In this course...

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    2. Thermodynamics
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    9. Weather Systems: High latitude and tropical
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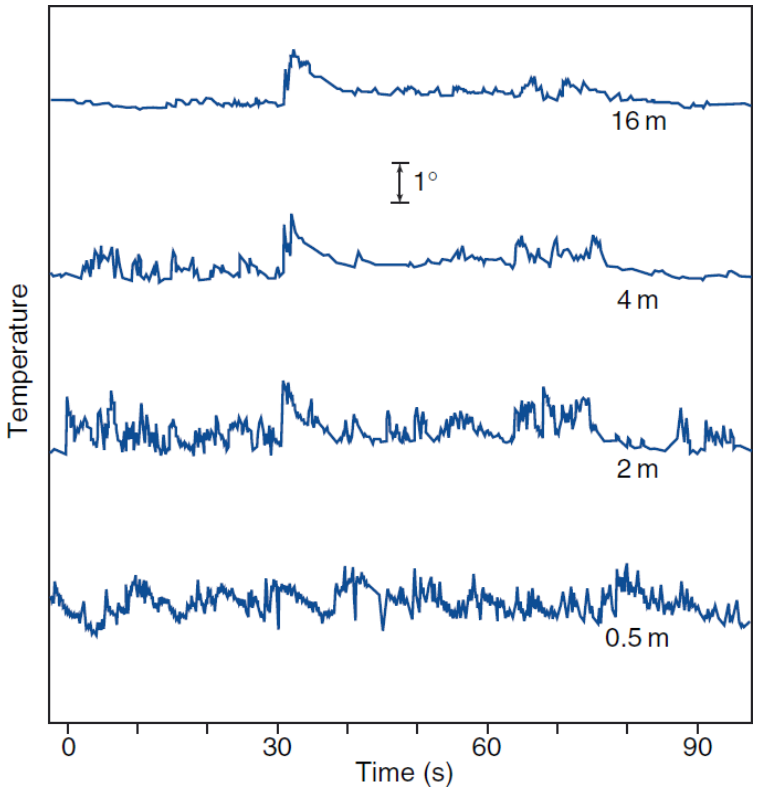
The atmospheric boundary layer (ABL)

I. Turbulence
II. The surface energy balance
III. Vertical structure
IV. Evolution

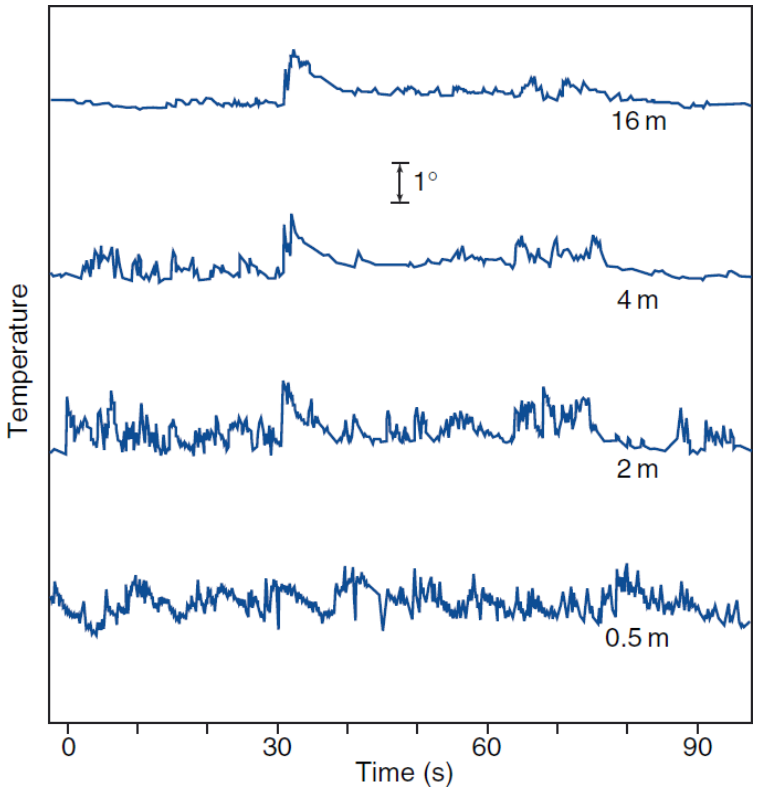
The atmospheric boundary layer (ABL)

Observations from the inner (surface) layer toward the outer (mixed) layer



- Short time scales of eddies; predictability $\sim$O(seconds).
- Larger time scale oscillations exist with a well-defined mean and standard deviation
  - ➔ Turbulence not completely random. It is instead *quasi-random*.
- Given the difficulty in solving exact solutions to predict the evolution of individual eddies, it is possible to take a statistical approach to describe the net effect of many eddies.

The atmospheric boundary layer (ABL)



This is accomplished through **Reynolds averaging**, where instanteneous quantities are decomposed into its time–averaged and fluctuating quantities to derive solutions to the governing equations with approximations based on knowledge of the properties of flow turbulence:

$$\overline{a} = \frac{1}{N}\sum_{i}^{N} a_i$$

$$a_i' = a_i - \overline{a}$$

$$var(a) = \sigma_a^2 = \frac{1}{N}\sum_{i}^{N} [a_i - \overline{a}]^2 = \overline{[a']^2}$$

$$cov(w,a) = \sigma_w \sigma_a = \frac{1}{N}\sum_{i}^{N} [w_i - \overline{w}]\,[a_i - \overline{a}] = \overline{w'a'}$$

The atmospheric boundary layer (ABL)

Some definitions/terminology

Stationary process: σ_a^2 is relatively constant over time.

Stationary flow: σ_u^2 is relatively constant over time.

Homogeneous: When σ_u^2 is relatively uniform in space.

Isotropic: Turbulent intensity at any one point is the same in all directions ($\sigma_u^2 = \sigma_v^2 = \sigma_w^2$)

anisotropic: Not isotropic. In ABL, generally this means that there is much greater turbulent energy in vertical direction, such as in *thermals*.

thermal: A relatively small-scale, rising current of bouyant air produced when the atmosphere is heated enough locally by the earth's surface to produce absolute instability in its lowest layers.

The atmospheric boundary layer (ABL)

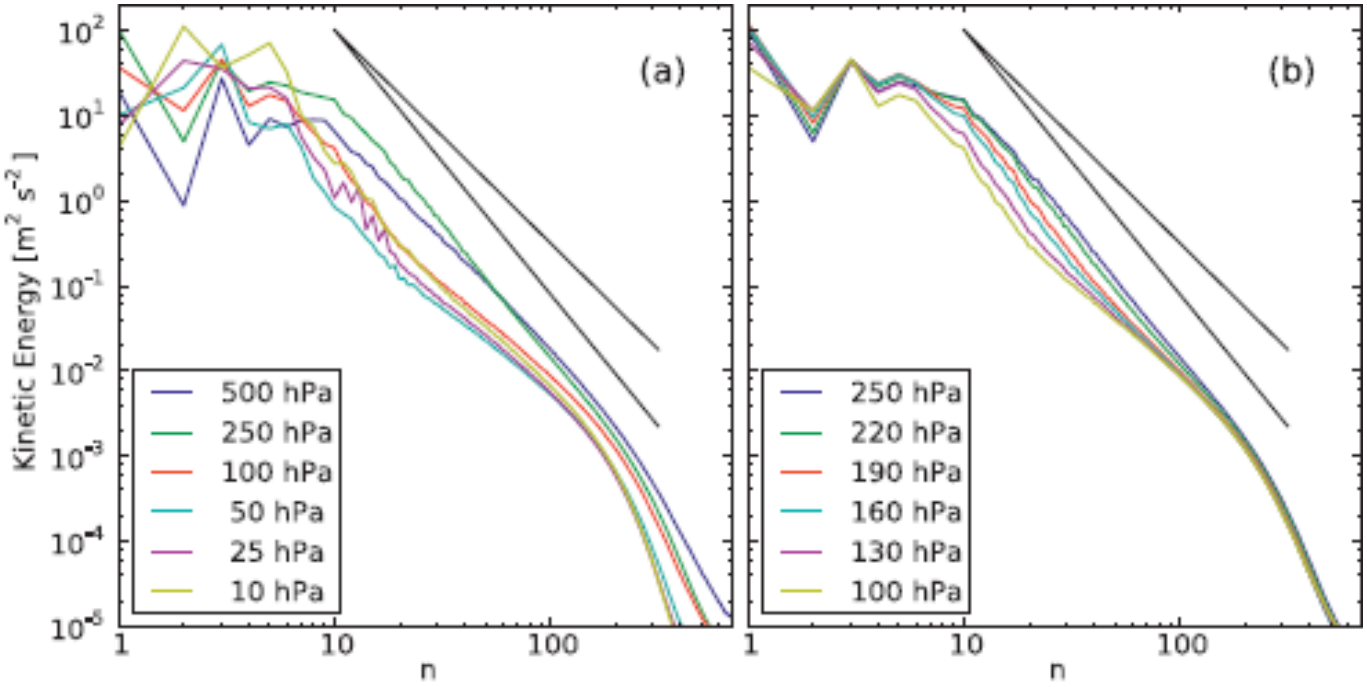
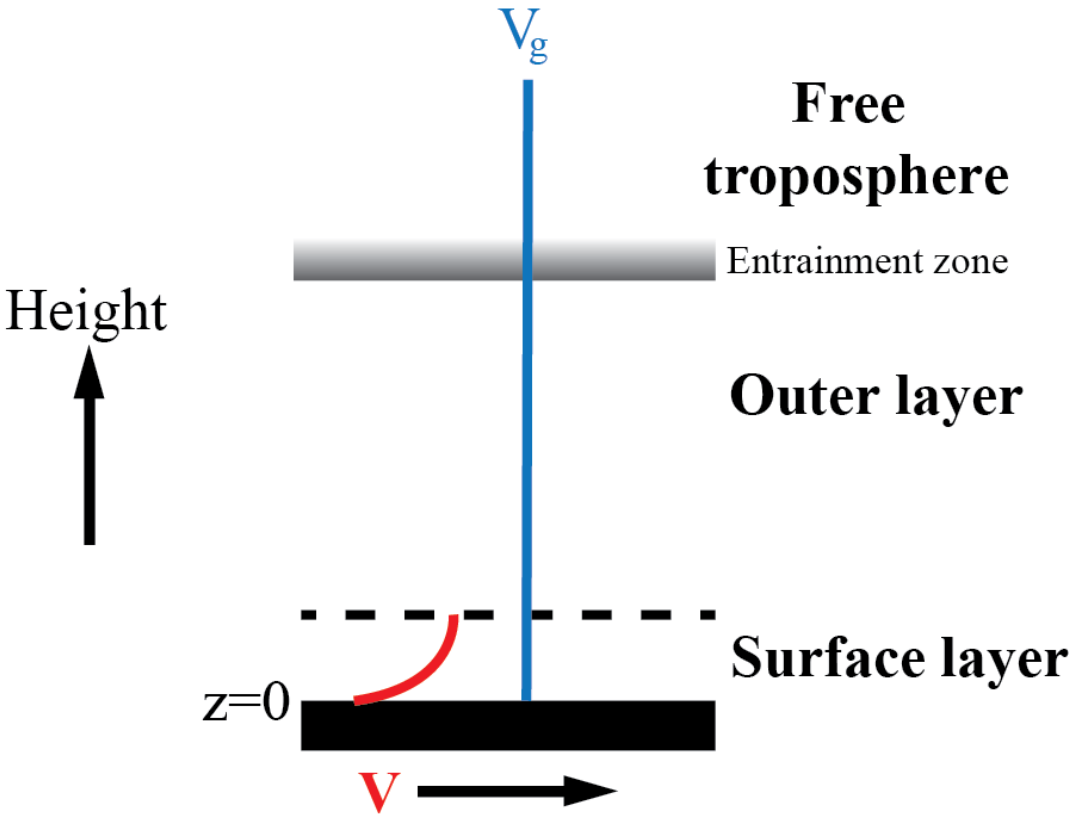


FIG. 1. Kinetic energy spectra at selected model levels (a) spanning the troposphere to stratosphere and (b) in the tropopause region. Lines with slopes of −3.1 and −2.5 have been added to both panels for comparison.

(From Burgess, Erler, Shepherd 2013, JAS)

- Kinetic energy spectra in ECMWF analyses
- $-\frac{5}{3}$ slope at inertial scales, -3 slope for higher wavenumbers

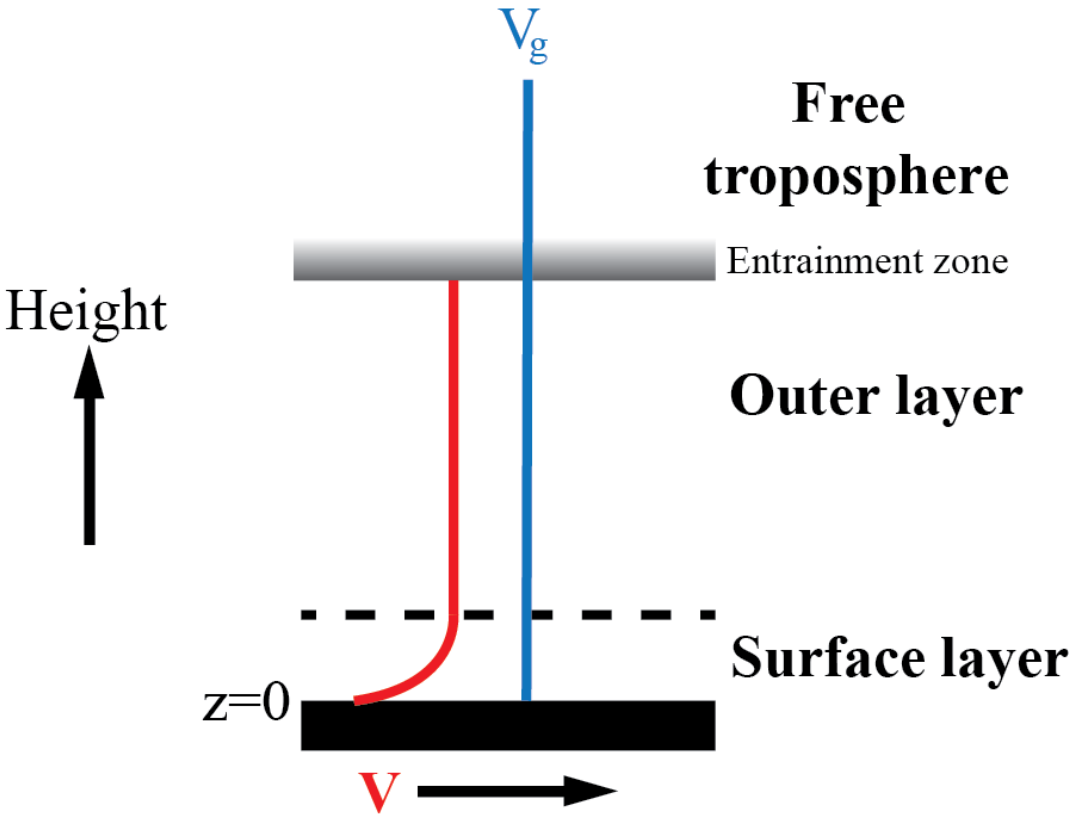
Evolution of the ABL: Wind



Daytime ABL

- Drag at ground reduces wind speed in surface layer ($V < V_g$).

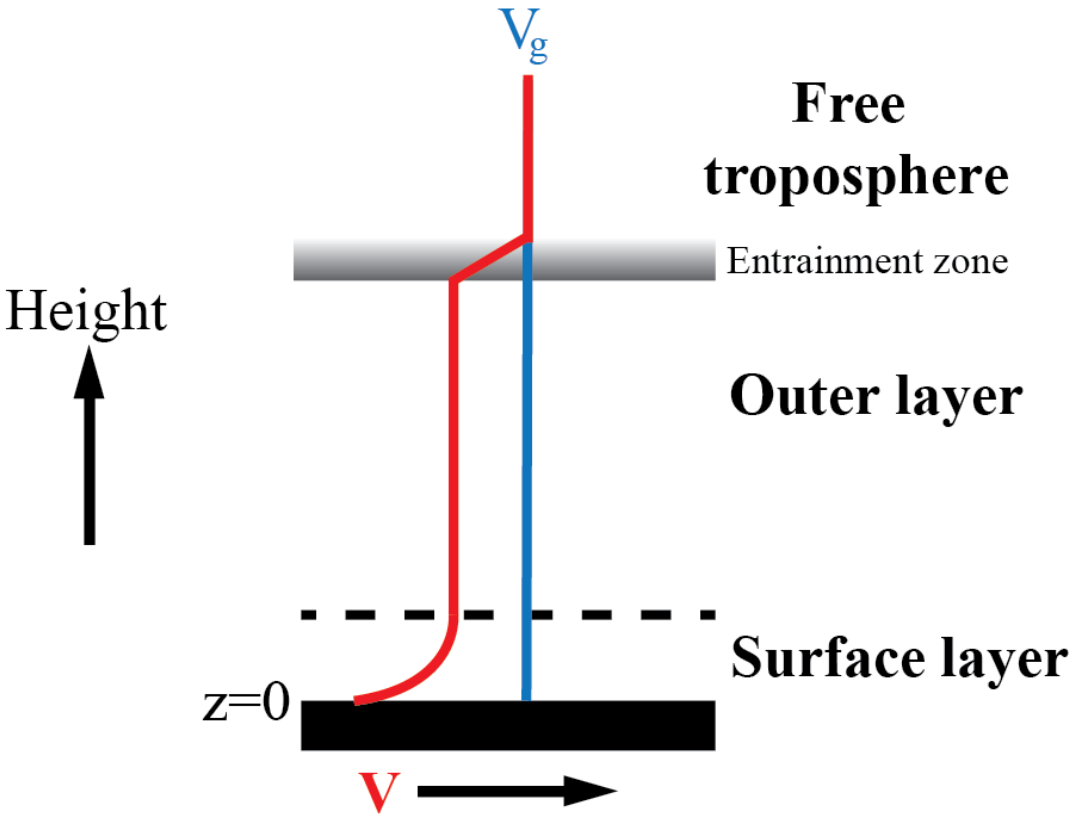
Evolution of the ABL: Wind



Daytime ABL

- Drag at ground reduces wind speed in surface layer ($V < V_g$).
- Turbulent eddies mix momentum to top of PBL in outer layer.

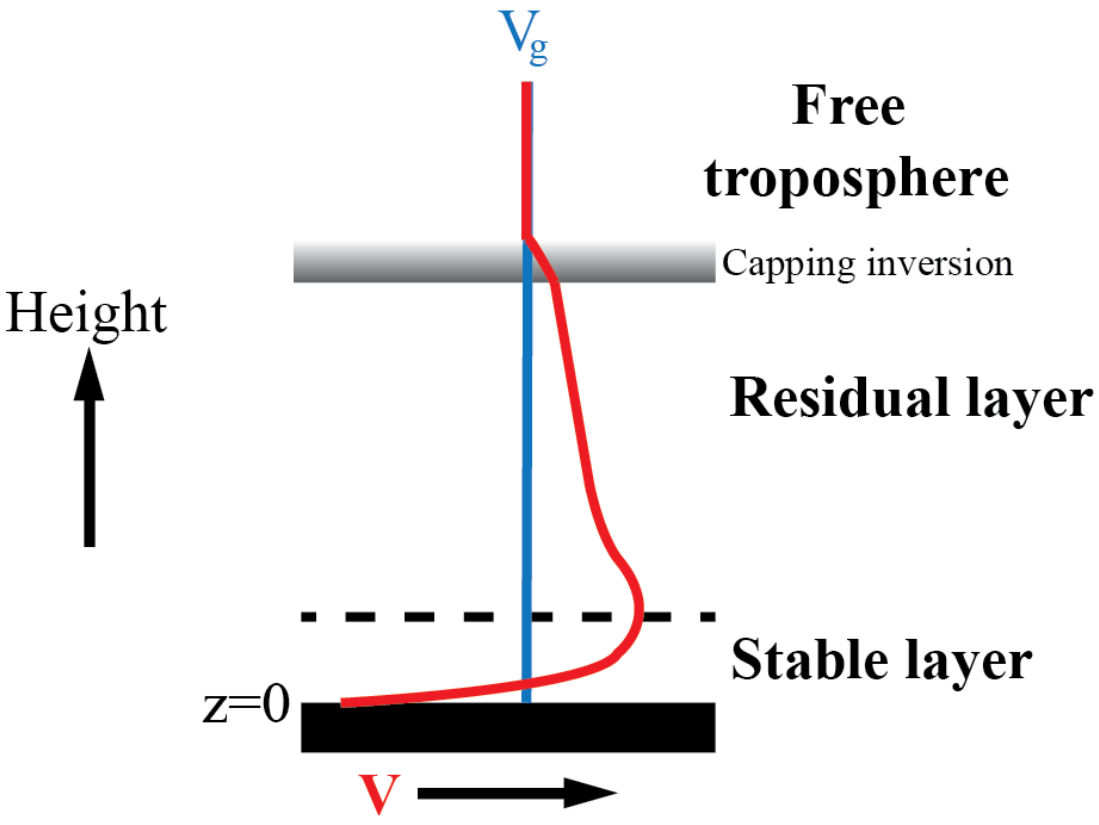
Evolution of the ABL: Wind



Daytime ABL

- Drag at ground reduces wind speed in surface layer ($V < V_g$).
- Turbulent eddies mix momentum to top of PBL in outer layer.
- Winds relax to geostrophic in free troposphere.

Evolution of the ABL: Wind



Nighttime ABL

- Turbulence suppressed to stable layer due to radiative cooling $\Rightarrow$ residual layer becomes frictionless.
- Residual layer accelerates toward geostrophic flow, but Corolis causes an inertial oscillation with $V > V_g$.
- Nocturnal jet forms at top of stable layer.

Evolution of the ABL