<table>
<thead>
<tr>
<th>Scale</th>
<th>Distance Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global scale</td>
<td>&gt; 20000 km</td>
</tr>
<tr>
<td>Synoptic scale</td>
<td>2000–20000 km</td>
</tr>
<tr>
<td>Mesoscale</td>
<td>2–2000 km</td>
</tr>
<tr>
<td>Microscale</td>
<td>&lt; 2 km</td>
</tr>
</tbody>
</table>

**TIME and SPACE SCALES of ATMOSPHERIC MOTION**

- **Seconds to minutes**
- **Minutes to hours**
- **Hours to days**
- **Days to a week or more**

**Typical Phenomena**
- Global scale: Long Waves
- Synoptic scale: Mid-Latitude Hs & Ls, Wx fronts
- Mesoscale: Hurricanes, Tropical Storms
- Microscale: Small Turbulent Eddies, Tornadoes, Waterspouts, Dust devils, Land/Sea breeze, Mountain/valley breeze, Chinook and Santa Ana winds
Smog layer over Santiago, Chile
Boundary layer capped with clouds
Typical values of the Bowen Ratio ($B=\frac{H}{H_L}$)

<table>
<thead>
<tr>
<th>Surface type</th>
<th>$B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>desert</td>
<td>$&gt;10$</td>
</tr>
<tr>
<td>semi-arid grassland</td>
<td>5</td>
</tr>
<tr>
<td>grassland/forest</td>
<td>0.5</td>
</tr>
<tr>
<td>irrigated orchards/grass</td>
<td>0.2</td>
</tr>
<tr>
<td>ocean</td>
<td>0.1</td>
</tr>
<tr>
<td>ice/snow surfaces</td>
<td>-10 to 10*</td>
</tr>
</tbody>
</table>

* strongly dependent upon the meteorology/air-mass
Surface skin temperature over New York City

SURFACE TEMPERATURE
Landsat ETM 7
Aug 14 2002
10:30 AM

less than 21 C
21.1 - 22
22.1 - 23
23.1 - 24
24.1 - 25
25.1 - 26
26.1 - 27
27.1 - 28
28.1 - 29
29.1 - 30
30.1 - 31
more than 31

www.gisdevelopment.net/aars/acrs/1991/psq/ps015.as
Diurnal skin temperature range (July)

Fig. 1. Diurnal range of surface temperature in control simulation, with contour interval 5°C. (a) January and (b) July.
Land surface heterogeneity

Profiles over the cloudy subtropical ocean

Fig. 3. Mixing ratio (solid line) and temperature (dashed line) profiles from the radiosonde launched at 0200 UTC (2000 LT) on 16 Oct 2001. The temperature inversion appears to be around 15 mb (~150 m) deep, which is 5 times as thick as the moisture inversion.

From Caldwell et al. (2005)
Temperature profile from the South Pole

From Hudson and Brandt (2005)

Fig. 3. Temperature profile measured at South Pole Station on 25 Sep 2001. Data above 660 hPa are from a routine radiosounding with an RS80; those below 660 hPa are from a tethered sounding with an RS80. (a) The full tropospheric sounding is shown, and (b) the lowest 500 m are enlarged. The surface pressure was 674 hPa.
Example questions for midterm

1. (a) On a summer day that is clear with no frontal activity over land, sketch diurnal variations of winds at 2 and 500 meters. Explain why.
(b) Describe general characteristics of turbulence.
(c) Describe Taylor’s frozen turbulence hypothesis.

2. Based on the following information derive a) the magnitude and direction of pressure gradient force, Coriolis force, and friction force per unit mass near the surface; b) the average magnitude of the actual wind shear across the boundary layer; and c) the frictional veering of the wind across the boundary layer; and d) the average value of the Richardson number and existence of turbulence in the PBL.

At 45°N, the surface geostrophic wind speed is 17 m s⁻¹ at 145 deg (wind directions use meteorological convention);
PBL = 1000 m, assume the winds are geostrophic at this height;
Assume that the measurement at 1 m height is representative of the surface wind and the pressure at 1 m is 1000 mb;
The atmosphere is dry.
The observations are

| Height (m) | 1   | 1000 |
| Wind speed (m s⁻¹) | 10  | 20   |
| Wind direction (deg) | 110 | 135  |
| Temperature (°C)    | 25  | 23   |

3. For the Ekman layer in the barotropic atmosphere, the equations of motion can be written as
\[ -f(v - v_e) = K(\frac{d^2}{dz^2})(u - u_e) \]
\[ f(u - u_e) = K(\frac{d^2}{dz^2})(v - v_e) \]
where K is the effective viscosity.
The boundary conditions are
\[ u = 0, v = 0, \text{ at } z = 0 \]

The solutions are
\[ u - u_e = e^{-az}[u_e \cos(az) + v_e \sin(az)] \]
\[ v - v_e = e^{-az}[u_e \sin(az) - v_e \cos(az)] \]
where \( a = (f/2K)^{1/2} \).

(a) Using Eq.(2), obtain the horizontal shear stress components \( \tau_{xz} \) and \( \tau_{zy} \).
(b) In a coordinate system with the x axis parallel to the geostrophic wind, write down the expressions for the normalized vertical components (\( u/G \) and \( v/G \) where G is the magnitude of geostrophic wind).
(c) In the same coordinate system draw the wind hodograph using the expressions above as function of az from 0 to 2π.
(d) If \( f = 10^{-4} \text{ s}^{-1} \) and \( K = 4 \text{ m}^2 \text{ s}^{-1} \), what is the Ekman layer thickness?
Fig. 2. Observed and theoretical Ekman spirals adapted from Figure 9 of Chereskin (1995). Note that the shallowest measurement depth is 8 m, and also that for a mean wind speed of 7 m s$^{-1}$, the authors estimate that the thickness of the wave boundary layer is 5 m. The eddy viscosity and the Ekman depth for the fitted theoretical profile are, respectively, $v_E = 2.7 \times 10^{-2}$ m$^2$ s$^{-1}$ and $L = 25$ m. The theoretical spiral has been offset from the origin for clarity. Scales are cm s$^{-1}$ for currents, and m s$^{-1}$ for wind.