Observations of turbulence using the Aquadopp HR Profiler

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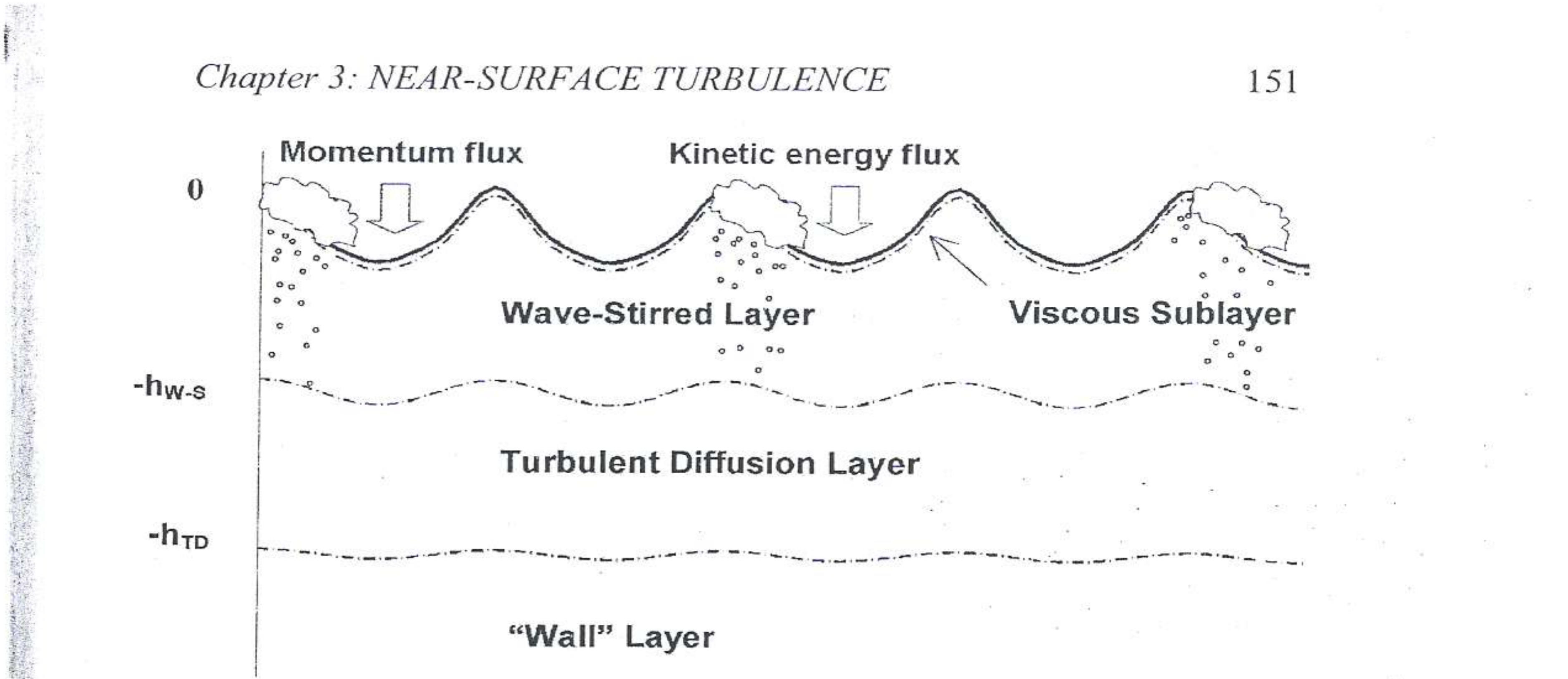
Outline

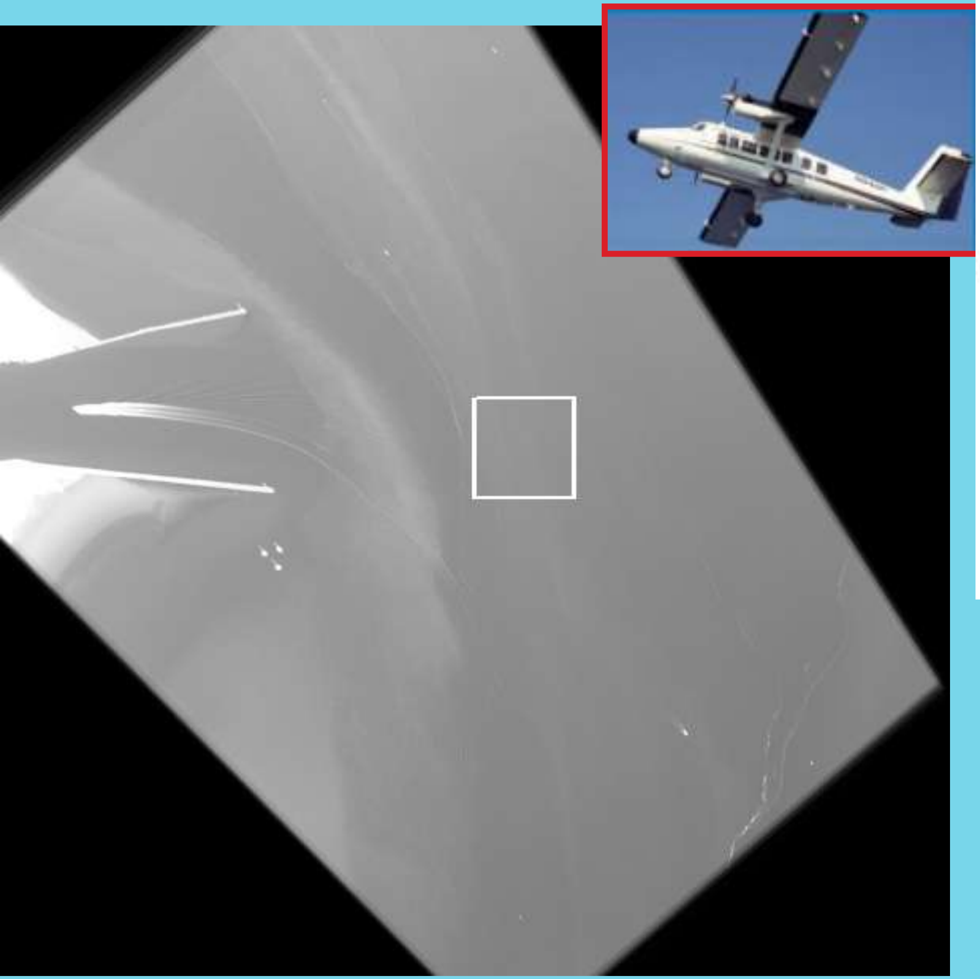
1) Motivation, Experimental setup, and Instrumentation.
2) Investigative Query
3) Data analysis and Results
4) Conclusions

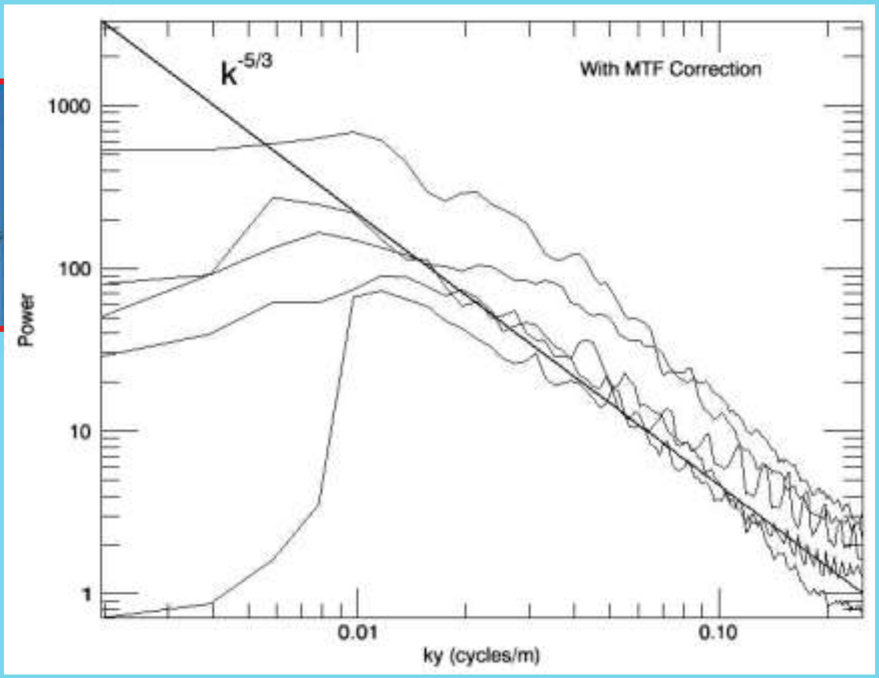
Importance of Riverine Turbulence

1) Plays a role in air-sea momentum flux and heat & gas exchange.
2) Allows boundary layer to communicate information into the river interior.



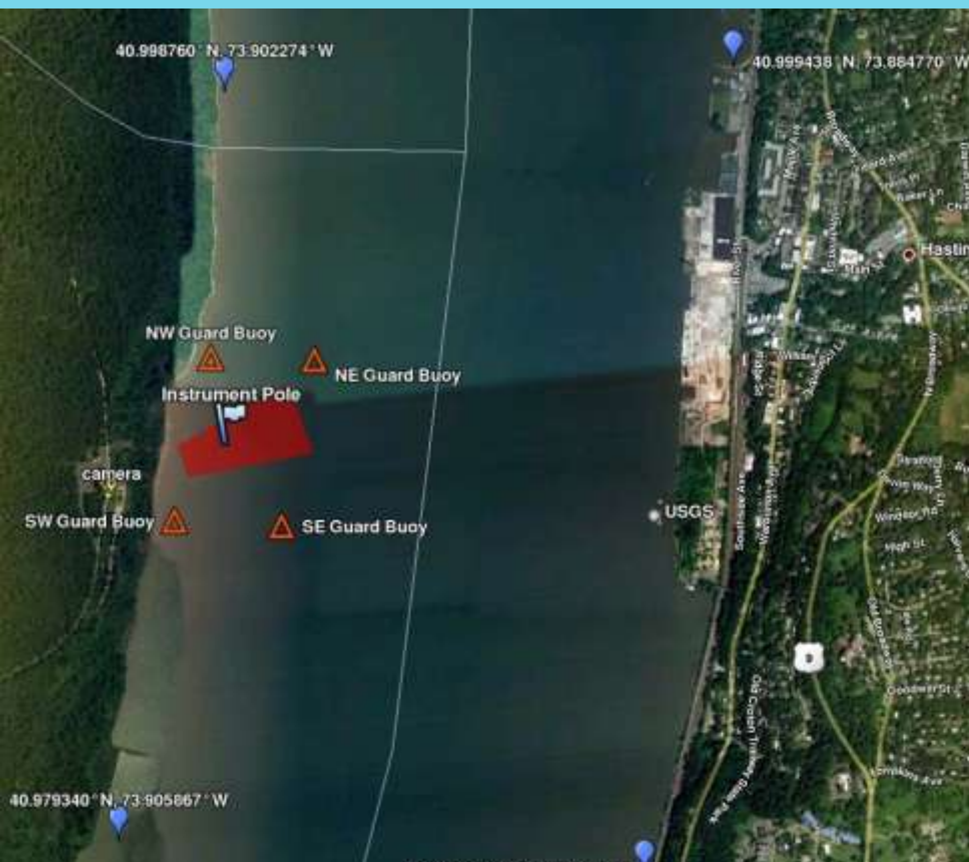
<u>Turbulent intensity</u> proportional to surface EO radiance which is what **Airborne Remote Optical Spotlight System (AROSS)** captures to do current estimation.





1-D spectra for five 512 m data cubes exhibiting expected *k-5/3* slope with energy containing scale of ~100 m.
(Dugan and Piotrowski, 2011)

Hudson River near State Line Lookout in Palisades Interstate Park, NJ



20 miles north of Manhattan

State Line Lookout Instrumentation

2 MHz Aquadopp/CTD

1 MHz Aquadopp/CTD/ADV

2 MHz Aquadopp/CTD

Air-Sea Flux Package

1200 KHz Bottom Mounted RDI ADCP
~17' MLLW Water Depth

Piling Instruments

Diver Gauge Deployment Depths

November 12, 2010 @7:15 AM

Diver

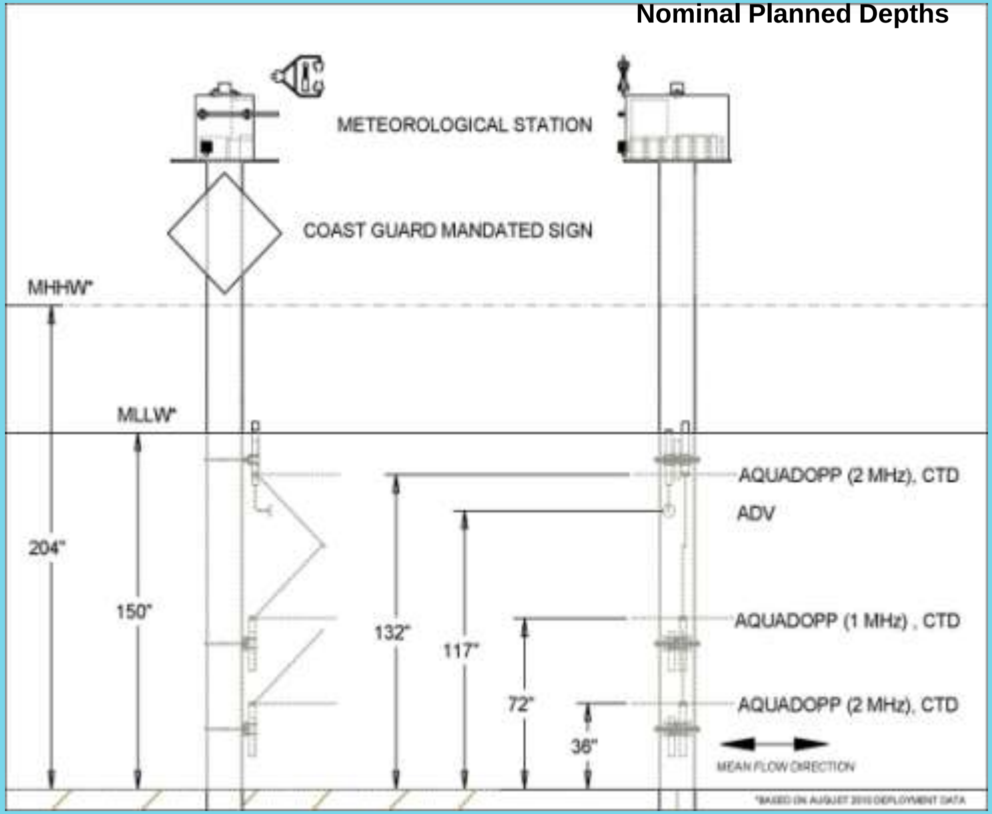
2'

5.5'

7'

11'

15'



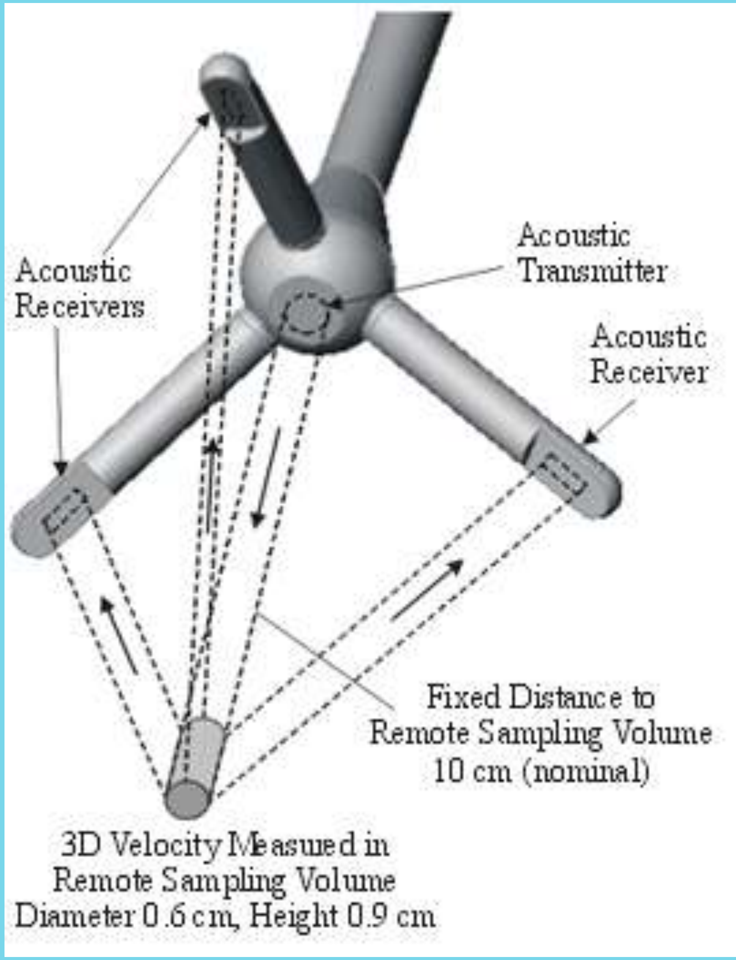
ADV

- 10 min bursts at top of every 1/2 hr.
- samp freq = 25 Hz

Aquadopp

- 59.9 min bursts at top of every hr.
- samp freq = 2 Hz

ADV Schematic

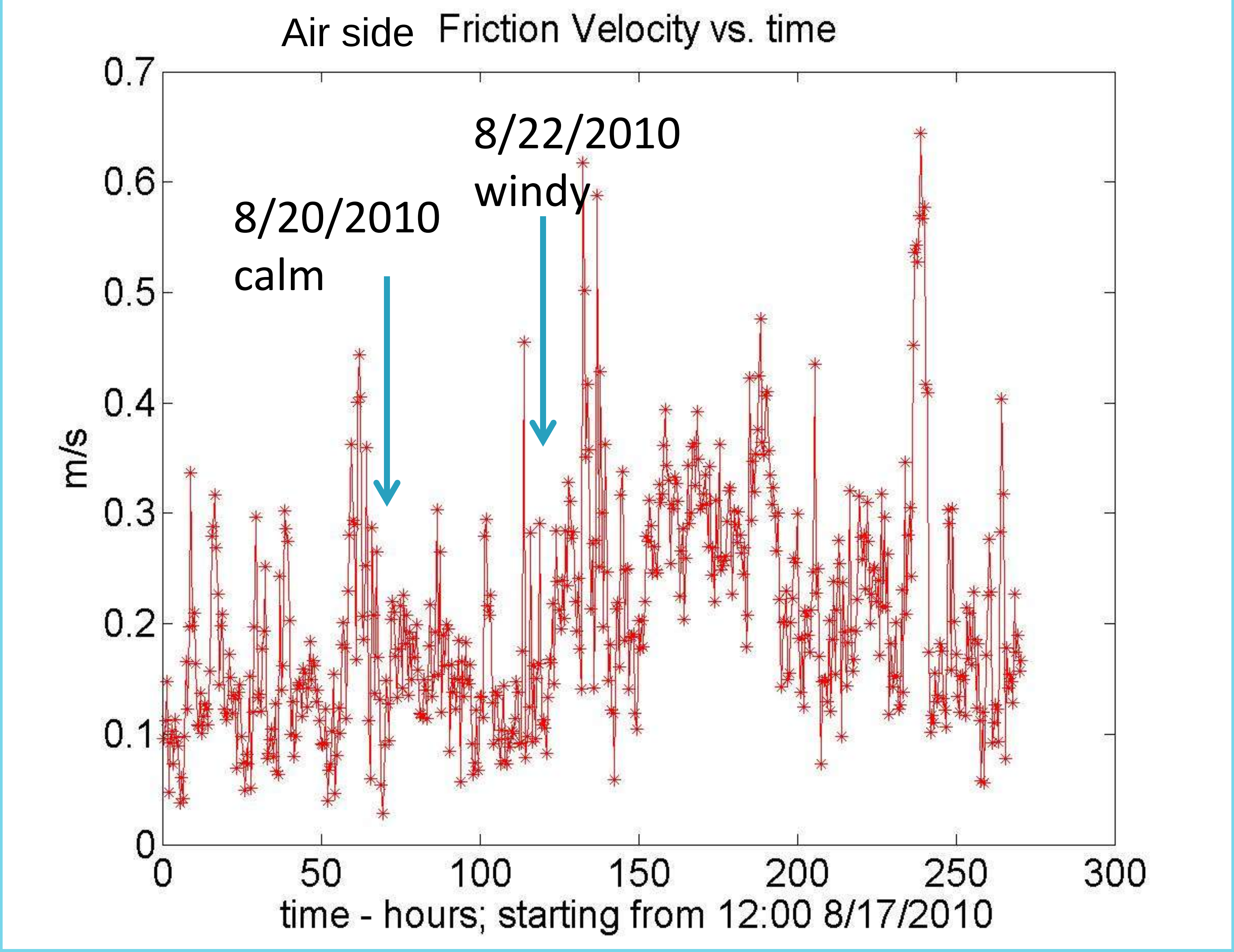


Question

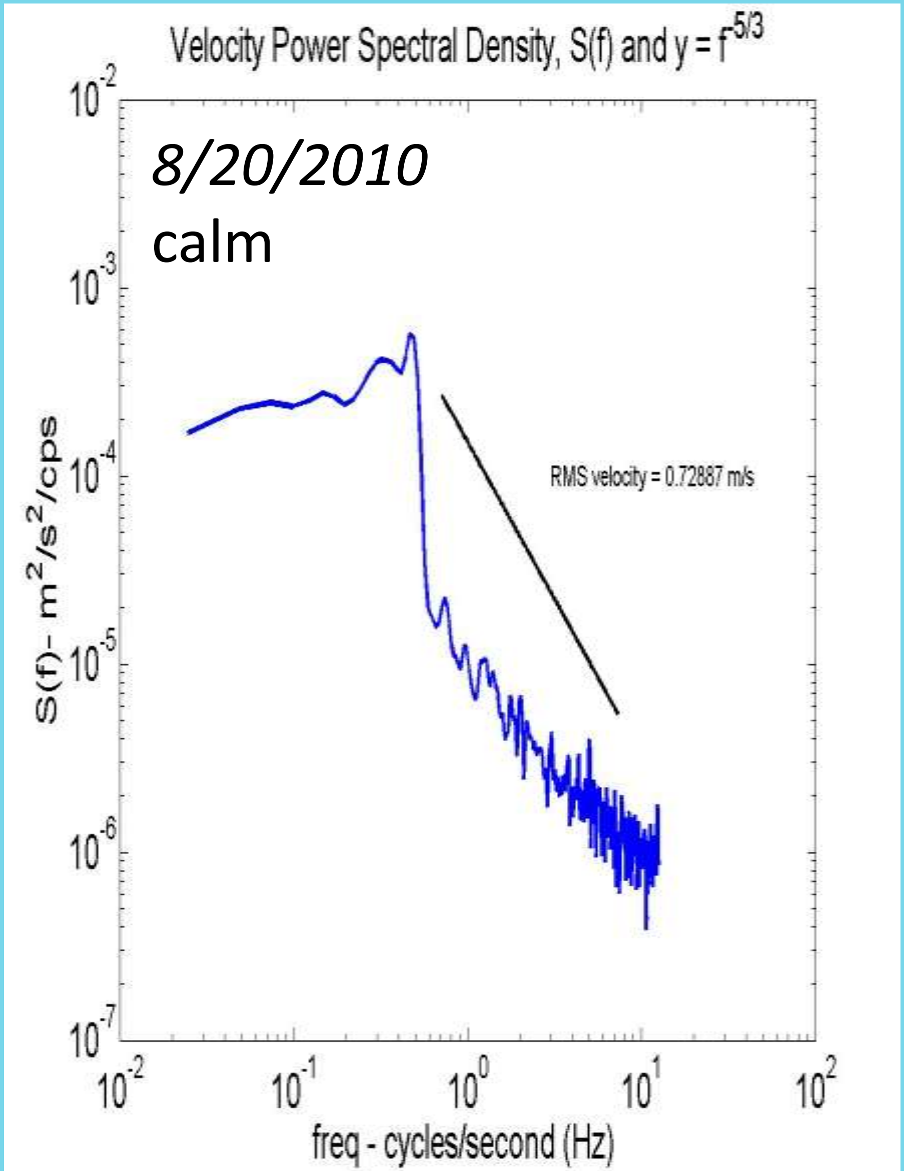
Given an aquadopp profiler and an acoustic doppler velocimeter, what can we say about the structure of riverine turbulence?

Consider 2 cases:

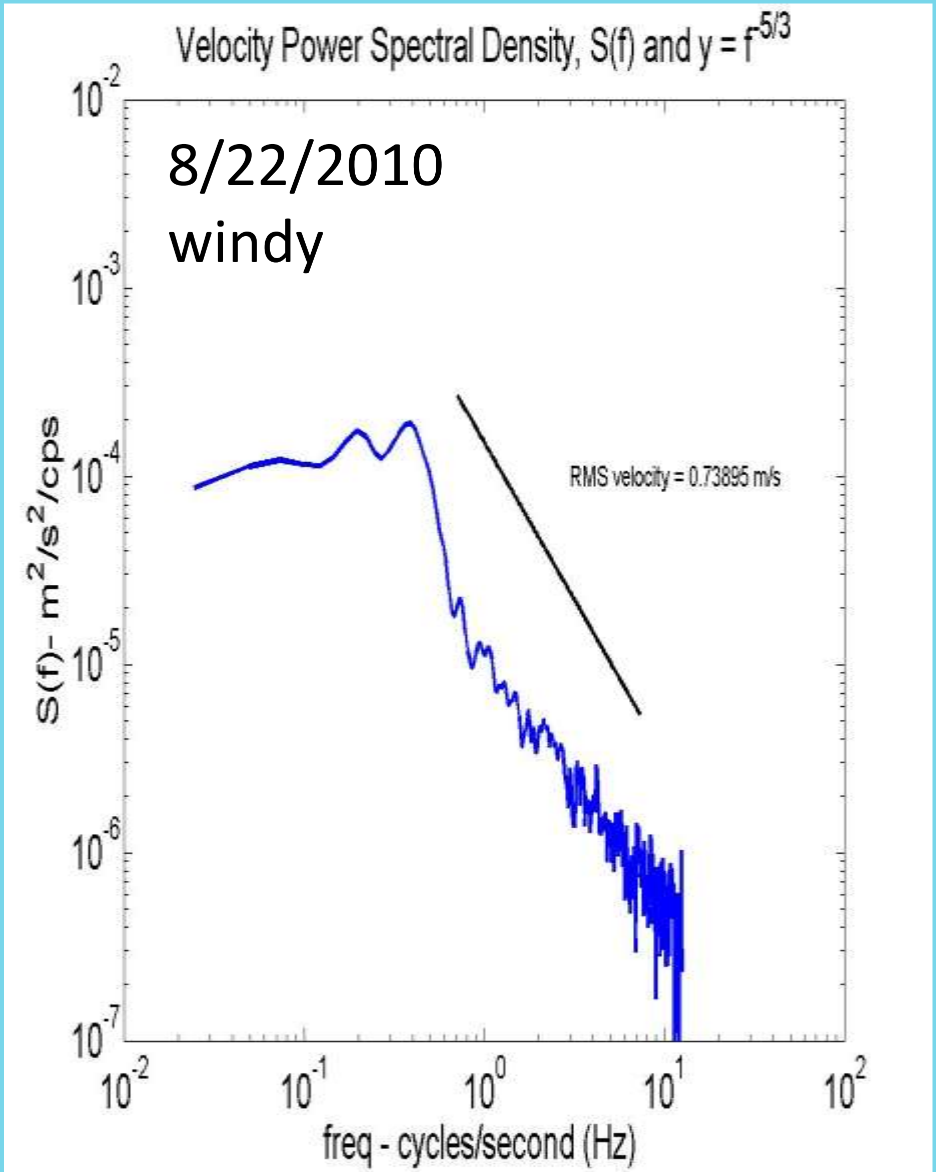
1) 8/20/2010 – 8:51 AM EST (calm)
2) 8/22/2010 – 11:34 AM EST (overcast and windy)


Air side Friction Velocity vs. time
8/22/2010
windy
8/20/2010
calm
m/s
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
50
100
150
200
250
300
time - hours; starting from 12:00 8/17/2010

ADV spectra



Velocity Power Spectral Density, S(f) and y = f^-5/3
8/20/2010
calm
RMS velocity = 0.72887 m/s
S(f)- m^2/s^2/cps
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-2
10^-1
10^0
10^1
10^2
freq - cycles/second (Hz)



Velocity Power Spectral Density, S(f) and y = f^-5/3
8/22/2010
windy
RMS velocity = 0.73895 m/s
S(f)- m^2/s^2/cps
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-2
10^-1
10^0
10^1
10^2
freq - cycles/second (Hz)

When waves are not present!

Homogenous Isotropic Turbulence!

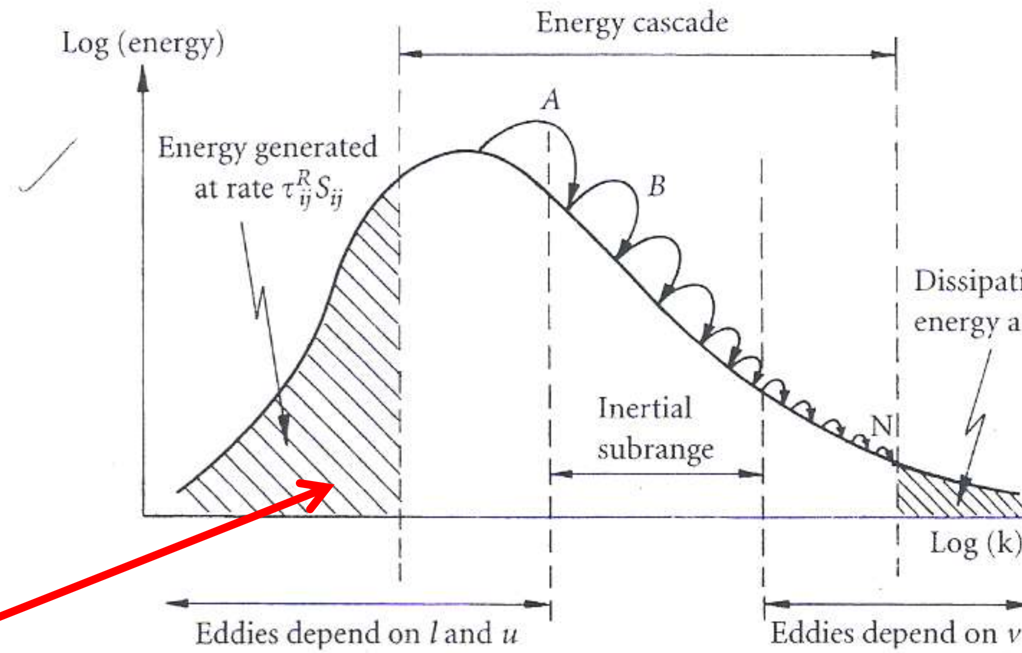


Figure 5.1 Schematic representation of the energy cascade.

Frozen Turbulence Hypothesis

$$S(\omega) = \frac{18}{55} C \epsilon^{\frac{2}{3}} U_d^{\frac{2}{3}} \omega^{\frac{-5}{3}}$$

Evidently, in the case of Batchelor's data we have Π =
where A is approximately constant during the decay and of t
of unity, $A \sim 1.1 \pm 0.2$. Note, however, that the value of Re
early experiments is modest. The more recent data of Pear
much higher Re and suggests that the asymptotic value of A is
This is consistent with Kaneda et al.'s (2003) findings.

Now consider the smallest scales. Suppose they have a char
velocity v and length scale η. Since the rate of dissip
mechanical energy is $\nu\langle \boldsymbol{\omega}^2 \rangle$ we have

$$\varepsilon \sim \nu v^2 / \eta^2 .$$

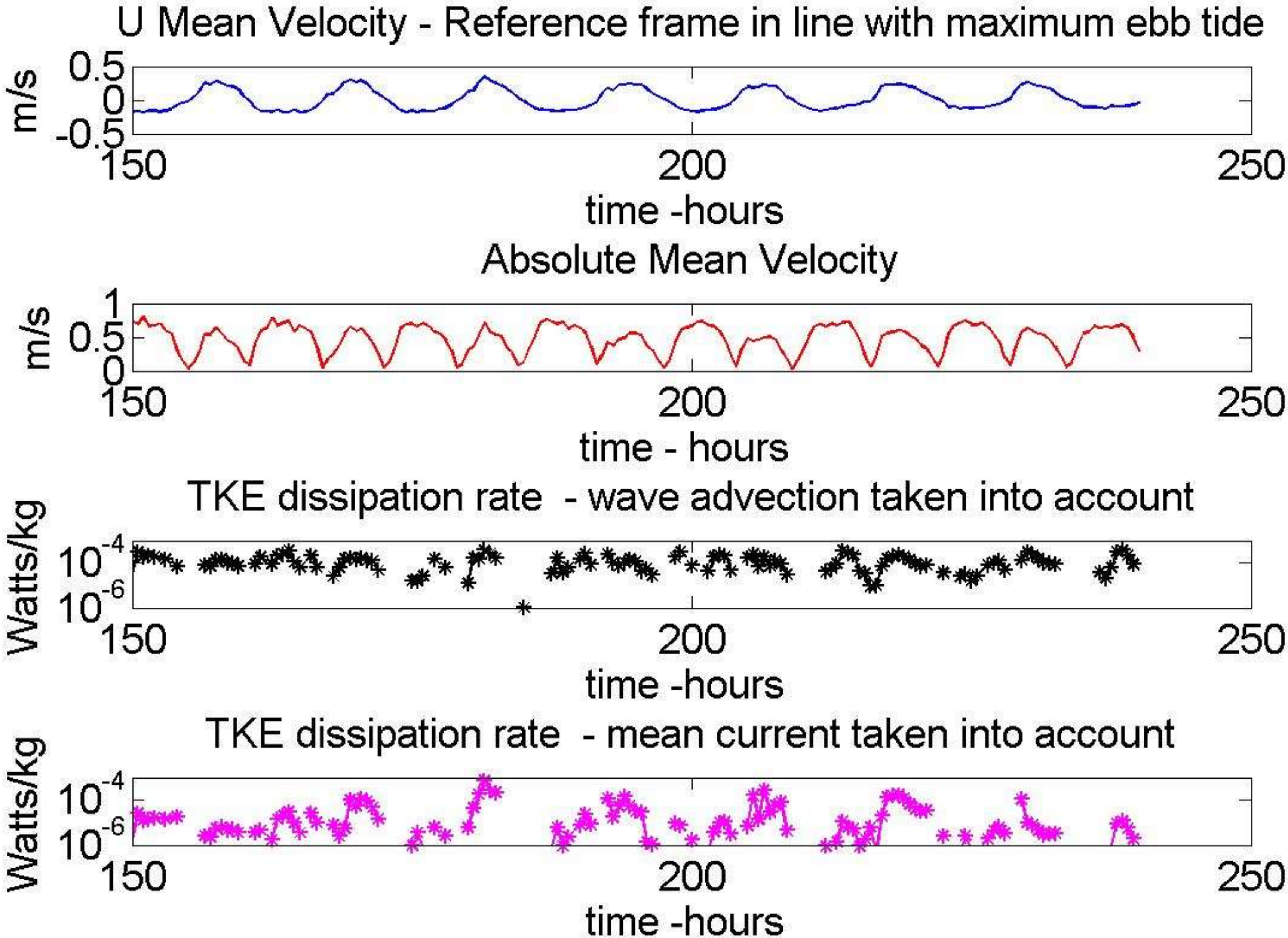
When waves are present!

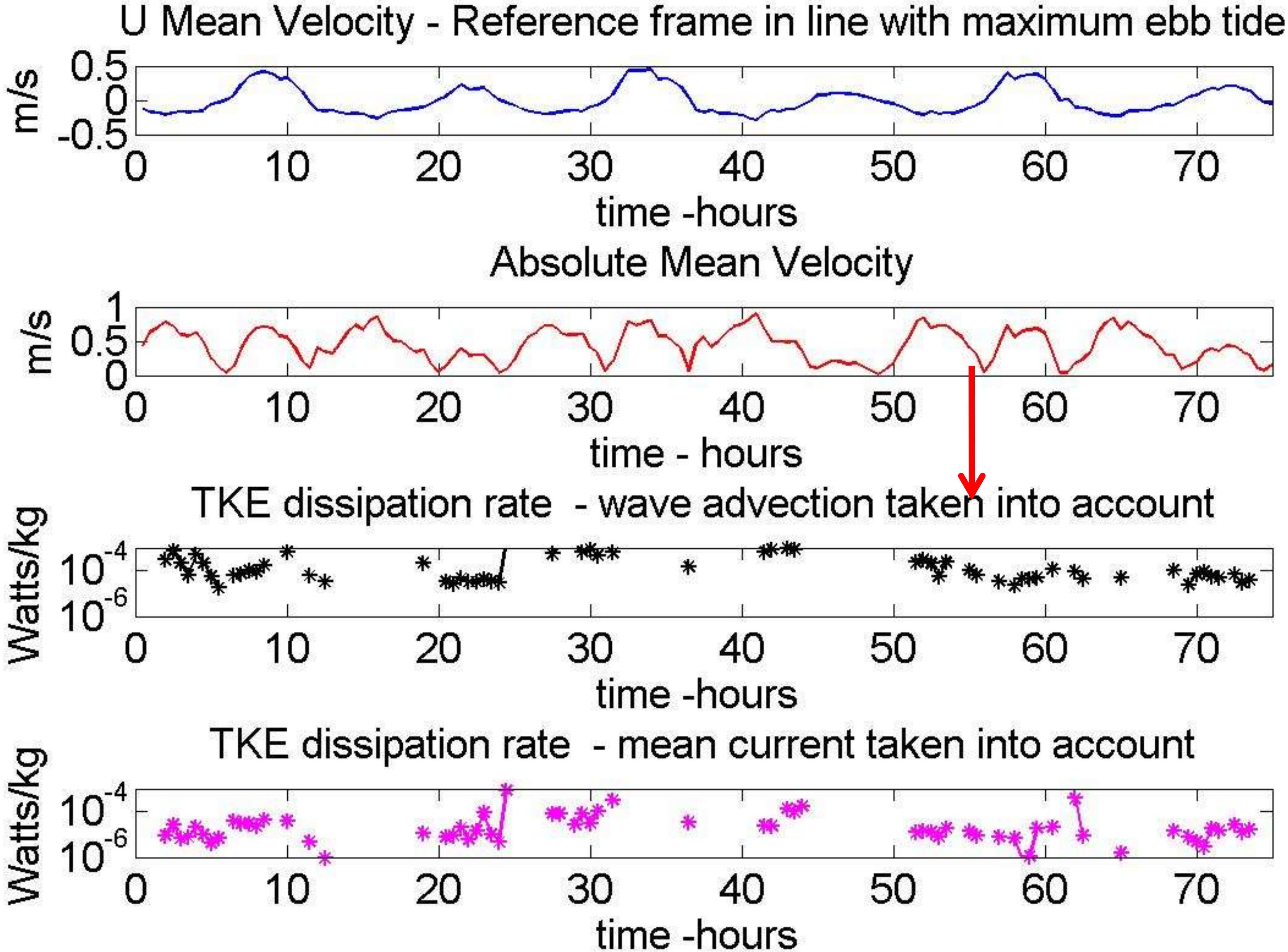
- Inertial subrange often contaminated with **surface wave motion**.

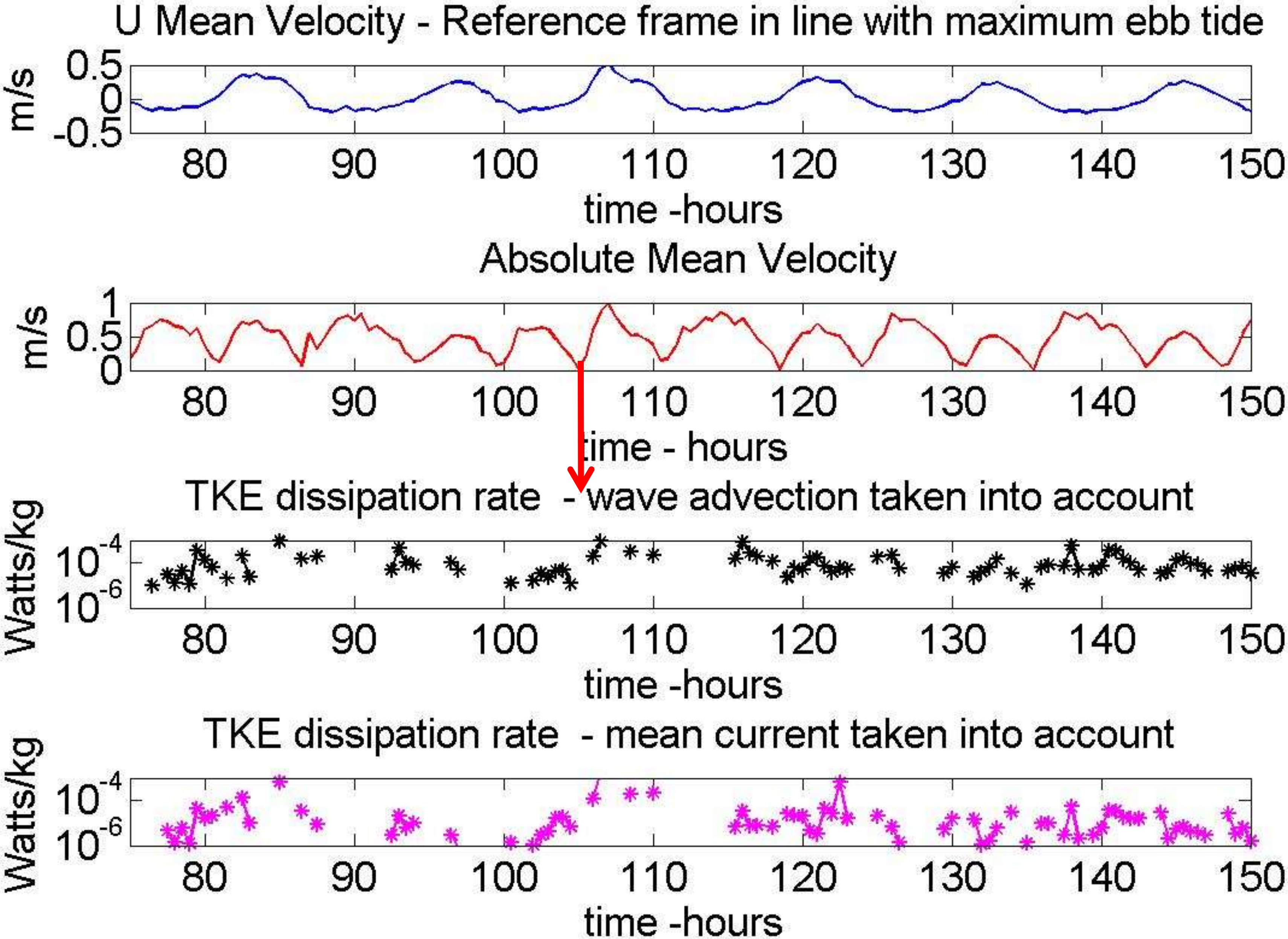
Bryan et al. modeled the effect of wave advection of turbulence past a probe by invoking Taylor's hypothesis.
Considered monochromatic waves rather than mean current.

$$\epsilon = \left(\frac{55}{14}\frac{1}{\alpha U_{rms}^{\frac{2}{3}}}\right)^{\frac{3}{2}}\left[S_1(f)\cdot f^{\frac{5}{3}}\right]^{\frac{3}{2}}\cdot 2\pi\cdot\left(2^{\frac{2}{3}}\frac{\Gamma\left(\frac{5}{6}\right)\Gamma\left(\frac{4}{3}\right)}{\Gamma\left(\frac{1}{2}\right)\Gamma\left(\frac{2}{3}\right)}\right)^{\frac{3}{2}}$$

What does epsilon vs. tidal velocity look like?


U Mean Velocity - Reference frame in line with maximum ebb tide
m/s
0.5
0
-0.5
150
200
250
time -hours
Absolute Mean Velocity
m/s
1
0.5
0
150
200
250
time - hours
TKE dissipation rate - wave advection taken into account
Watts/kg
10-4
10-6
150
200
250
time -hours
TKE dissipation rate - mean current taken into account
Watts/kg
10-4
10-6
150
200
250
time -hours


U Mean Velocity - Reference frame in line with maximum ebb tide
m/s
0.5
0
-0.5
0 10 20 30 40 50 60 70
time -hours
Absolute Mean Velocity
m/s
1
0.5
0
0 10 20 30 40 50 60 70
time - hours
TKE dissipation rate - wave advection taken into account
Watts/kg
10^{-4}
10^{-6}
0 10 20 30 40 50 60 70
time -hours
TKE dissipation rate - mean current taken into account
Watts/kg
10^{-4}
10^{-6}
0 10 20 30 40 50 60 70
time -hours

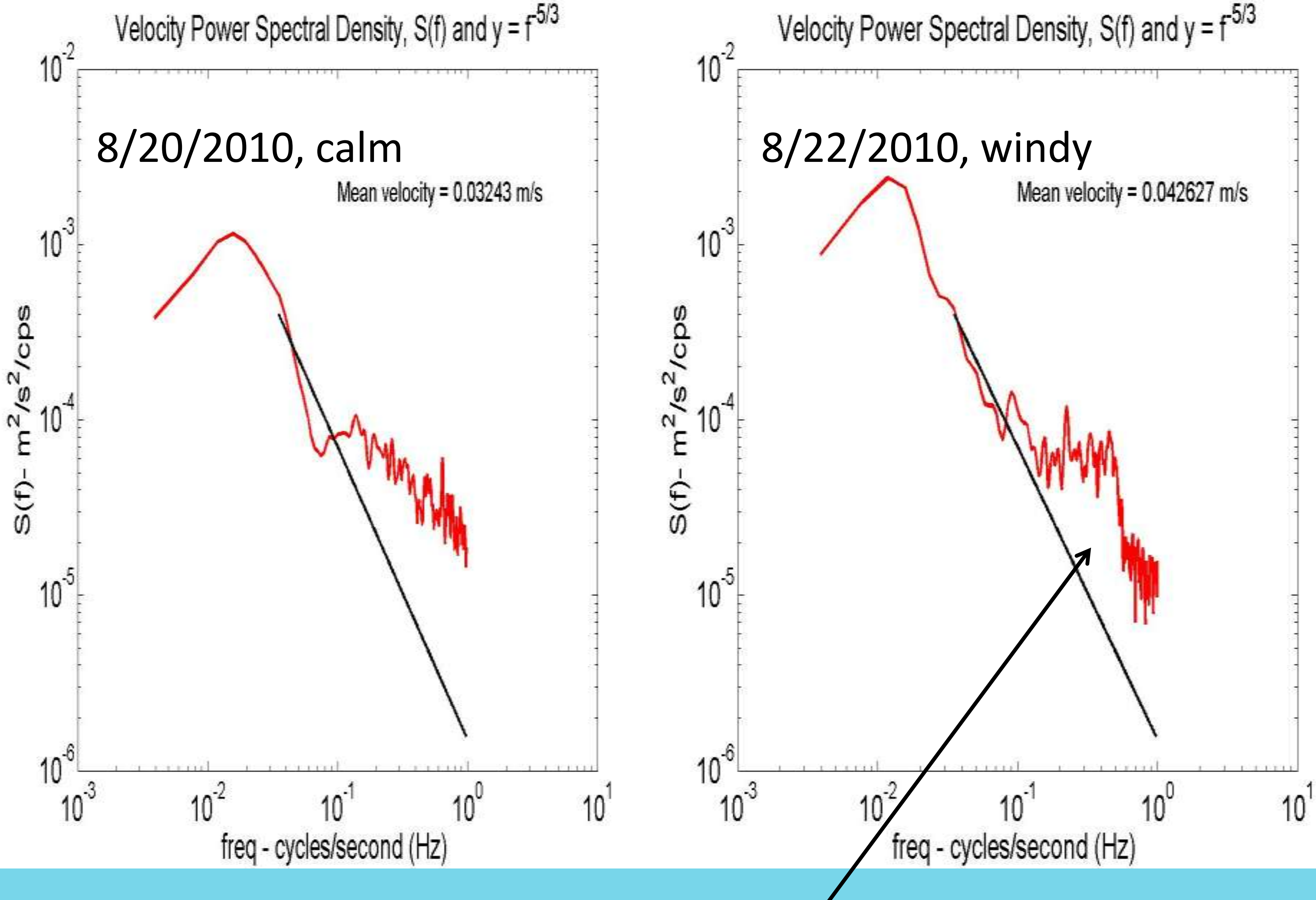


U Mean Velocity - Reference frame in line with maximum ebb tide
m/s
0.5
0
-0.5
80
90
100
110
120
130
140
150
time -hours
Absolute Mean Velocity
m/s
1
0.5
0
80
90
100
110
120
130
140
150
time - hours
TKE dissipation rate - wave advection taken into account
Watts/kg
10^-4
10^-6
80
90
100
110
120
130
140
150
time -hours
TKE dissipation rate - mean current taken into account
Watts/kg
10^-4
10^-6
80
90
100
110
120
130
140
150
time -hours

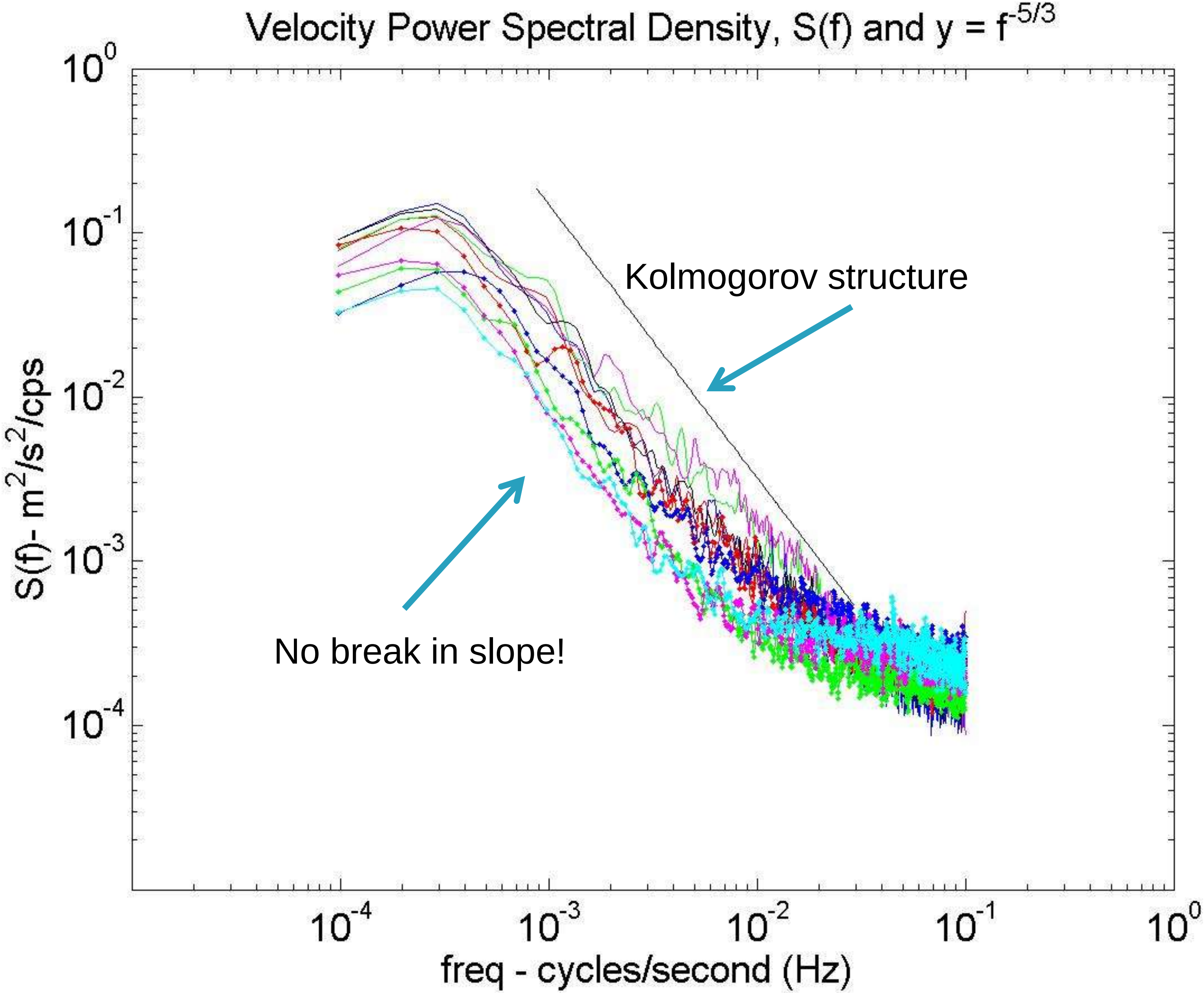
ADV Results

1) High frequency part of spectrum (1 -> 10 Hz) consistent with presence of wind forcing and surface wave field.
2) Epsilon is weakly correlated with peaks in ebb and flood tide.

What about the aquadopp profiler data?



Evidence of wave structure at 0.4 Hz



Velocity Power Spectral Density, S(f) and y = f^-5/3
Kolmogorov structure
No break in slope!
S(f)- m^2/s^2/cps
freq - cycles/second (Hz)
10^0
10^-1
10^-2
10^-3
10^-4

Aquadopp Results

1) Spectra produced from 0.5 sec sampled data for (0.1 -> 1 Hz) consistent with friction velocity.
2) Spectra produced from 5 sec sampled data for (0.001-> 0.009Hz) shows Kolmogorov shape.
3) There is no change in slope at periods ~15 min. Suggests that large eddies are horizontal & do not ‘feel’ the boundary layer stress.