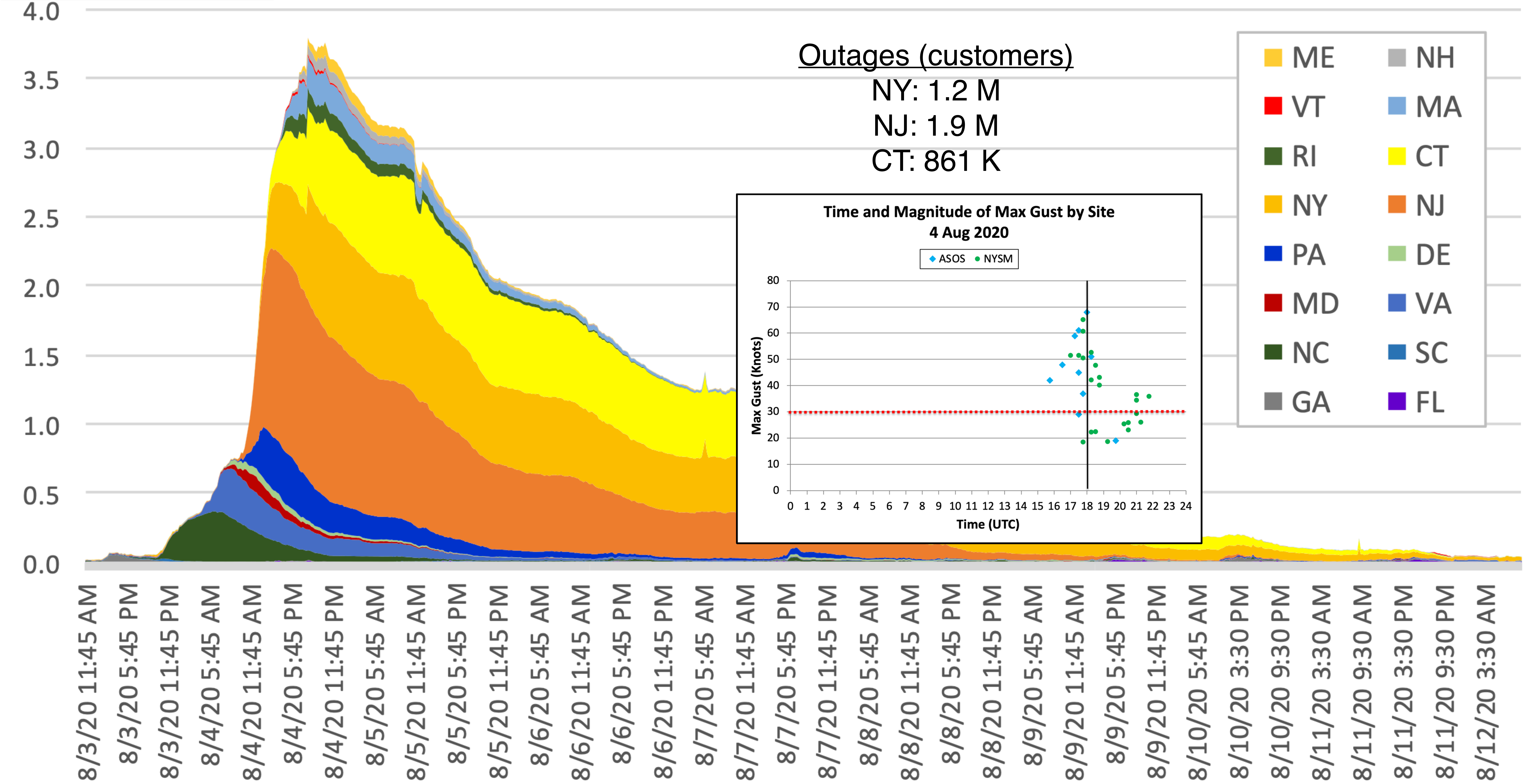
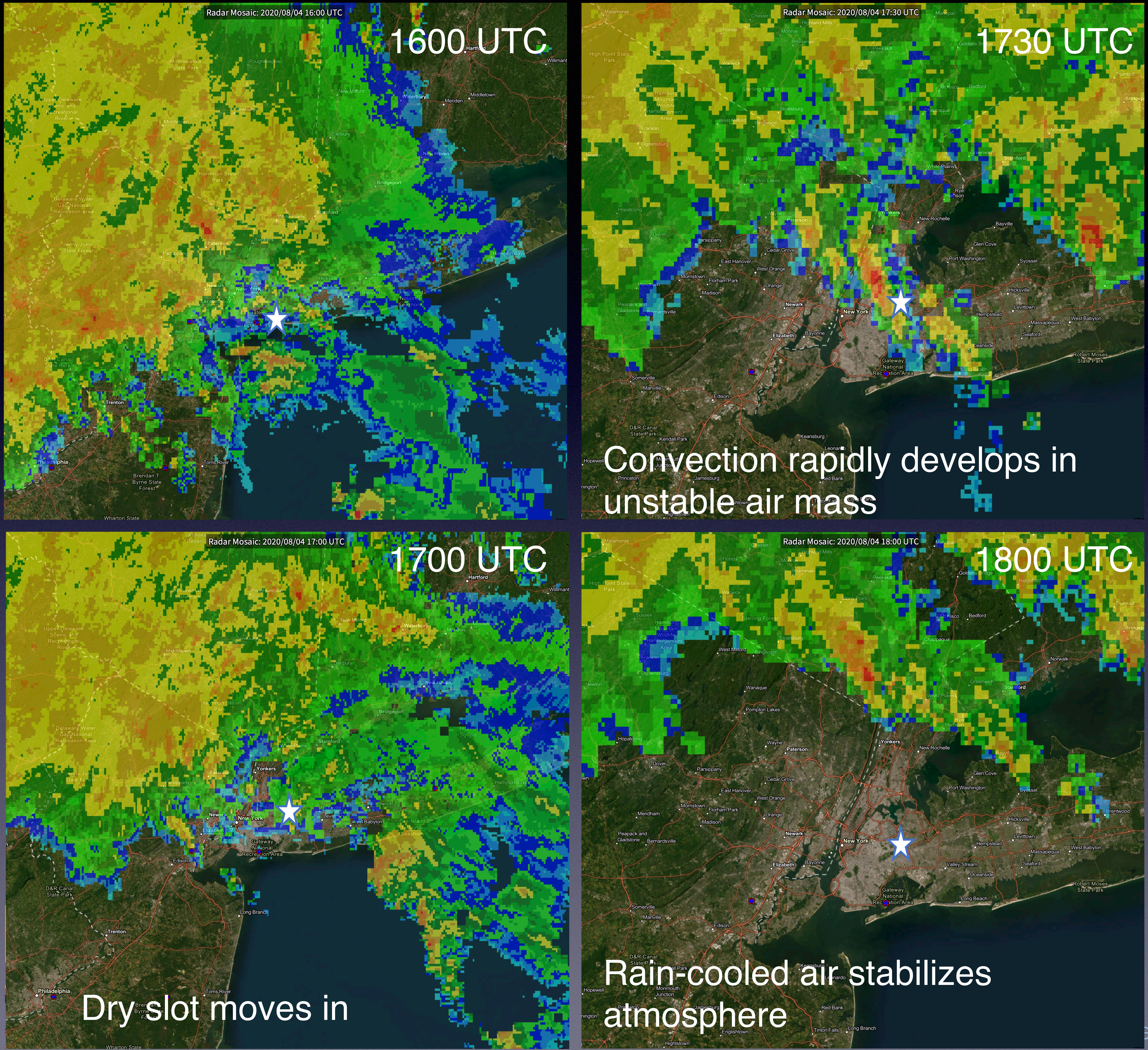
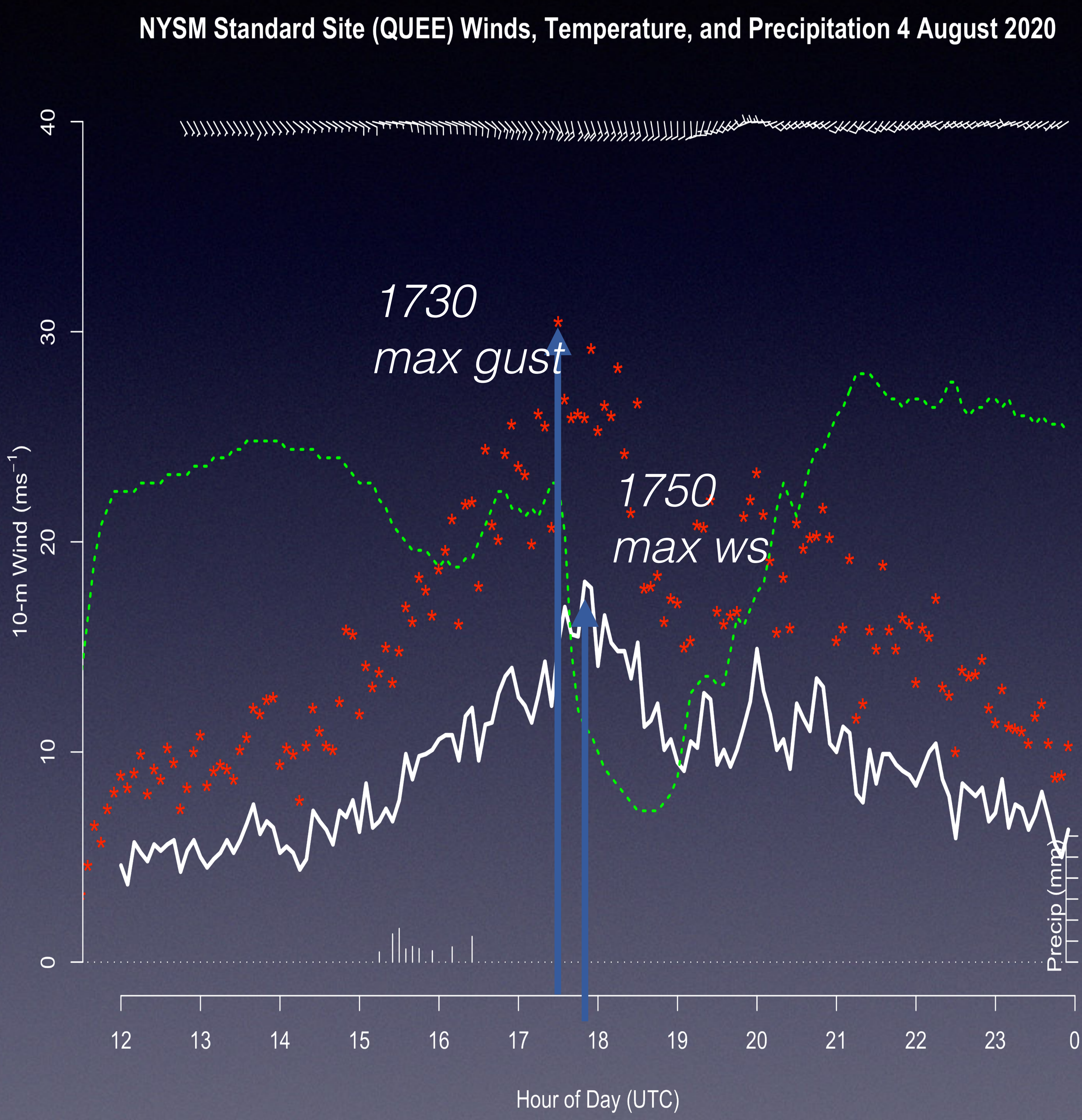
ATMOSPHERIC SCIENCES RESEARCH CENTER 1961

U.S. DEPARTMENT OF ENERGY

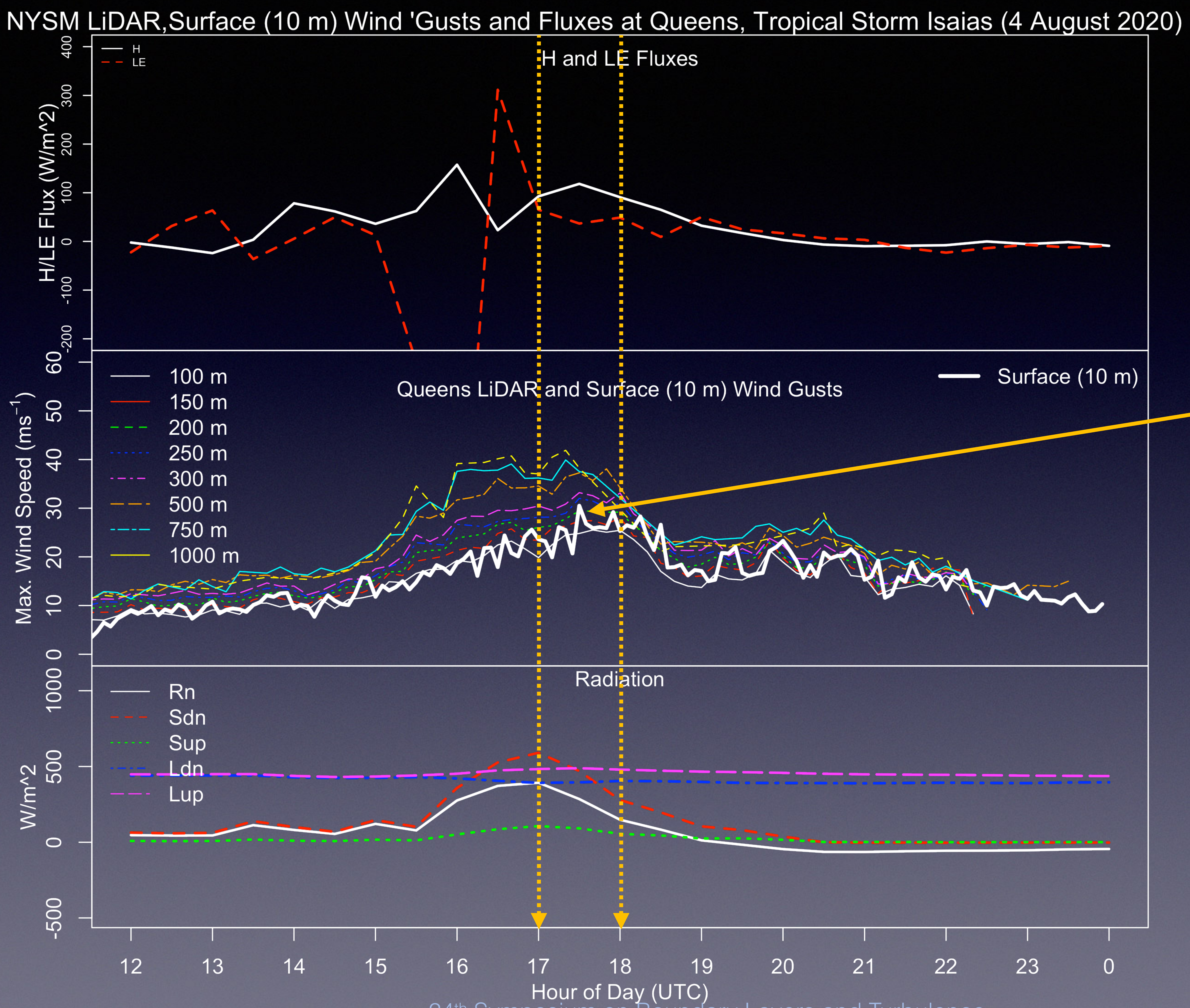
Customer Outages by State (millions)



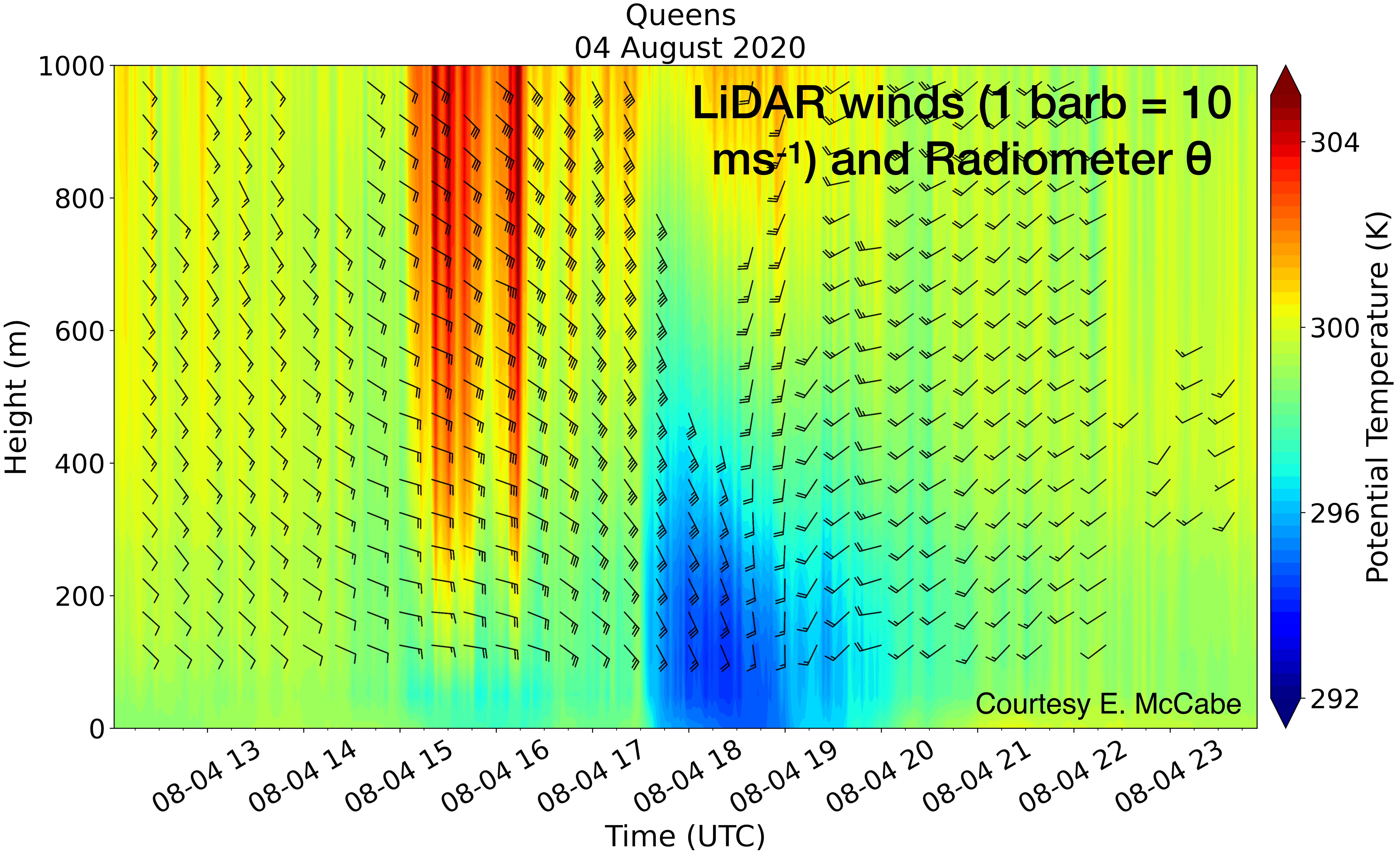

Radar Mosaic: 2020/08/04 16:00 UTC
1600 UTC
Radar Mosaic: 2020/08/04 17:30 UTC
1730 UTC
Convection rapidly develops in unstable air mass
Radar Mosaic: 2020/08/04 17:00 UTC
1700 UTC
Dry slot moves in
Radar Mosaic: 2020/08/04 18:00 UTC
1800 UTC
Rain-cooled air stabilizes atmosphere


NYSM Standard Site (QUEE) Winds, Temperature, and Precipitation 4 August 2020
1730
max gust
1750
max ws
10-m Wind (ms⁻¹)
Temperature (C)
Precip (mm)
Hour of Day (UTC)
0
10
20
30
40
12
13
14
15
16
17
18
19
20
21
22
23
0

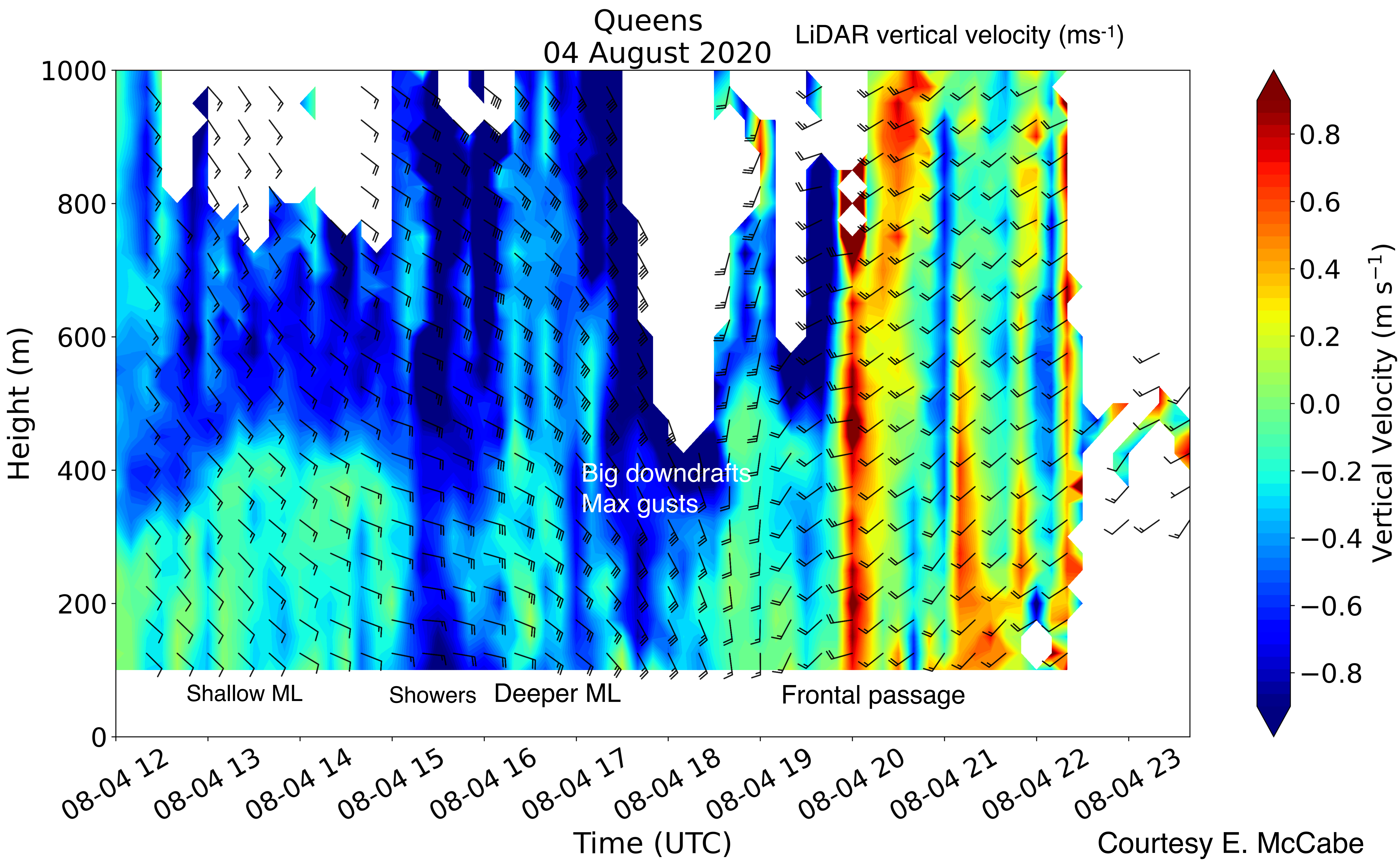
ence



Response to H↑, S_{dn}↑, R_n↑—mixing results in little difference in peak gusts between 10 m and 300 m AGL



Queens
04 August 2020
LiDAR winds (1 barb = 10 ms-1) and Radiometer θ
Courtesy E. McCabe
Height (m)
Time (UTC)
Potential Temperature (K)
0
200
400
600
800
1000
08-04 13
08-04 14
08-04 15
08-04 16
08-04 17
08-04 18
08-04 19
08-04 20
08-04 21
08-04 22
08-04 23
292
296
300
304



Queens
04 August 2020
LiDAR vertical velocity (ms-1)
Height (m)
1000
800
600
400
200
0
Big downdrafts
Max gusts
Shallow ML
Showers
Deeper ML
Frontal passage
08-04 12
08-04 13
08-04 14
08-04 15
08-04 16
08-04 17
08-04 18
08-04 19
08-04 20
08-04 21
08-04 22
08-04 23
Time (UTC)
Vertical Velocity (m s−1)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
Courtesy E. McCabe