SESSION 7: BOUNDARY LAYER VARIABLES

BL VARIABLE TYPES

- Surface Variables
  - Roughness (z_0)

- Thermodynamic Variables
  - Virtual (Potential) Temperature
  - Water Vapor Variables

- Kinematic Variables
  - Gust Factor
  - Turbulence Intensity
  - Friction Velocity

BL THERMODYNAMIC VARIABLES

- Most of these are forms of temperature:
  - Potential temperature (altitude-corrected temperature) → θ
  - Virtual Potential Temperature → θ_v
  - Virtual Temperature → T_v

- Virtual temperature accounts for water vapor in a parcel of air.

- Since water vapor *reduces* air density, a correction is needed.

BL THERMODYNAMIC VARIABLES

- Virtual Temperature – the temperature a dry air parcel must have to maintain the same density as a humid air parcel:

$$T_v = T(1 + 0.61r)$$

Where r is the mixing ratio (in grams / gram)

- The virtual temp is the same as the regular temperature in a dry air parcel.

- In a humid parcel, the Tv can be 2-3 degrees greater than the actual T

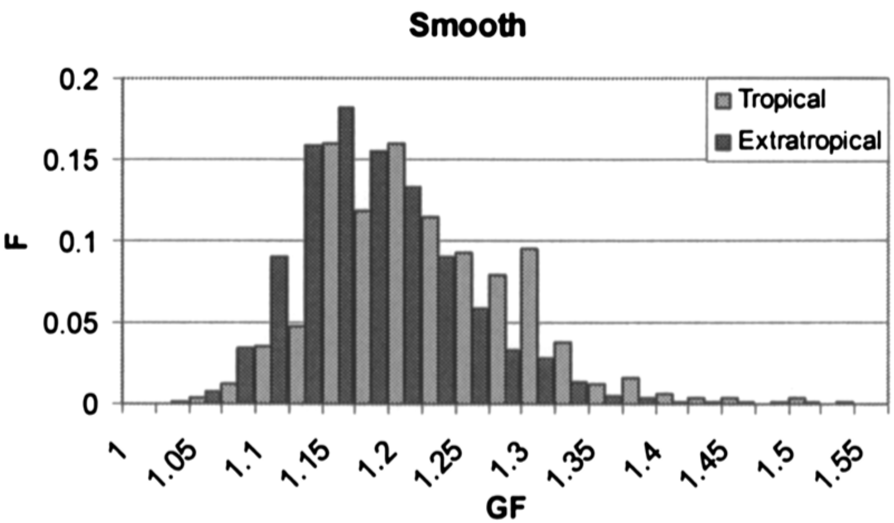
BL KINEMATIC VARIABLES

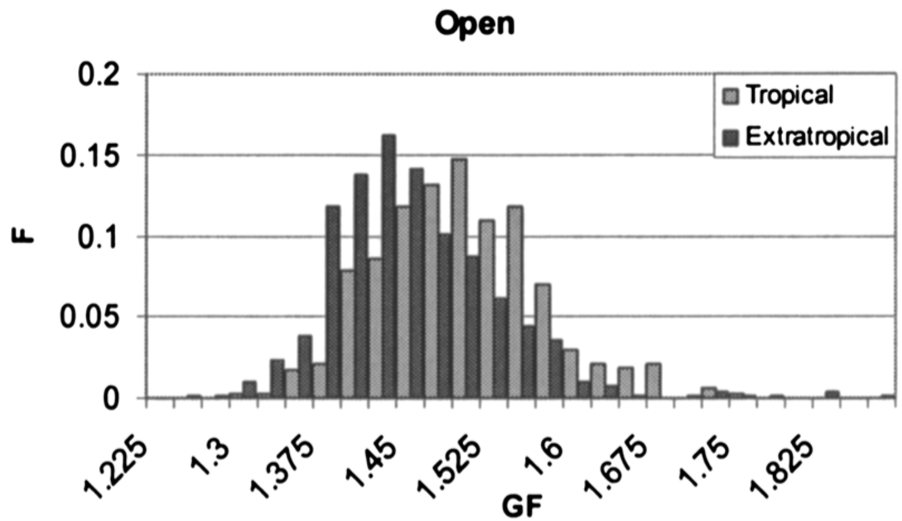
- Gust Factor
  - The ratio between the peak wind over some time period and the mean over the same time period. For example:

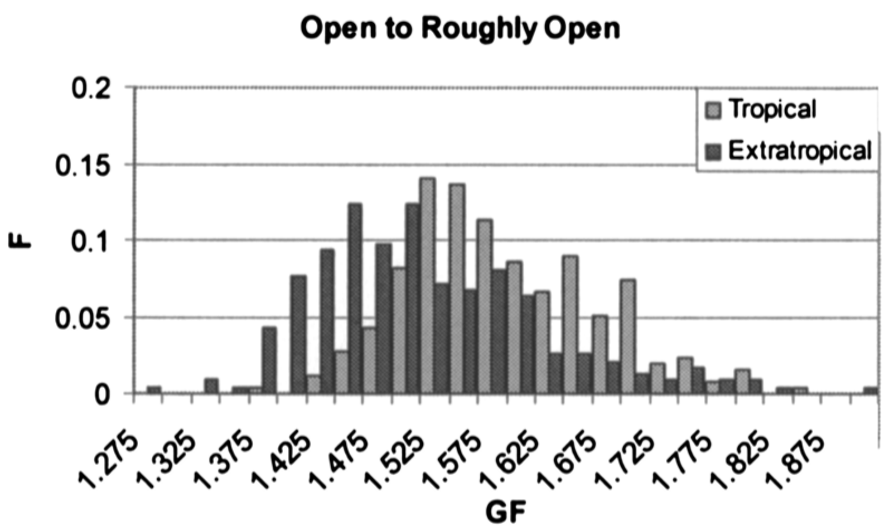
$$GF = \frac{U_{3,max}}{\overline{U}_{600}}$$

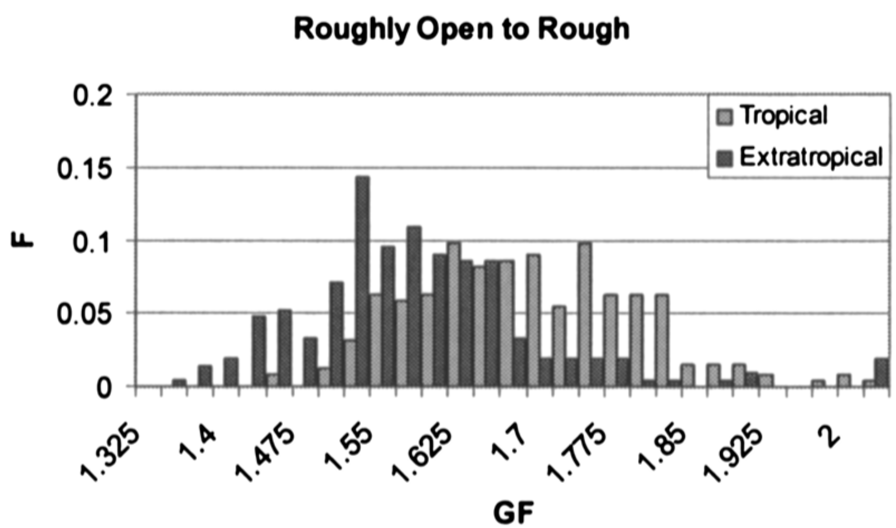
- The result describes how different a gust is from the mean wind.

- Different averaging times can be used for either and will yield different results.


Smooth
0.2
0.15
0.1
0.05
0
F
Tropical
Extratropical
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
1.55
GF

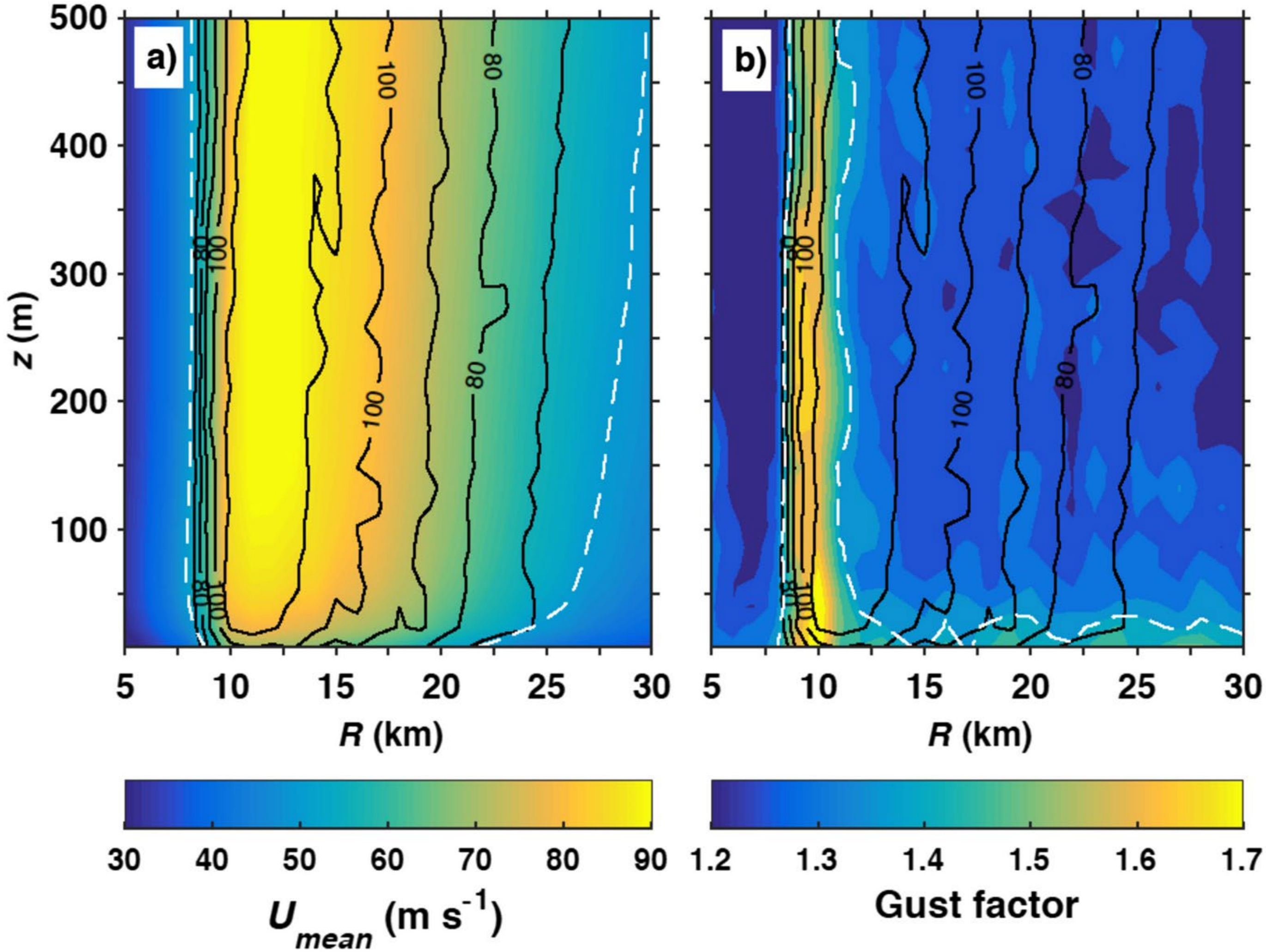

Open
0.2
0.15
0.1
0.05
0
F
Tropical
Extratropical
1.225
1.3
1.375
1.45
1.525
1.6
1.675
1.75
1.825
GF


Open to Roughly Open
0.2
0.15
0.1
0.05
0
F
Tropical
Extratropical
1.275
1.325
1.375
1.425
1.475
1.525
1.575
1.625
1.675
1.725
1.775
1.825
1.875
GF


Roughly Open to Rough
0.2
0.15
0.1
0.05
0
F
Tropical
Extratropical
1.325
1.4
1.475
1.55
1.625
1.7
1.775
1.85
1.925
2
GF

BL KINEMATIC VARIABLES

- Can be especially important for offshore turbines in hurricane regions or during intense thunderstorms



BL KINEMATIC VARIABLES

- Gust Factor
  - Also used to convert between different averaging times → "Durst Curve"

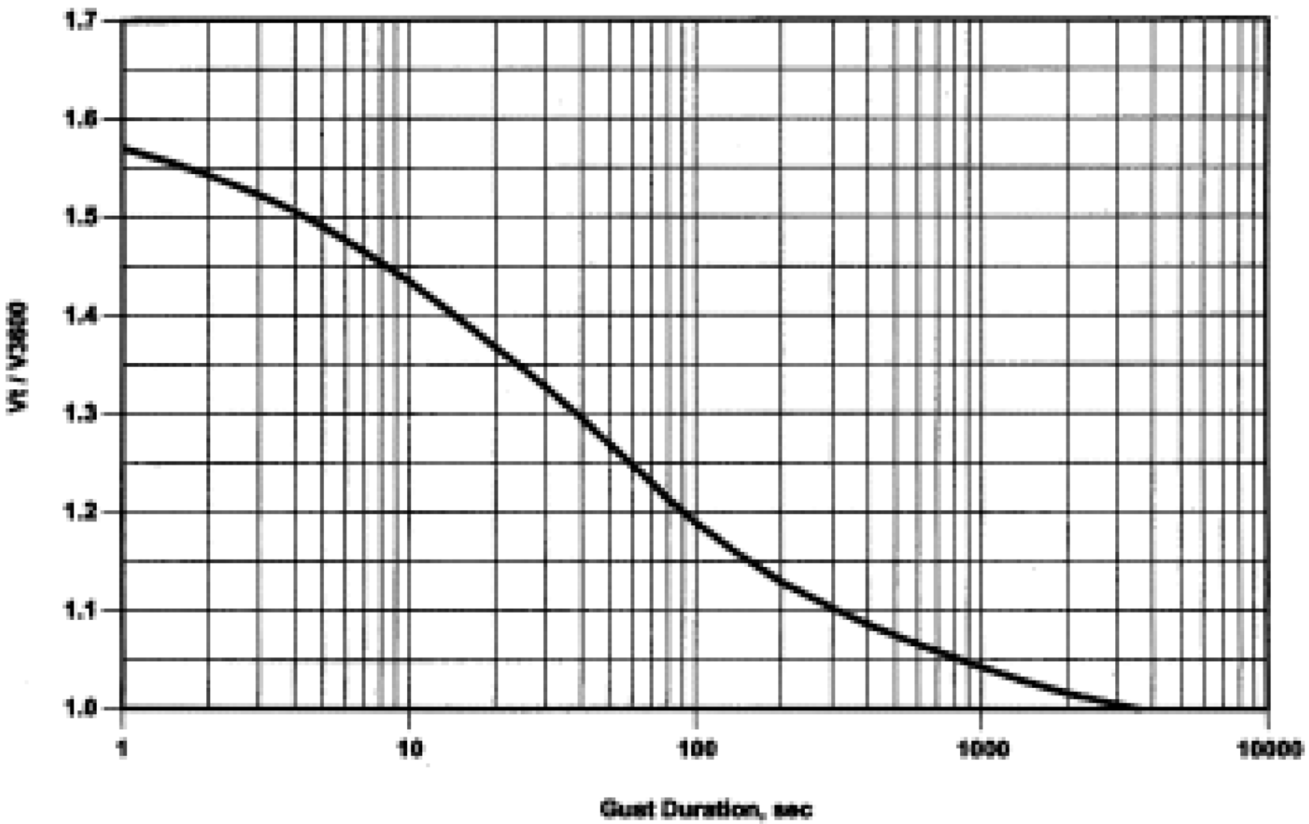


FIGURE C6-4 MAXIMUM SPEED AVERAGED OVER t_s TO HOURLY MEANS SPEED

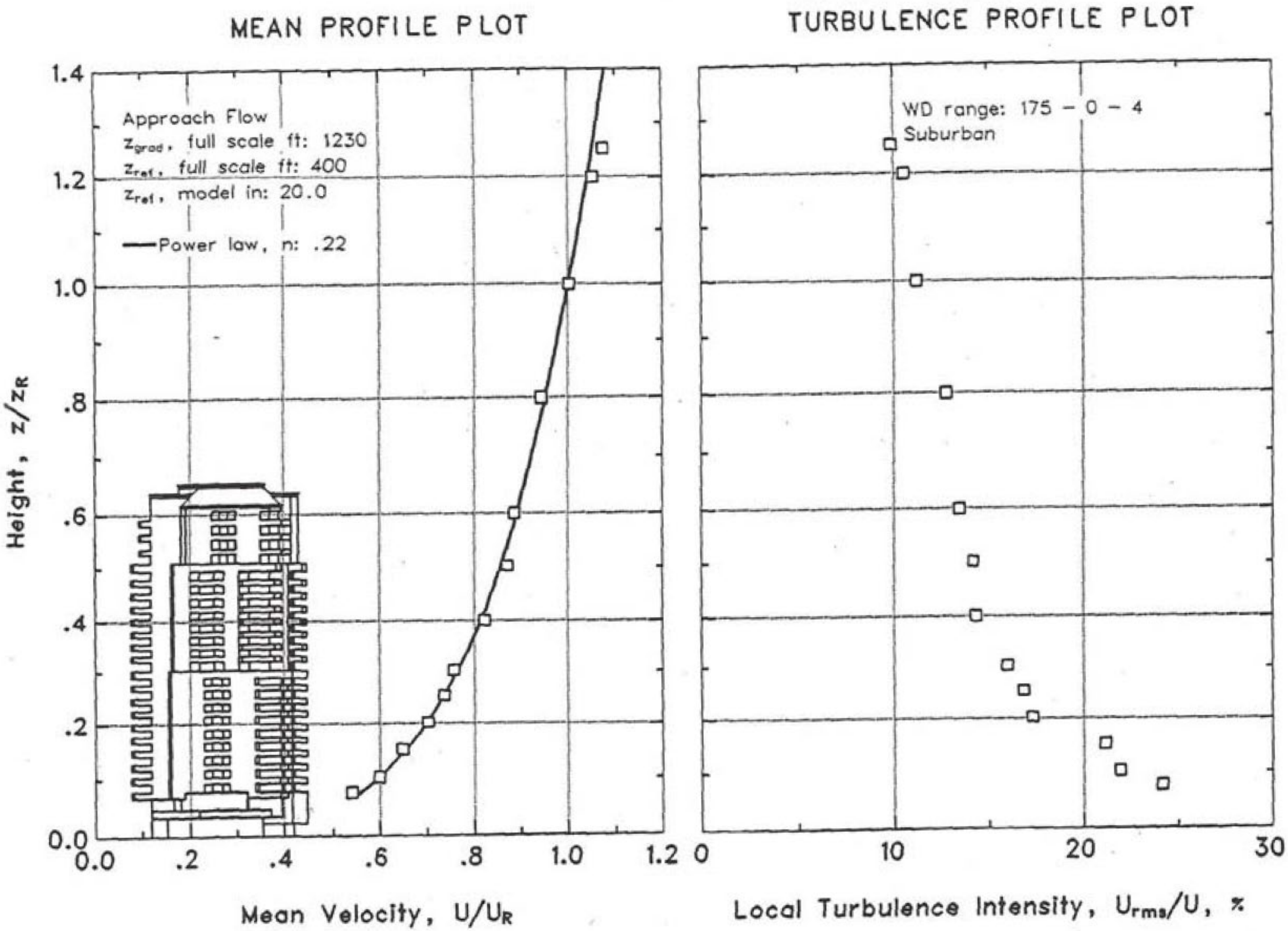
BL KINEMATIC VARIABLES

- Turbulence Intensity (TI, I)
  - The ratio between the standard deviation and the mean over the same time period. For example:

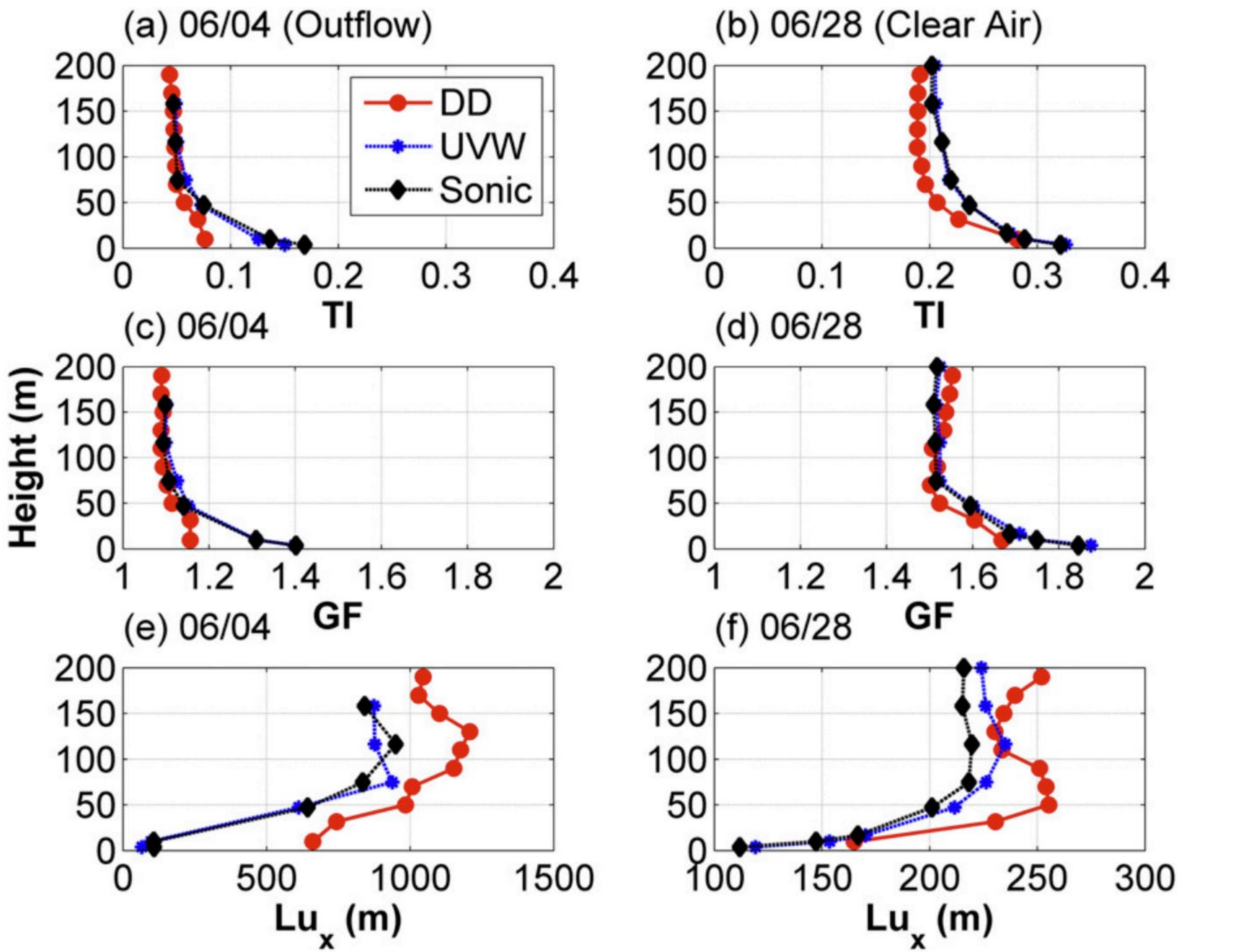
$$I_u = \frac{\sigma_u}{\overline{U}_{600}}$$

- The result:
  - describes the variation in the wind speed about the mean.
  - Is usually expressed as a %
  - Decreases with height

- Different averaging times will yield different results.



MEAN PROFILE PLOT
TURBULENCE PROFILE PLOT
Approach Flow
z_{grad}, full scale ft: 1230
z_{ref}, full scale ft: 400
z_{ref}, model in: 20.0
Power law, n: .22
WD range: 175 – 0 – 4
Suburban
Height, z/z_R
Mean Velocity, U/U_R
Local Turbulence Intensity, U_{rms}/U, %
0.0
.2
.4
.6
.8
1.0
1.2
1.4
0
10
20
30



(a) 06/04 (Outflow)
(b) 06/28 (Clear Air)
DD
UVW
Sonic
TI
TI
(c) 06/04
(d) 06/28
Height (m)
GF
GF
(e) 06/04
(f) 06/28
Lu_x (m)
Lu_x (m)

BL KINEMATIC VARIABLES

- Friction Velocity (u_*)
  - Describes a measure of the drag force per unit surface area of the ground (Stull 2017)
  - The square is also called the kinematic stress – same idea.

- Computed by:

Kinematic Stress

$$u_*^2 = \frac{\tau}{\rho}$$

OR

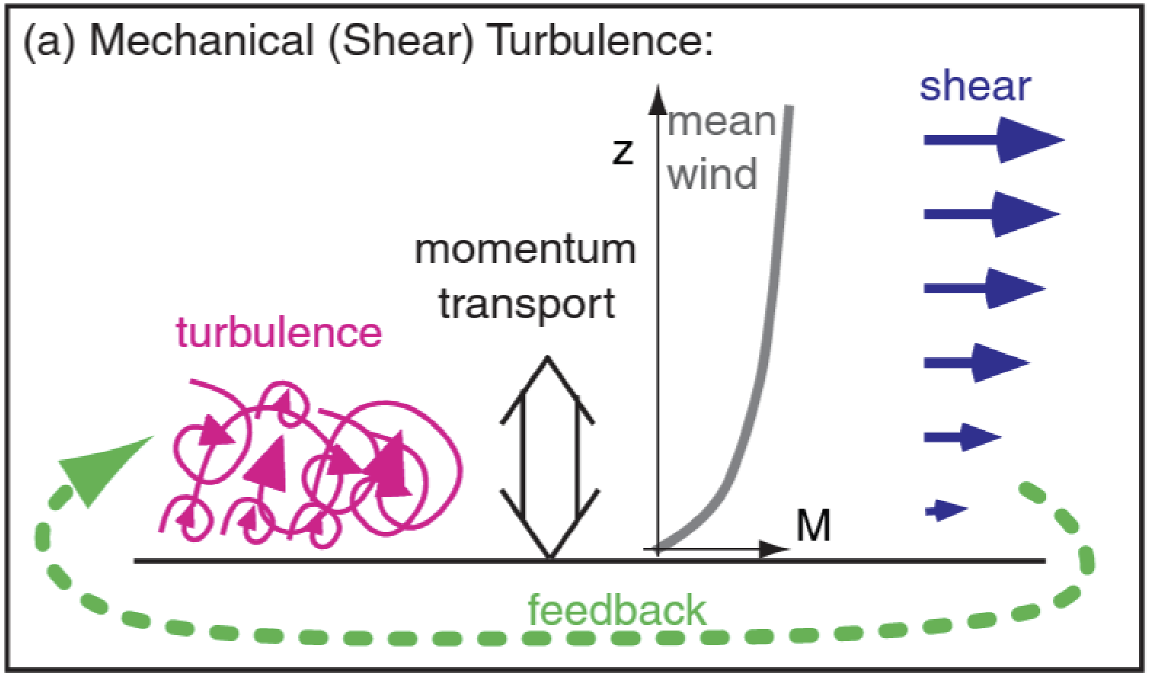
Eddy-Covariance

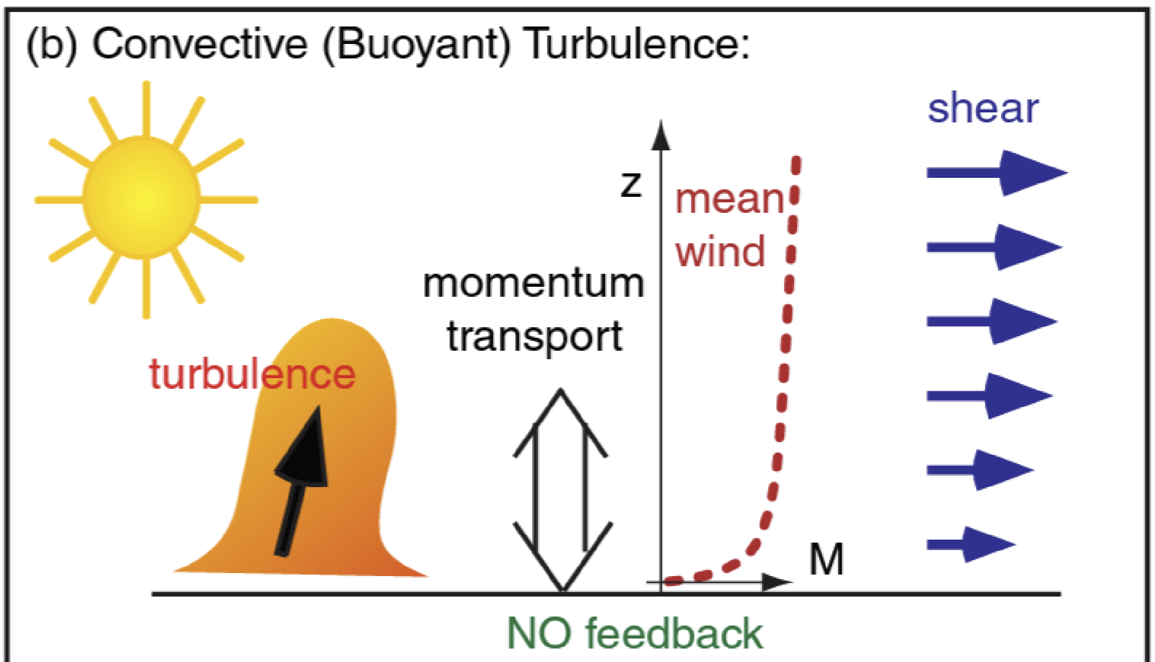
$$u_* = \left[\left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2\right]^{1/4}$$

BL VARIABLE TYPES

- Combo Variables
  - Fluxes
    - Sensible Heat
    - Latent Heat
    - Momentum
  - Obukhov Length

- These combination variables help to describe properties of the flow, e.g., whether turbulence is being generated by shear or buoyancy


(a) Mechanical (Shear) Turbulence:
shear
z
mean
wind
momentum
transport
turbulence
M
feedback


(b) Convective (Buoyant) Turbulence:
shear
z
mean
wind
momentum
transport
turbulence
M
NO feedback

TURBULENT FLUXES

- Fluxes are generally computed as covariances:

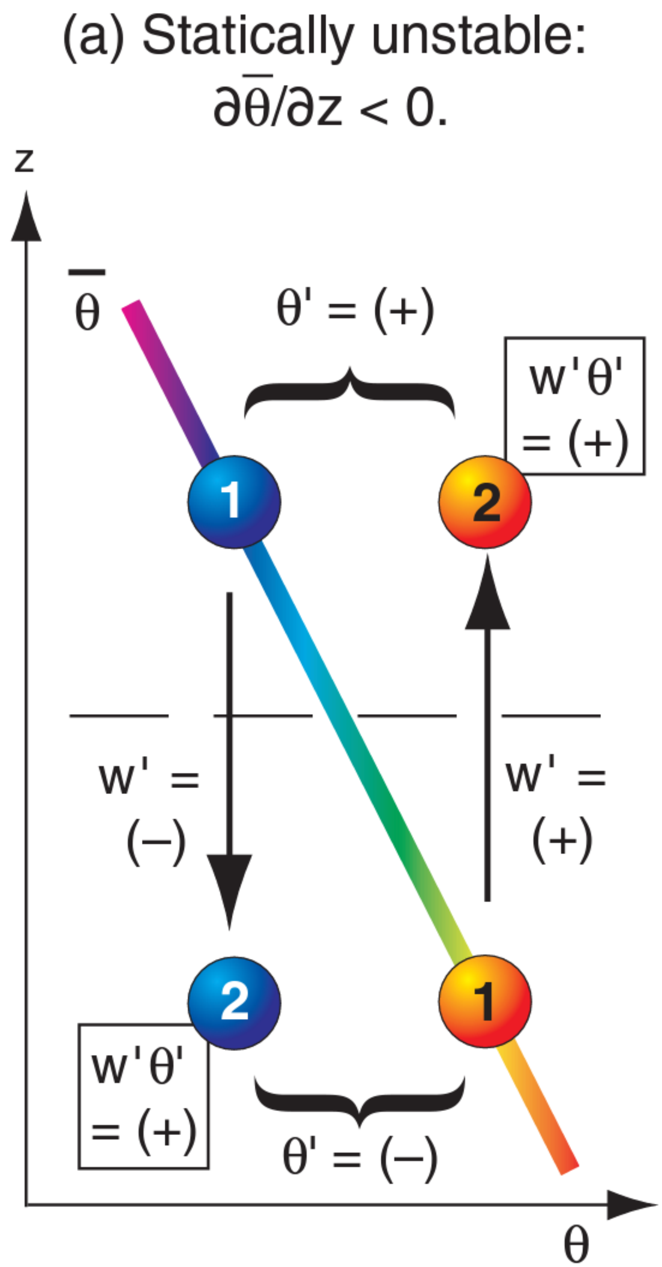
$$\begin{aligned}\text{covar}(w,\theta) &= \frac{1}{N}\sum_{k=1}^{N}(W_k-\bar{W})\cdot(\theta_k-\bar{\theta})\\ &= \frac{1}{N}\sum_{k=1}^{N}(w_k{}')\cdot(\theta_k{}')\\ &= \overline{w'\theta'}\end{aligned}$$

- Where theta is a measure of temperature (potential temperature) and w is the vertical velocity.
  - This is an example of surface heat flux

- Sign indicates direction (up or down)

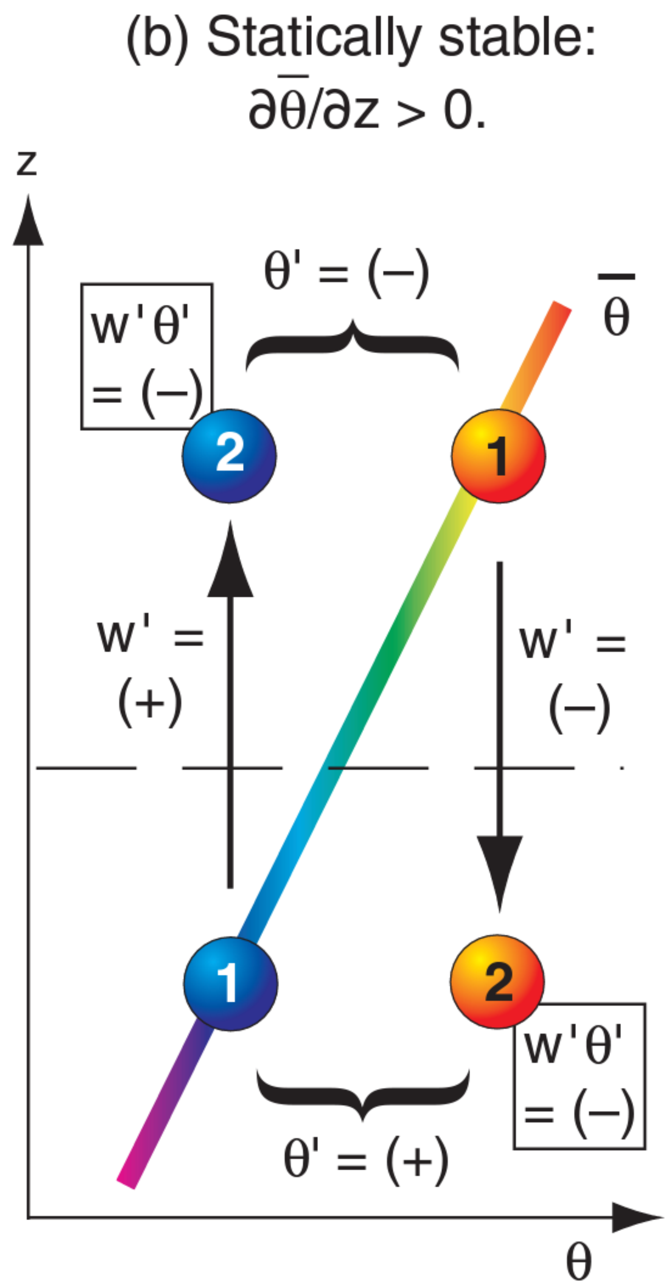
HEAT FLUX: UNSTABLE

- Warm air rising and cold air sinking produce the same sign.



HEAT FLUX: STABLE

- Stable BLs have a negative heat flux
- Buoyancy being counter-acted by turbulence
- Wind shear mechanically generating turbulence.



MOMENTUM FLUX

- Covariance between two turbulent components of the wind:

$$\overline{u'w'}$$

$$\overline{v'w'}$$

- A little unit magic proves that these are also a form of surface stress. Hence,

$$u_* = \left[\left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2\right]^{1/4}$$

BL STABILITY

- L is referred to as the Obukhov Length:

$$L = \frac{-{u_*}^3}{k \cdot (|g| / T_v) \cdot F_{Hsfc}}$$

- Where F is surface heat flux and Tv is the virtual temperature.
- L has units of meters:
  - Positive in stable atmosphere
  - Negative in unstable conditions.

ACTIVITY

	A	B	C	D	E
1	Given:				
2	t (s)	θ (°C)	r (g/kg)	U (m/s)	W (m/s)
3	0	21	6.0	10	-5
4	0.1	28	9.5	6	4
5	0.2	29	10.0	7	3
6	0.3	25	8.0	3	4
7	0.4	22	6.5	5	0
8	0.5	28	9.5	15	-5
9	0.6	23	7.0	12	-1
10	0.7	26	8.5	16	-3
11	0.8	27	9.0	10	2
12	0.9	24	7.5	8	-4
13	1.0	21	6.0	14	-4
14	1.1	24	7.5	10	1
15	1.2	25	8.0	13	-2
16	1.3	27	9.0	5	3
17	1.4	29	10.0	7	5
18	1.5	22	6.5	11	2
19	1.6	30	10.5	2	6
20	1.7	23	7.0	15	-1
21	1.8	28	9.5	13	3
22	1.9	21	6.0	12	-3
23	2.0	22	6.5	16	-5

- Using the data in the table and the definitions provided, compute the surface heat flux for this data set.