The Frictional Force

The force of friction acts in a direction opposite the motion of air, and therefore, always acts to reduce the speed of the flow. In the atmosphere, the force of friction is ultimately realized on the molecular scale as individual faster-moving air molecules collide with slower-moving air molecules or with the earth. Except very close to the earth's surface, friction acts primarily through the mixing of parcels of air moving at different speeds. The turbulent motions that lead to the mixing of air are called **turbulent eddies**, and they arise primarily from three sources, as shown in Figure 7.5. **Mechanical turbulence** develops when air encounters obstructions associated with ground roughness. Trees, buildings, and terrain features all deflect air in different directions, mixing air down from aloft and up from the surface. **Thermal turbulence** develops when the air near the earth's surface is heated sufficiently during the day that it becomes unstable and rises to higher altitudes. When convection carries slower-moving surface air to altitudes where the winds are stronger, the mixing that occurs reduces the air motion at the higher altitude. Thermal turbulence may also transport fast-moving air downward from higher altitudes, producing gusty surface winds. **Wind shear** exists when winds change (increase or decrease) over some distance. **Shear-induced turbulence** occurs when wind speed changes rapidly with distance, typically with height. When the vertical shear of the wind becomes large, tumbling motions begin to develop in the flow that mix the layers of faster and slower moving air, smoothing the vertical wind profile. These tumbling motions are what commercial aircraft often experience when the captain turns on the "fasten seat belt" sign in midflight. Although turbulent motions can also be generated by horizontally sheared flow, such motions rarely occur because horizontal shear is typically weak.

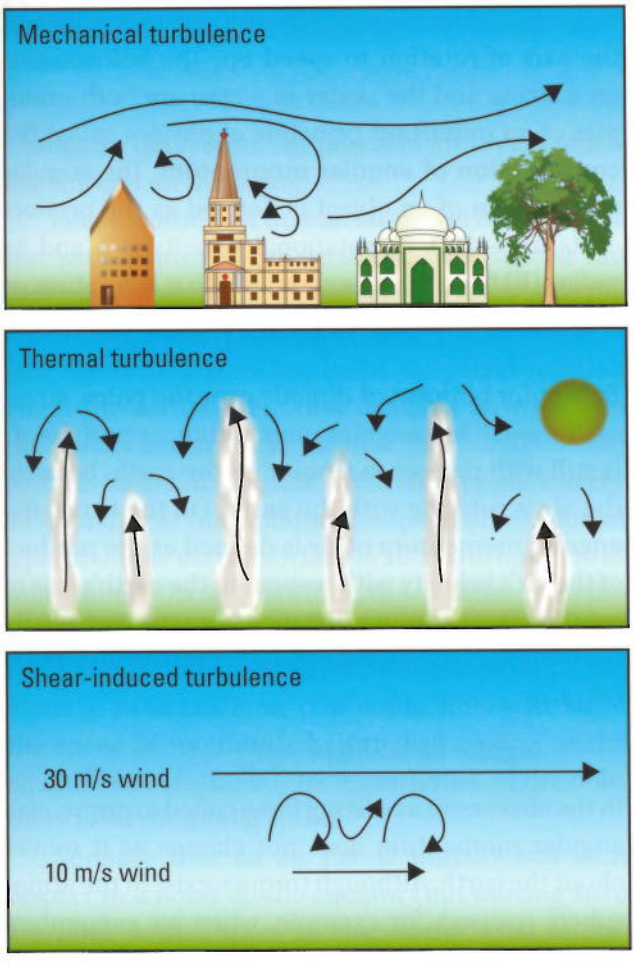

FIGURE 7.5 Principal mechanisms that lead to turbulent mixing in the lower atmosphere.

Frictional drag is strongest near the Earth's surface and decreases rapidly with height. The atmospheric layer in which friction is an important force is called the **boundary layer**, or sometimes, the **friction layer**. The depth of the boundary layer depends on the underlying surface roughness (hills, buildings, trees, etc.), surface heating, atmospheric stability, and the wind speed. On a night with weak winds, the boundary layer over a large lake may only extend upward a few hundred meters, while the boundary layer over a city on a hot, windy afternoon may extend upward a few thousand meters.