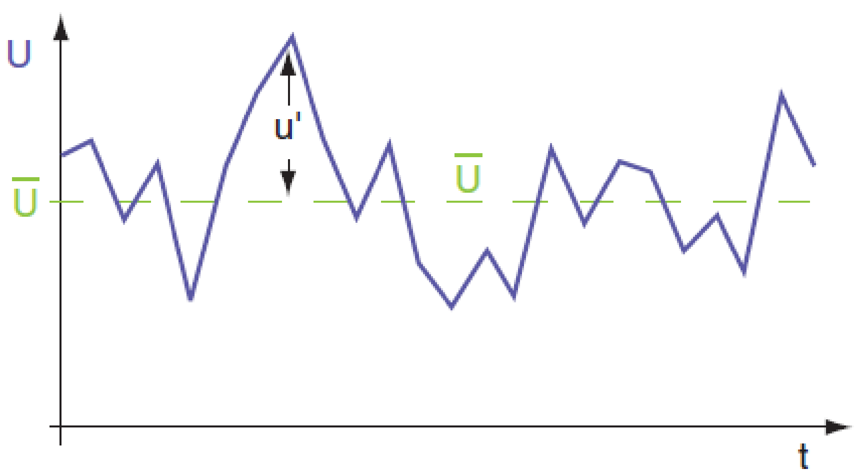
BOUNDARY LAYER TURBULENCE

- The wind can be separated into two basic components:
  - Mean → relatively constant over short periods of time, but varying over the course of hours
  - Turbulence → irregular, quasi-random, nonlinear variations or gusts with durations of seconds to minutes.

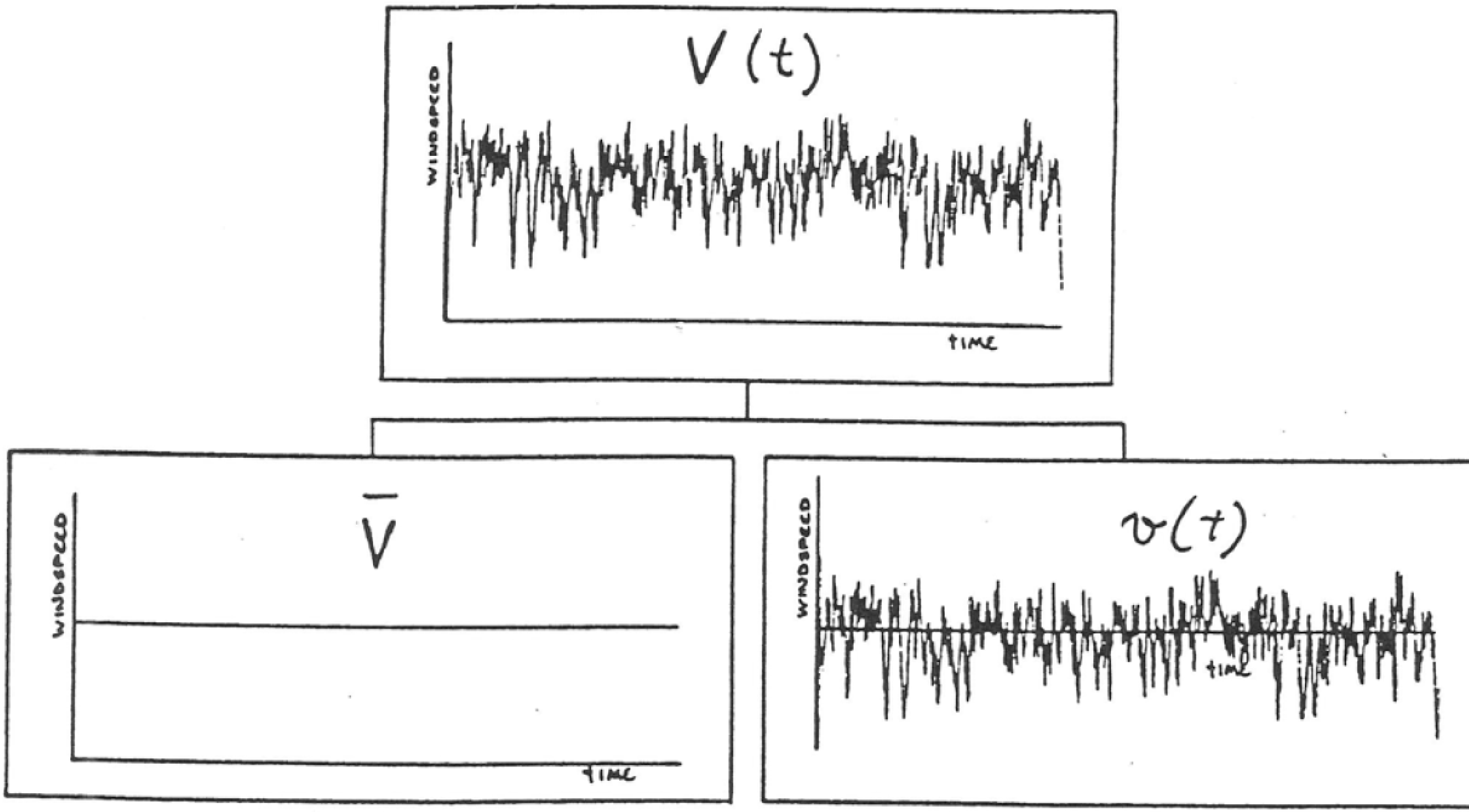


$$u'(t) = U(t) - \overline{U}$$

$$v'(t) = V(t) - \overline{V}$$

$$w'(t) = W(t) - \overline{W}$$

INSTANTANEOUS WIND SPEED



MEAN

FLUCTUATING COMPONENT.

TURBULENCE

- The averages are defined over time (30 min – 1 hr.) or horizontal distance (50 to 100 km).
- Primed quantities indicate short term fluctuations associated with small scale swirls of motion, called eddies.
- Turbulence is the superposition of many eddies of many different sizes.
- Turbulence is dissipative → goes away unless something is there to make it.

$$u'(t) = U(t) - \overline{U}$$

$$v'(t) = V(t) - \overline{V}$$

$$w'(t) = W(t) - \overline{W}$$

$$T'(t) = T(t) - \overline{T}$$

$$r'(t) = r(t) - \overline{r}$$

TURBULENCE MATH

- Since it is chaotic, it is based on statistics.
- Variance $\sigma_w{}^2$

$$\begin{aligned} &= \frac{1}{N}\sum_{k=1}^{N}(W_k - \bar{W})^2 \\ &= \frac{1}{N}\sum_{k=1}^{N}(w_k{}')^2 \\ &= \overline{w'^{\,2}} \end{aligned}$$

- Standard Deviation: $\sigma_w = \sqrt{\sigma_w{}^2} = \overline{(w')^2}^{\,1/2}$

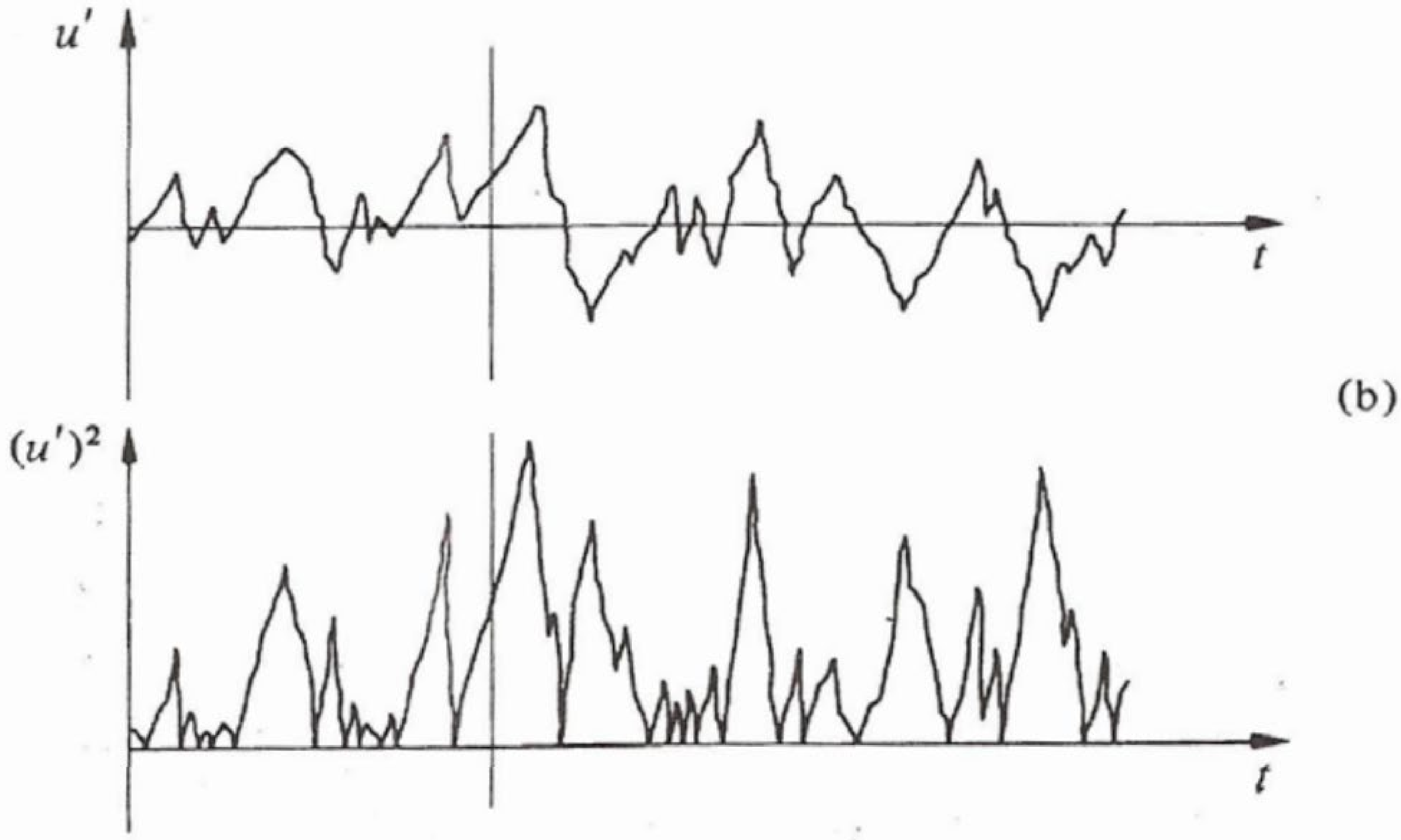
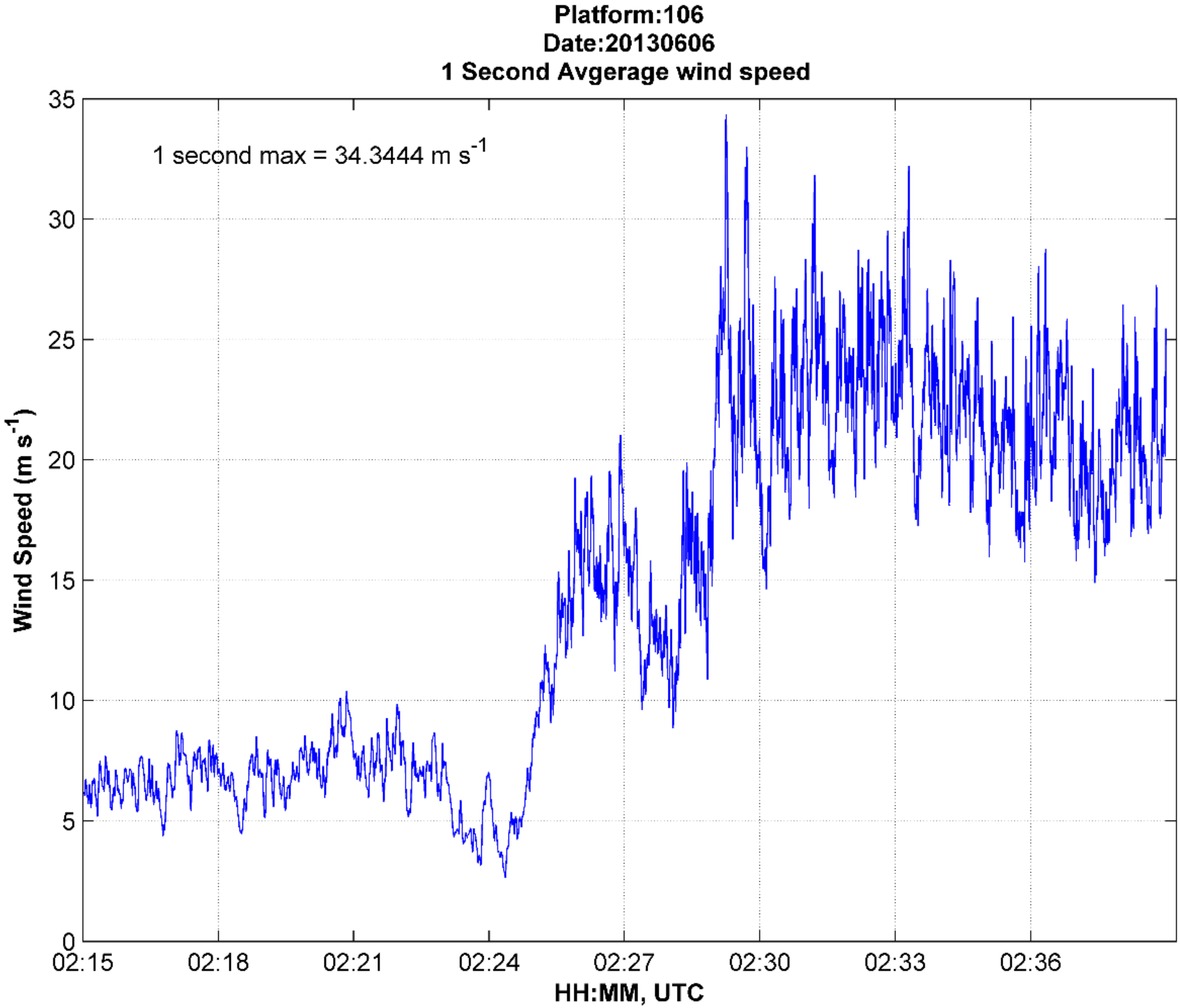
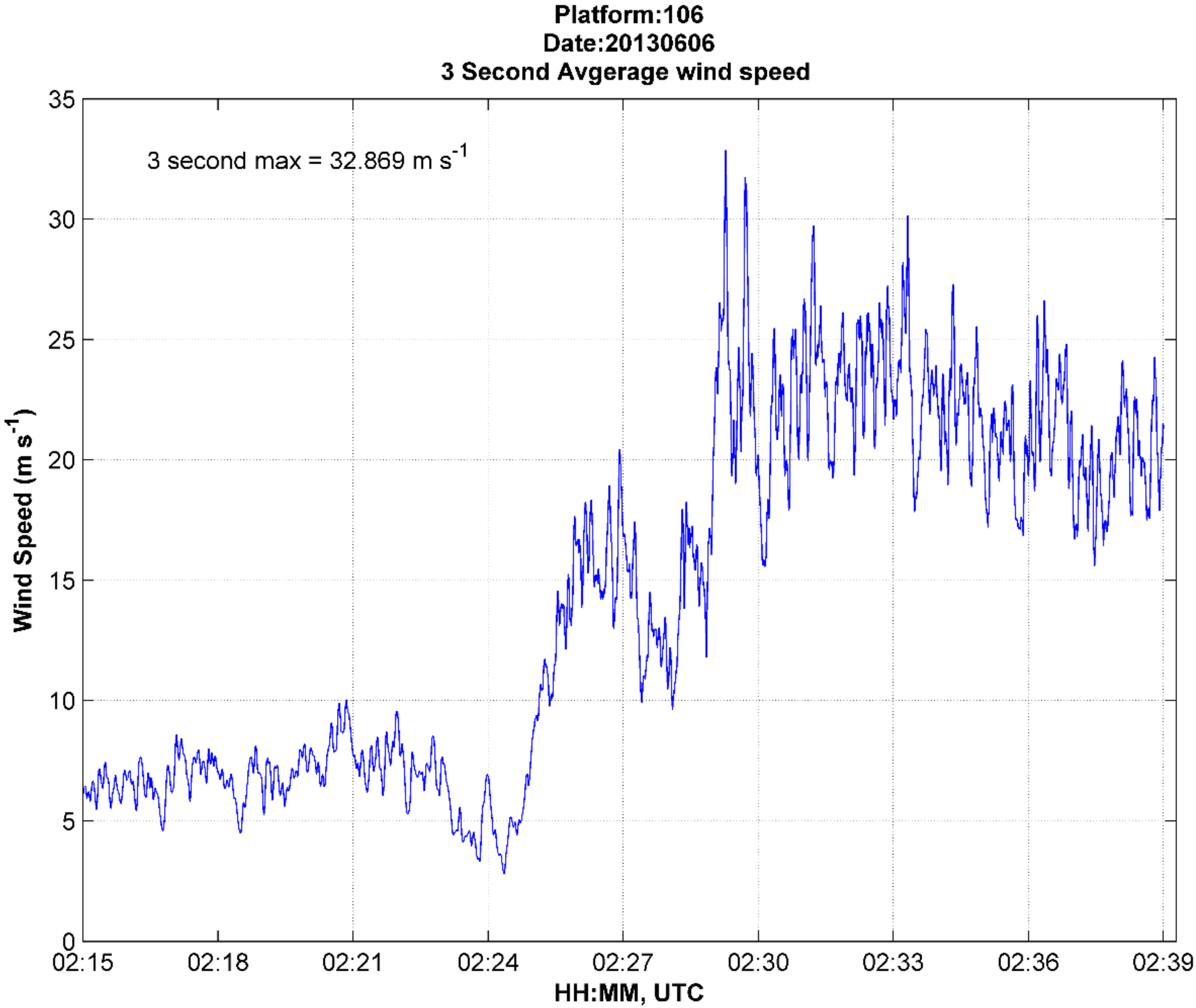


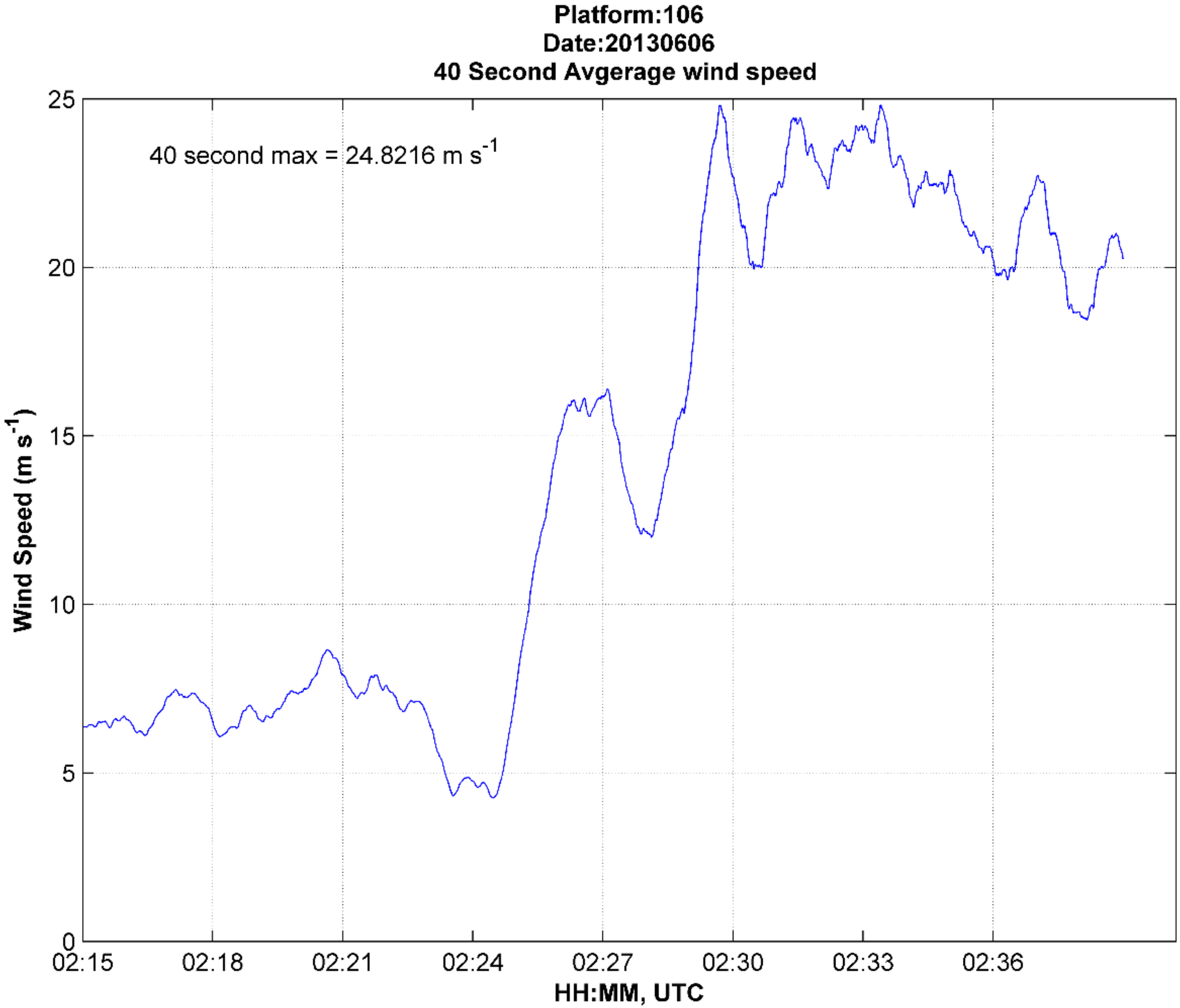
Fig. 3.19

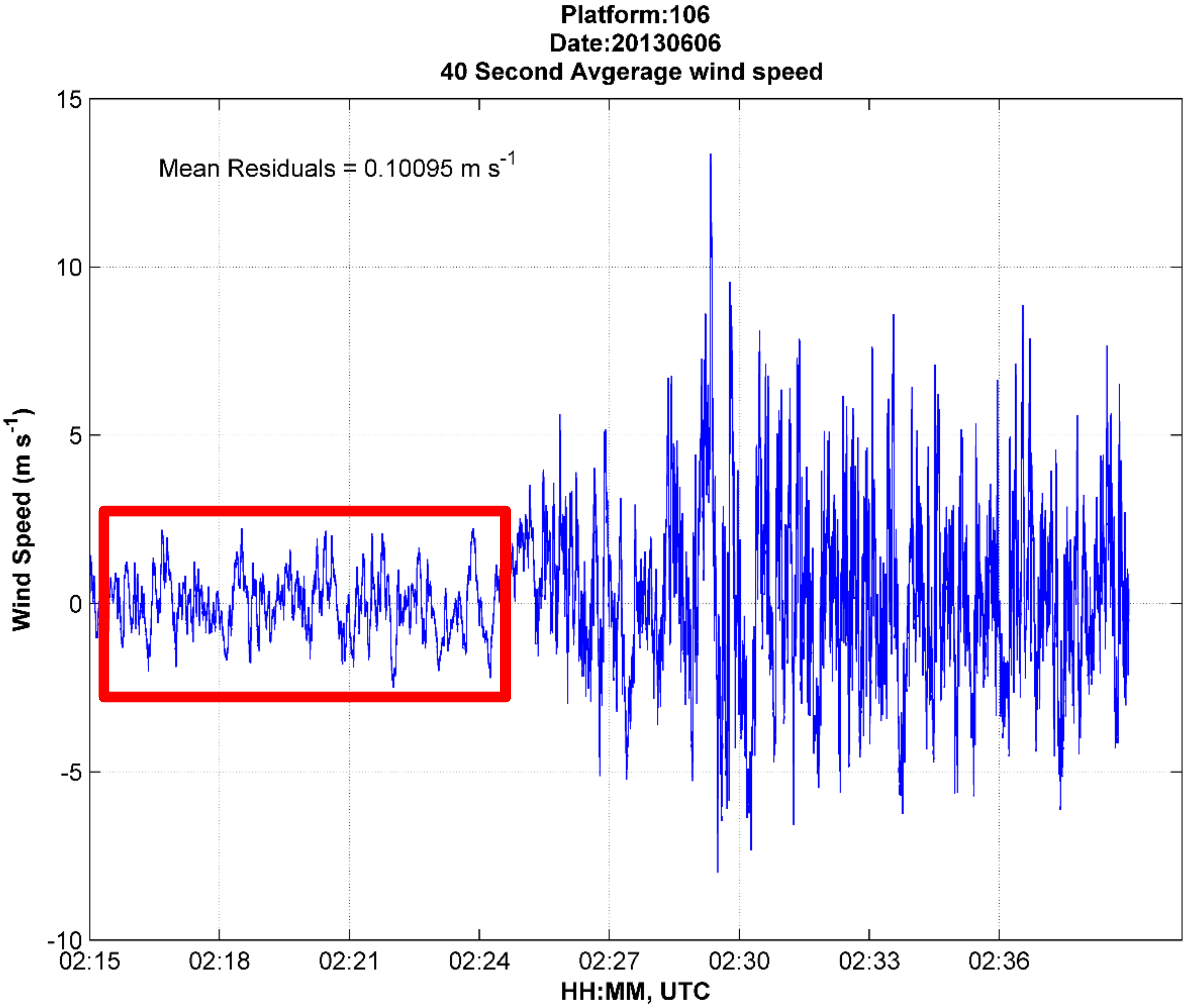
Houghton & Carruthers (p.86)


Platform:106
Date:20130606
1 Second Avgerage wind speed
1 second max = 34.3444 m s-1
Wind Speed (m s-1)
35
30
25
20
15
10
5
0
02:15
02:18
02:21
02:24
02:27
02:30
02:33
02:36
HH:MM, UTC



Platform:106
Date:20130606
3 Second Avgerage wind speed
3 second max = 32.869 m s-1
Wind Speed (m s-1)
35
30
25
20
15
10
5
0
02:15
02:18
02:21
02:24
02:27
02:30
02:33
02:36
02:39
HH:MM, UTC


Platform:106
Date:20130606
40 Second Avgerage wind speed
40 second max = 24.8216 m s-1
Wind Speed (m s-1)
25
20
15
10
5
0
02:15
02:18
02:21
02:24
02:27
02:30
02:33
02:36
HH:MM, UTC


Platform:106
Date:20130606
40 Second Avgerage wind speed
Mean Residuals = 0.10095 m s-1
Wind Speed (m s-1)
15
10
5
0
-5
-10
02:15
02:18
02:21
02:24
02:27
02:30
02:33
02:36
HH:MM, UTC

TURBULENCE

- Turbulence can be isotropic:

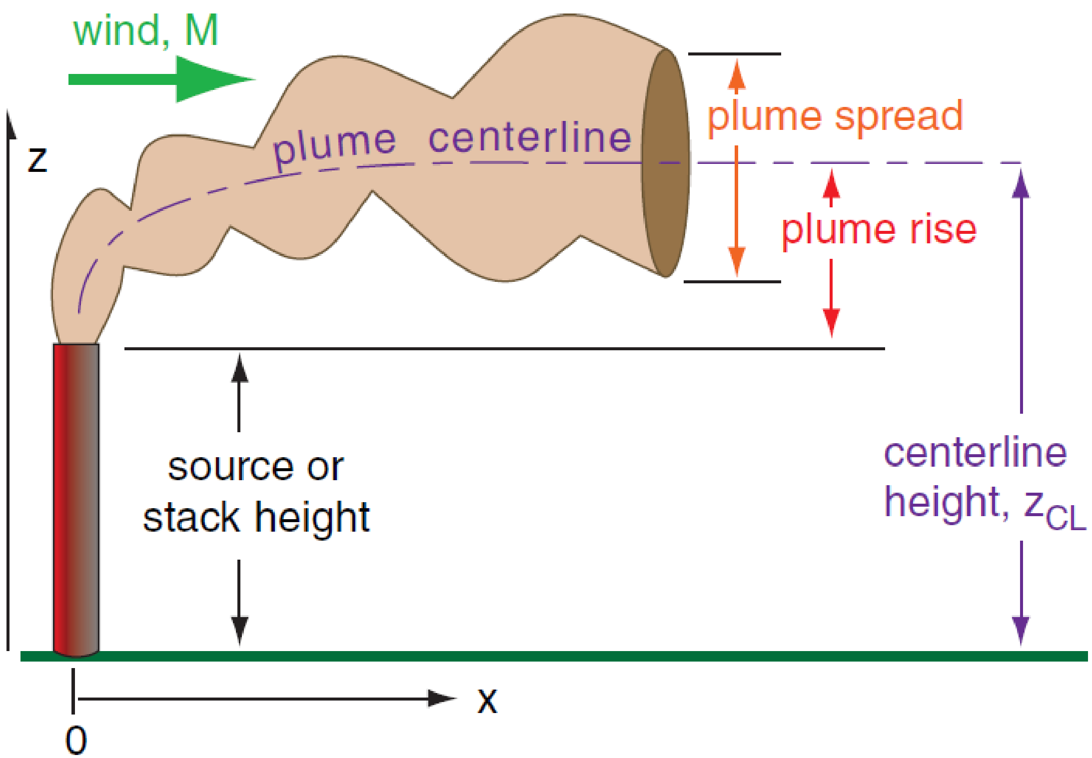
$$\sigma_u^{\;2} \approx \sigma_v^{\;2} \approx \sigma_w^{\;2}$$

but it is more often anisotropic.

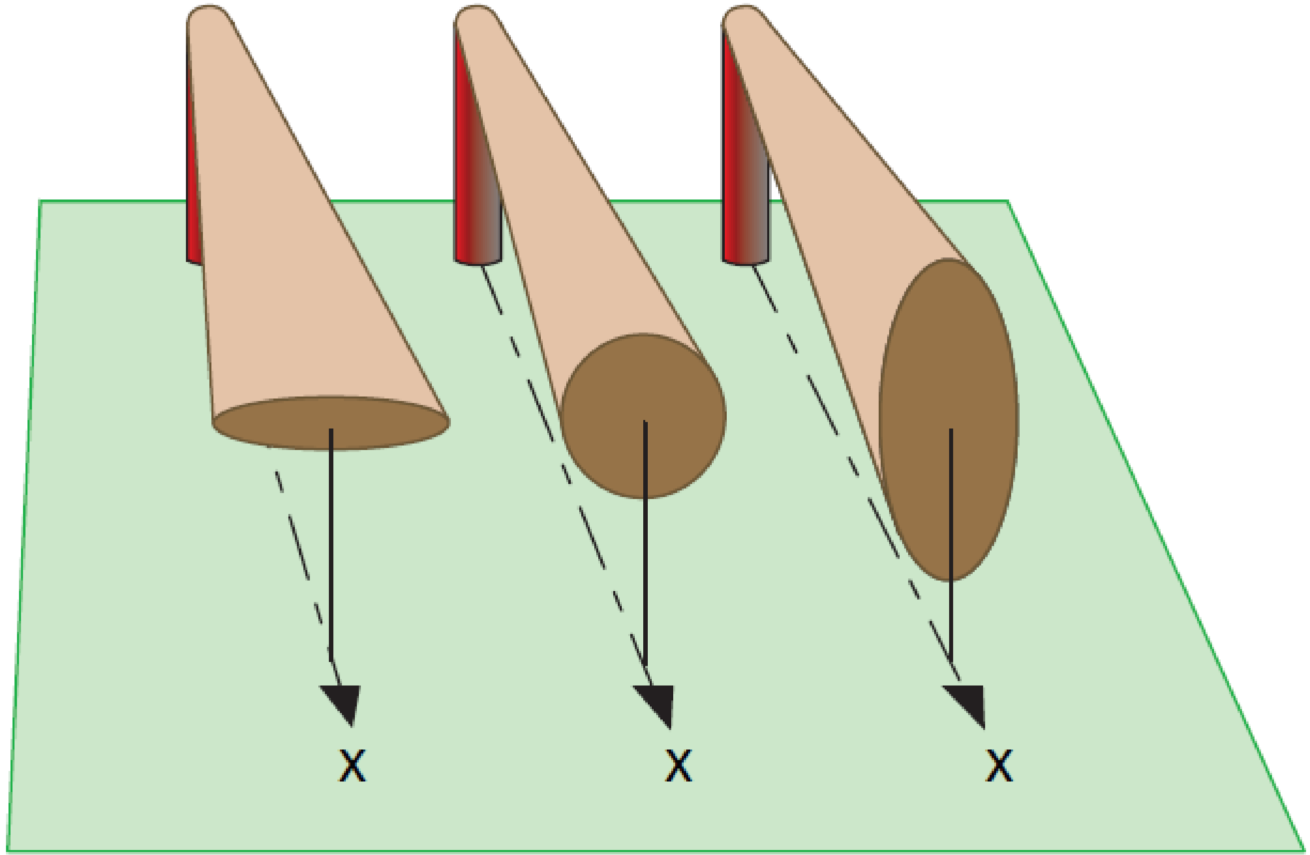
- Example: during strong day time heating, rising thermals create stronger vertical motion then horizontal. This causes a point source to become dispersed (spread out) in the vertical faster than the horizontal.
  - Ex. Smoke plumes

SMOKE PLUME SCIENCE

- Anthropogenic sources of pollution are often concentrated at points, like the top of smoke stacks.



Statically: stable neutral unstable

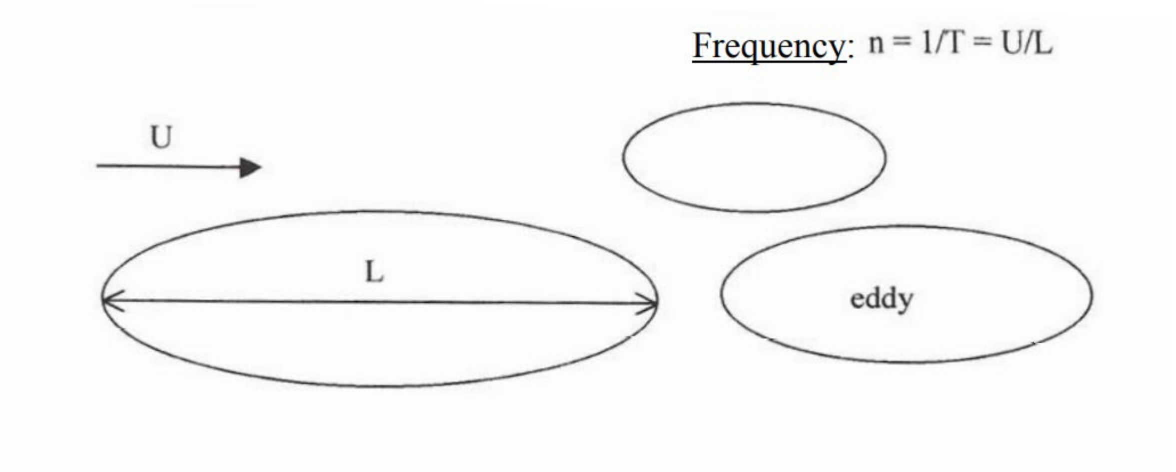


Isotropy:	anisotropic	isotropic	anisotropic
Behavior:	fanning	coning	looping
Std Deviations:	$\sigma_z < \sigma_y$	$\sigma_z = \sigma_y$	$\sigma_z > \sigma_y$
	$\sigma_w < \sigma_v$	$\sigma_w = \sigma_v$	$\sigma_w > \sigma_v$

BOUNDARY LAYER TURBULENCE

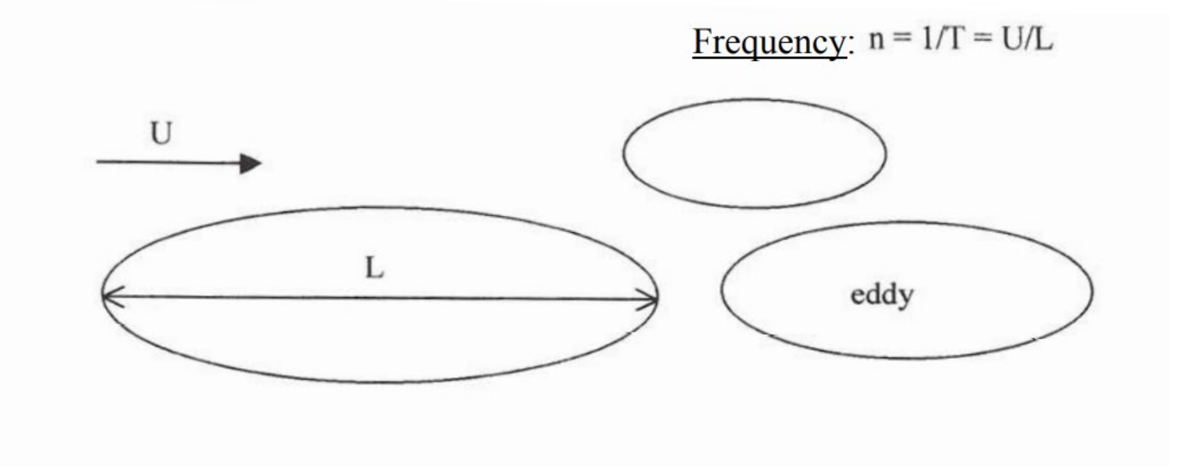
- Like EM radiation, turbulence exists on a spectrum → Gusts can be different sizes and last for different periods of time.

- Analyze the spectrum of turbulence through harmonic analysis (i.e., Fourier Analysis).
  - Provides the energy at different frequencies of turbulence.
  - Frequency is then related to size via Taylor's Hypothesis



BOUNDARY LAYER TURBULENCE

- With this model of turbulence:
  - Low frequency fluctuation implies a large eddy (gust / lull) moving past the sensor
  - High frequency fluctuation implies a small eddy moving past the sensor.
- Analysis performed on each component of the wind, since the eddies can vary in orientation.



BOUNDARY LAYER TURBULENCE

- What should we expect?
- Depends on the length of the record!

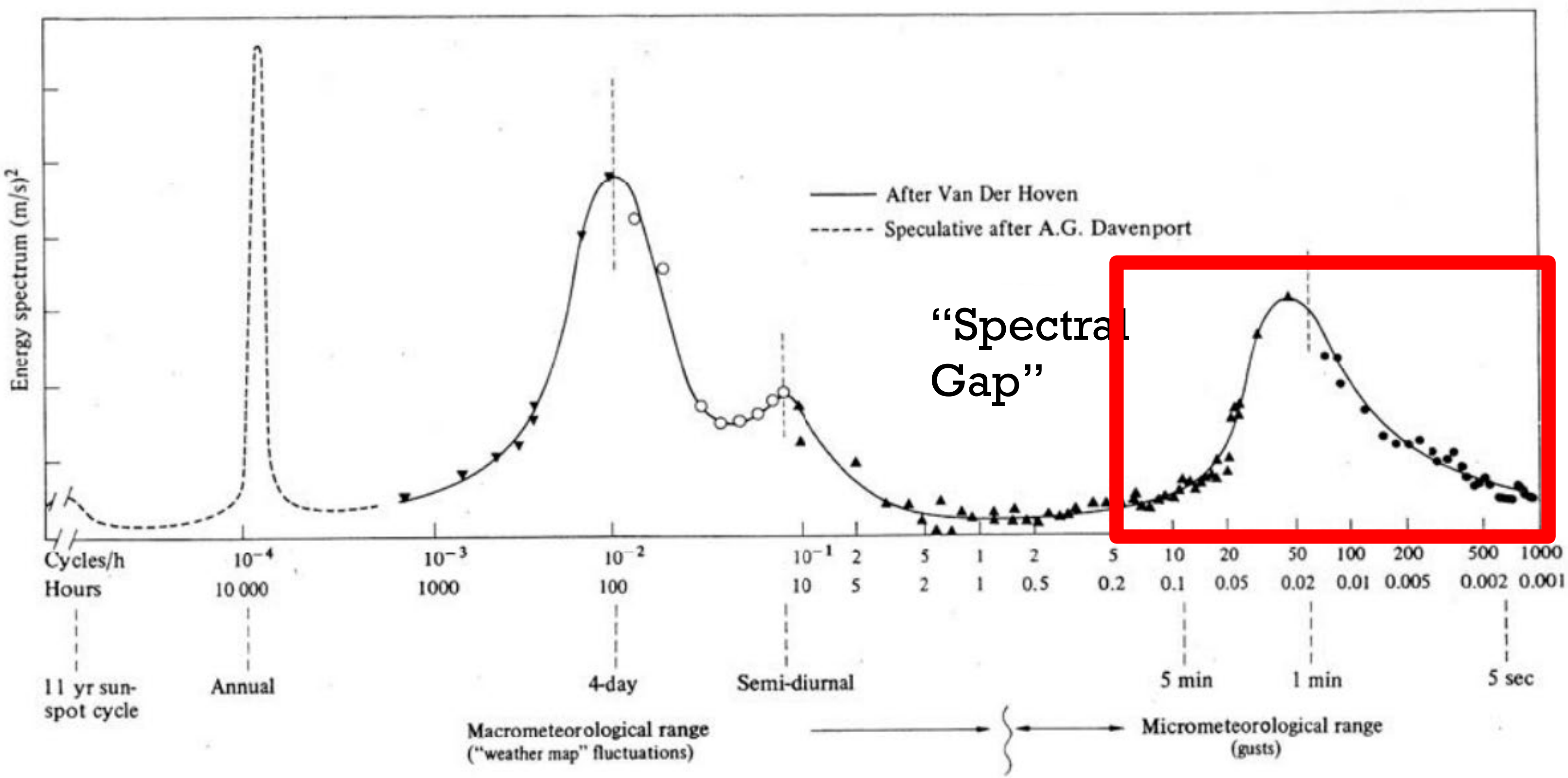
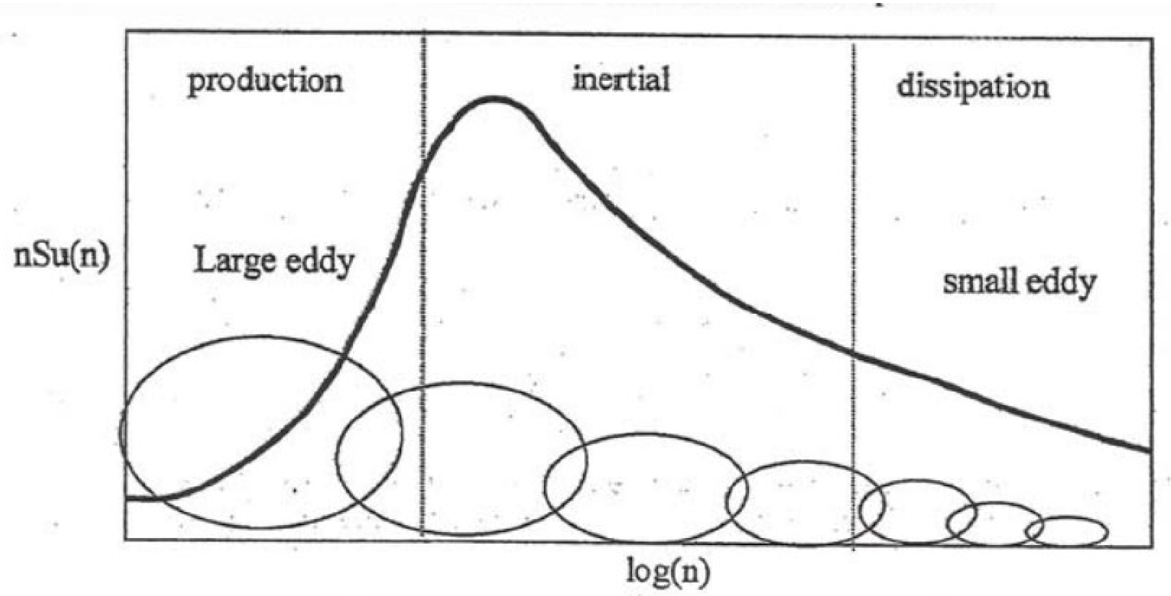


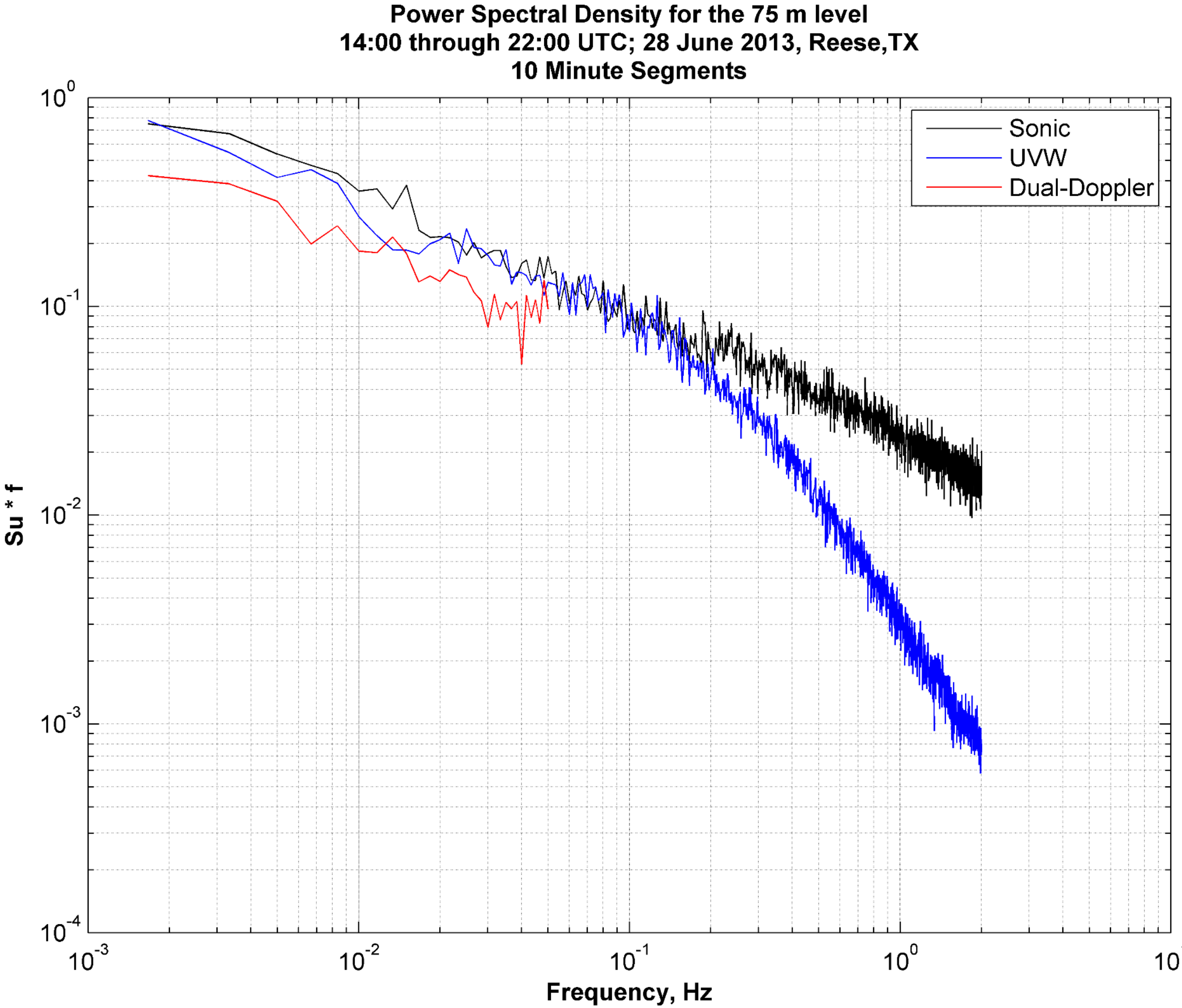
Fig. 3.23 Spectrum of horizontal wind speed near the ground for an extensive frequency range (from measurements at 100 m height by Van der Hoven at Brooklyn, NY, USA)

Houghton & Carruthers (p. 96)

BOUNDARY LAYER TURBULENCE



- **Production subrange:** turbulence generated from instabilities in the mean flow.
- **Inertial subrange:** larger eddies break up and transfer energy to smaller eddies.
- **Dissipation subrange:** eddies become so small that the viscous forces dissipate them as heat.


Power Spectral Density for the 75 m level
14:00 through 22:00 UTC; 28 June 2013, Reese,TX
10 Minute Segments
Sonic
UVW
Dual-Doppler
Su * f
Frequency, Hz
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}

BOUNDARY LAYER TURBULENCE

Science Graffito

"Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity – in the molecular sense."
– *L.F. Richardson*, 1922: "Weather Prediction by Numerical Process". Cambridge Univ. Press. p66.