Atmospheric Turbulence
Introduction

ME 7710 EFD
Why Study Turbulence?

Quote from John Wyngaard’s “Turbulence in the Atmosphere”, by Phil Thompson of NCAR

Lots of people have tried to develop a fundamental theory of turbulence. Some very well known people have given up on it. But I just can’t give up on it – it’s like a beautiful mistress. You know that she treats you badly, she’s being ornery, but you just can’t stay away from her. So periodically, this question comes up again in my mind, and I keep casting about for some different and simple and natural way of representing the motion of a fluid, and some way of treating the analytical difficulties. And I seem to get a little bit closer sometimes …
Life Cycle and Definitions of Turbulence

Turbulent Eddy – Batchelor 1950 – “does not refer to any specific local velocity distribution, it is simply a concise term for local turbulent motion with a length scale - an arbitrary local pattern characterized by size alone.

Figure 1.1 Instability of an axisymmetric jet. A laminar stream of air flows from a circular tube at the left at Reynolds number 10,000 and is made visible by a smoke wire. The edge of the jet develops axisymmetric oscillations, rolls up into vortex rings, and then abruptly becomes turbulent. Photograph courtesy Robert Drubka and Hassan Nagib. From Van Dyke (1982).

From Wyngaard’s “Turbulence in the Atmosphere”
Diurnal Cycle of the Convective Boundary Layer over “Simple Terrain”

Calm and clear days and nights in the desert southwest U.S., significant synoptic scale weather systems disrupt this cycle

Figure adapted from Stull (1988) by Dan Nadeau
What are characteristics of these time series that you see?
Correlation of Fluctuating Signals

Figure 2.1. Correlated and uncorrelated fluctuations. The fluctuating variable $a$ has the same sign as the variable $b$ for most of the time; this makes $\bar{a}\bar{b} > 0$. The variable $c$, on the other hand, is uncorrelated with $a$ and $b$, so that $\bar{a}\bar{c} = 0$ and $\bar{b}\bar{c} = 0$ (note that $\bar{a}\bar{b} \neq 0$, $\bar{a}\bar{c} \neq 0$ does not necessarily imply that $\bar{b}\bar{c} \neq 0$).
Defining Turbulence

• Break into groups to discuss
Atmospheric Spectrum of Wind Speed

- Peaks indicate the size of motion contributing most to the energy
- Separation of scales as a result of the “Spectral Gap”

Fig. 2.2 Schematic spectrum of wind speed near the ground estimated from a study of Van der Hoven (1957).
Ensemble Averaging

Figure 4.1. Ensemble of random functions of time, \( \langle u(t) \rangle \).

\[
\bar{U}^e(t, s) = \frac{1}{N} \sum_{i=1}^{N} U_i(t, s)
\]

Figure from “Turbulence and Random Processes in Fluid Mechanics”, 2\textsuperscript{nd} Ed, Landahl and Mollo Christensen
Reynolds Averaged Transport Equations