Activity 2: Pressure, Air Pressure, and Jet Streams

Introduction

One of the most important properties of the atmosphere is air pressure. It is important because differences in air pressure from place to place put air into motion (just as in the case of air rushing out of the open valve of an inflated tire). Pressure differences at altitudes of nine or more kilometers lead to the development of high-speed winds, called jet streams.

This activity uses sets of blocks to investigation basic understandings about pressure and pressure differences produced by density variations. These understandings are then applied to the atmosphere to introduce the basic causes of jet streams.

Upon completing this activity, you should be able to:

- Explain what pressure is and how it can vary vertically and horizontally.

- Describe how density contrasts between warm and cold air produce pressure differences at different levels in the atmosphere.

- Explain how pressure differences in the atmosphere can lead to high-speed winds called jet streams.

Materials

- Set of plastic blocks consisting of 5 large red and 5 smaller blue blocks, three clear plastic strips

Investigation

To study pressure, we must first define it. Pressure is a force acting on a unit area of surface (*e.g.*, pounds per square inch is a pressure measurement). Air pressure is described as the weight (a force) of an overlying column of air acting on a unit area of horizontal surface. To investigate the concept of pressure we will simulate the use of tall and short "blocks". Tall blocks are cube-shaped and short blocks have the same size base as the tall blocks but are half as high.

Whether tall or short, the blocks employed in this investigation have the following common characteristics:

> a. All blocks have the same weight regardless of the volume they occupy.
> b. All blocks have the same size square base.
> c. All individual blocks exert the same downward pressure on the surface beneath them (because the equivalent weights are acting on the same size bases).

1. **Figure 1** shows one tall red block and one short blue block side-by-side on their square bases on the flat horizontal surface of a table (**T**). Because both blocks weigh the same (although they have different volumes) and their bases are the same size, the blocks exert **[(*equal*)(*unequal*)]** pressure on the surface of the table.

2. The shorter blocks occupy half of the volume of the taller blocks while containing equal masses. (We know this because they weigh the same.) Because density is a measurement of mass per unit volume, the smaller blocks are **[(*twice*)(*half*)]** as dense as the larger blocks.

3. In **Figure 2**, another identical block was placed on top of each block already on the table. Each stack is now exerting **[(*the same*)(*twice the*)]** amount of pressure on the table as the single blocks did initially.

4. The pressure exerted on the table by the tall stack is **[(*equal*)(*not equal*)]** to the pressure exerted on the table by the short stack.

5. As shown in **Figure 3**, the two stacks are side-by-side with another identical block added to each stack (for a total of 3 blocks in each stack). An imaginary surface (**1**) has been inserted horizontally through the two stacks so that two shorter blocks and one taller block are positioned beneath the surface. Compare the pressure exerted on the imaginary surface by the overlying blocks. The taller-block stack exerts **[(*greater*)(*equal*)(*less*)]** pressure on this imaginary surface than does the shorter-block stack.

6. **Figure 4** shows two more blocks added for a total of five in each stack. A second imaginary horizontal surface (**2**) is added beneath the top short block and the three top tall blocks. The pressure exerted on the table (T) by the tall stack is **[(*equal*)(*unequal*)]** to the pressure exerted on the table by the short stack.

7. On the lower imaginary surface (**1**) in Figure 4, the pressure exerted by all the overlying short blocks is **[(*one-half*)(*three-fourths*)(*the same as*)]** the pressure exerted by all the overlying tall blocks.
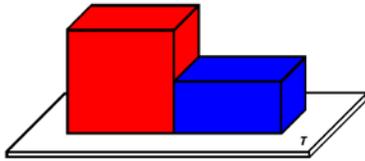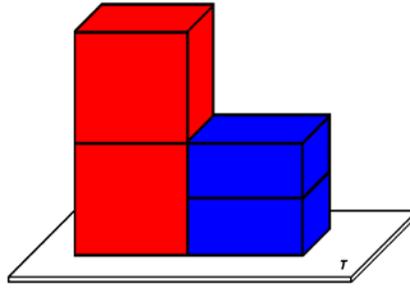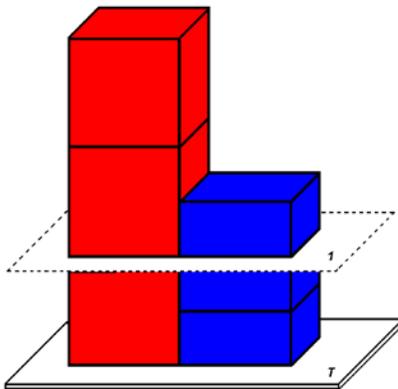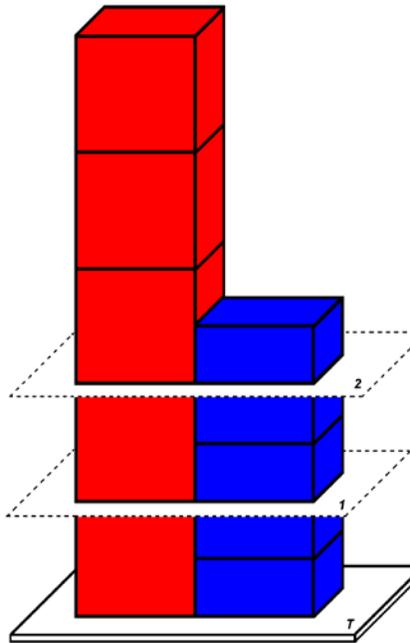
Figure 1.

Figure 2.

Figure 3.

Figure 4.

8. On the top imaginary surface (**2**) in Figure 4, the downward pressure exerted by the overlying short block is **[(_equal to_)(_one-half_)(_one-third_)]** the pressure exerted by the overlying tall blocks.

9. On the table top in Figure 4, there are 5 blocks in each column and therefore, no pressure difference between the columns. From the table top upward in Figure 4, the <u>difference</u> in downward pressure on the other imaginary horizontal surfaces exerted by the overlying portions of the two stacks **[(_increases_)(_decreases_)]** from levels 1 to 2.

10. In the **[(_taller, less dense_)(_shorter, more dense_)]** stack, the pressure decreases more rapidly with height.

11. Look at **Figure 5** showing a side view of the two stacks of pressure blocks. It is a view of the same blocks seen in the previous figure. **Following the example shown with the bottom blocks, draw straight lines connecting the mid-points of bases of blocks exerting the same pressures.** These lines connecting equal pressure dots become **[(_more_)(_less_)]** inclined with an increase in height.

To this point we have been examining the change in pressure with height in stacks of blocks of different density (short blocks versus tall blocks). Now we apply what we have learned to the rate at which air pressure drops with altitude in the atmosphere.

12. **Figure 6**, *Vertical Cross-Section of Air Pressure*, shows a cross-section of the atmosphere based on upper-air soundings obtained by radiosondes simultaneously at Miami, Florida and at Chatham, Massachusetts, approximately 1250 mi. (2000 km) apart at 12Z 09 December 2010. Air pressure values in millibars (mb) are plotted as marks at the altitudes where they were observed, starting with identical values (1000 mb) at the Earth's surface. Over Florida, the atmosphere was exerting a pressure of 200 mb at an altitude of approximately **[(_11,600_)(_12,000_)(_12,200_)]** m above sea level.

13. The atmosphere above the Massachusetts weather station was colder and therefore denser than the air above the more southern and warmer Florida location. Following the examples shown at the surface and at 925 mb, draw straight lines connecting equal air-pressure dots on the graph. Above the Earth's surface these lines representing equal air pressures are **[(_horizontal_)(_inclined_)]**.

14. Compare the lines of equal pressure you drew on Figures 5 and 6. They appear quite different because one deals with rigid blocks whereas the other deals with compressible air, and their scales are much different. However, both reveal the effect of density on pressure. The lines of equal pressure slope **[(_upward_)(_downward_)]** from the lower-density tall blocks (warm air column) above Florida to the higher-density short blocks (cold air column) above Massachusetts, respectively.

15. Because of the slope of the equal-pressure lines in Figure 6, it is evident that at 12,200 m above sea level the air pressure in the warmer air over Florida is **[(_higher than_)(_the same as_)(_lower than_)]** the air pressure in the colder Massachusetts air at the same 12,200-m altitude.

16. The influence of air temperature on the rate of pressure drop with altitude has important implications for pilots of aircraft that are equipped with air pressure altimeters. An air pressure altimeter is actually a barometer in which altitude is calibrated against air pressure.
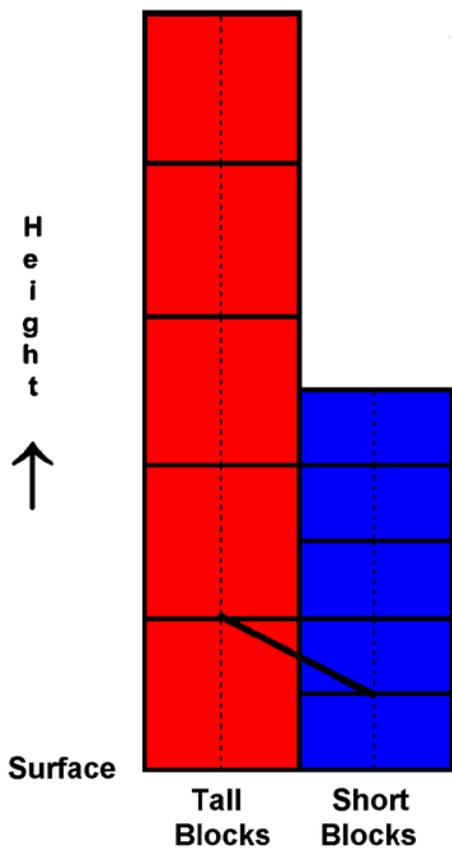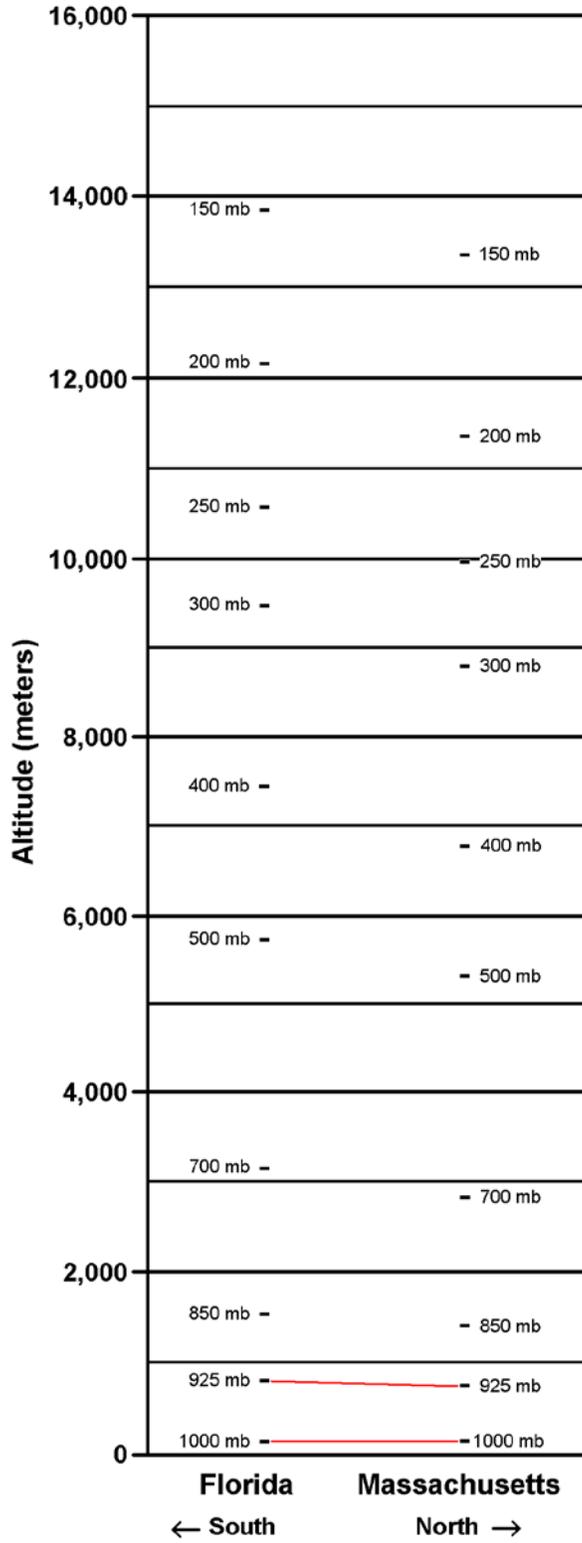
Figure 5. Stacked blocks.

Figure 6. Vertical cross-section of air pressure at 12Z 9 December 2010.

5

Imagine that a little before 12Z on 09 December 2010 an aircraft starts its flight from Florida to Massachusetts. At 12Z over southern Florida, the onboard pressure altimeter indicates that the aircraft is at 5800 meters above sea level. From Figure 6, the air pressure is about **[(_500_)(_400_)]** mb at an altitude of 5800 meters over Florida.

17. Relying on the pressure altimeter, the pilot continues to fly toward Massachusetts along a constant pressure level with an <u>indicated</u> altitude of 5800 meters. En route, the air temperature outside the aircraft gradually falls but the pilot does not alter the calibration between air pressure and altitude. Over Massachusetts, the pressure altimeter still reads 5800 meters, the *indicated altitude* of the aircraft. From Figure 6, however, it is evident that the *true altitude* of the aircraft over Massachusetts is **[(_lower than_)(_the same as_) (_higher than_)]** the altitude indicated by the altimeter.

18. The *true altitude* of the aircraft over Massachusetts is about **[(_5300_)(_5800_)(_6100_)]** meters.

19. In this example, the aircraft flew along a constant pressure surface (the 500-mb surface) which is at a **[(_higher_)(_lower_)]** altitude in warm air than in cold air. In actual practice, a pilot must adjust the aircraft's pressure altimeter to correct for changes in the altitude of pressure surfaces due to changes in air temperature en route. This correction ensures a more accurate calibration between air pressure and altitude.

Real World Applications: Pressure, Air Pressure and Jet Streams

Figures A and **B** are plotted profiles of air temperatures and atmospheric humidity at a series of pressure levels determined by radiosondes launched from about 70 upper air stations around the country at 12Z (7 am EST) and 00Z (7 pm EST) daily. Figure A is the profile from Green Bay, Wisconsin at 12Z on 10 April 2012 while Figure B is from the Little Rock, Arkansas site at the same time. The heavy curve to the right on each graph is the temperature curve where the horizontal axis is temperature in degrees Celsius increasing from –80 to +40 °C. Pressures decrease upward along the vertical axis, as they do in the atmosphere, from about 1000 mb to 100 mb.

1. Compare the temperatures at the same pressure levels between Green Bay and Little Rock. The air from the surface to about 300 mb is **[(*warmer*)(*cooler*)]** over Little Rock than over Green Bay.

2. In the case of the rigid pressure blocks, the air column over Little Rock is therefore like the **[(*blue*)(*red*)]** blocks.

3. An aircraft flying from Little Rock to Green Bay along a constant pressure surface in the upper atmosphere would then be arriving at a **[(*lower*)(*higher*)]** altitude in Green Bay than that of the surface over Little Rock.

From the text data for these two soundings, the 250-mb level occurred at 10,570 meters over Little Rock while that same pressure was found at 10,100 meters over Green Bay. The downward slope of this pressure level from south (Little Rock) to north (Green Bay) is similar to Figure 6. Such a slope implies a strong change of height at a constant pressure (250 mb) or, conversely, a strong change of pressure at a fixed altitude. Strong pressure changes over distance, called pressure gradients, drive winds to high speeds.

4. Therefore, this change of pressure at the same altitude over these two stations **[(*would*)(*would not*)]** imply the existence of strong winds at upper levels, *i.e.* a jet stream, between the stations.

Figure C is the 250-mb map for 12Z 10 APR 2012 from NOAA's Storm Prediction Center. The areas of highest wind speeds are color-coded where the dark blue boundary is 75 knots and the enclosed medium blue is shading is 100 knots. The wind speed scale is along the left edge of the map area. Wind barbs are dark blue with speed indicated by the convention of Activity 1.

5. Note the locations of Little Rock, Arkansas and Green Bay, Wisconsin on the Figure C map. From the shading and wind barbs, there **[(*is*)(*is not*)]** a jet stream located between the cities at this time.
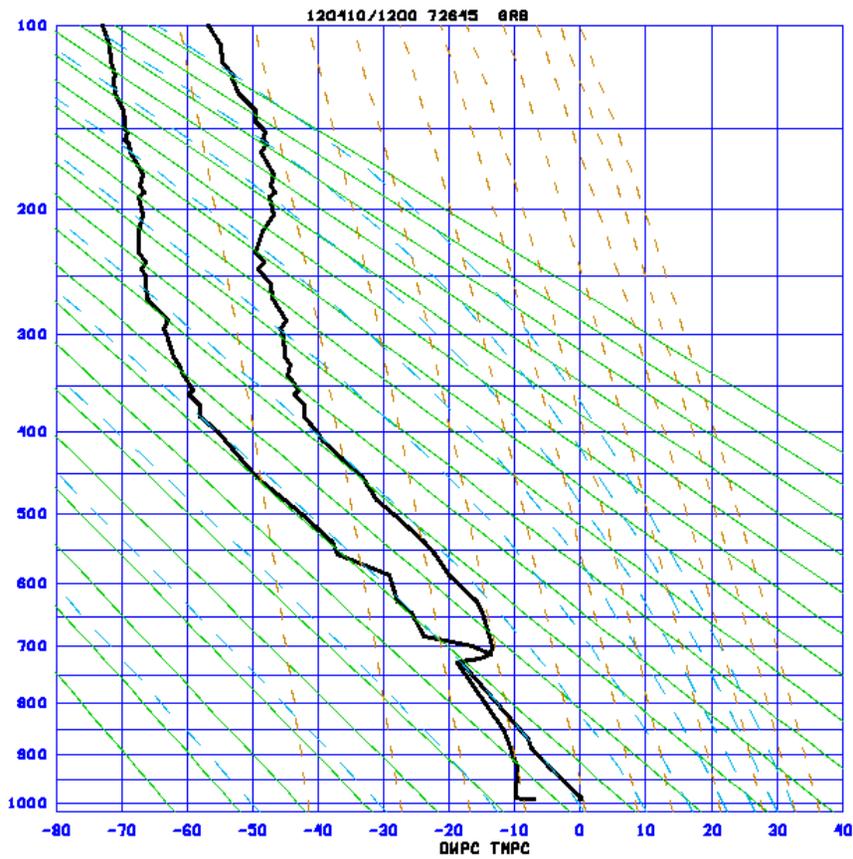
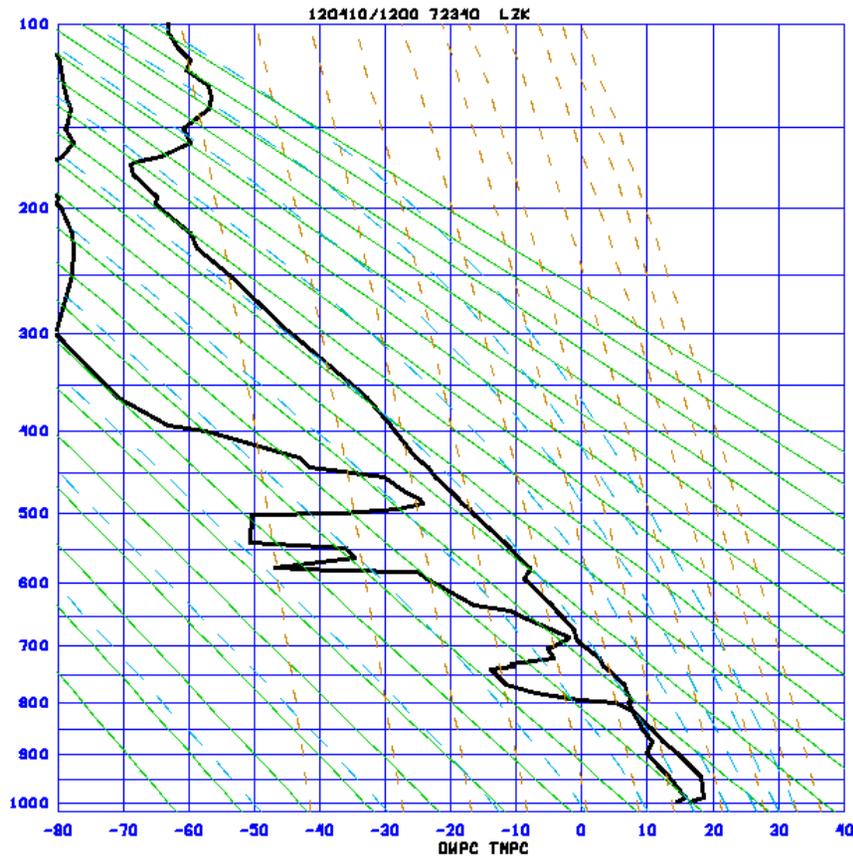Figure A. Radiosonde observation from Green Bay, WI at 12Z 10 APR 2012.

Figure B. Radiosonde observation from Little Rock, AR at 12Z 10 APR 2012.

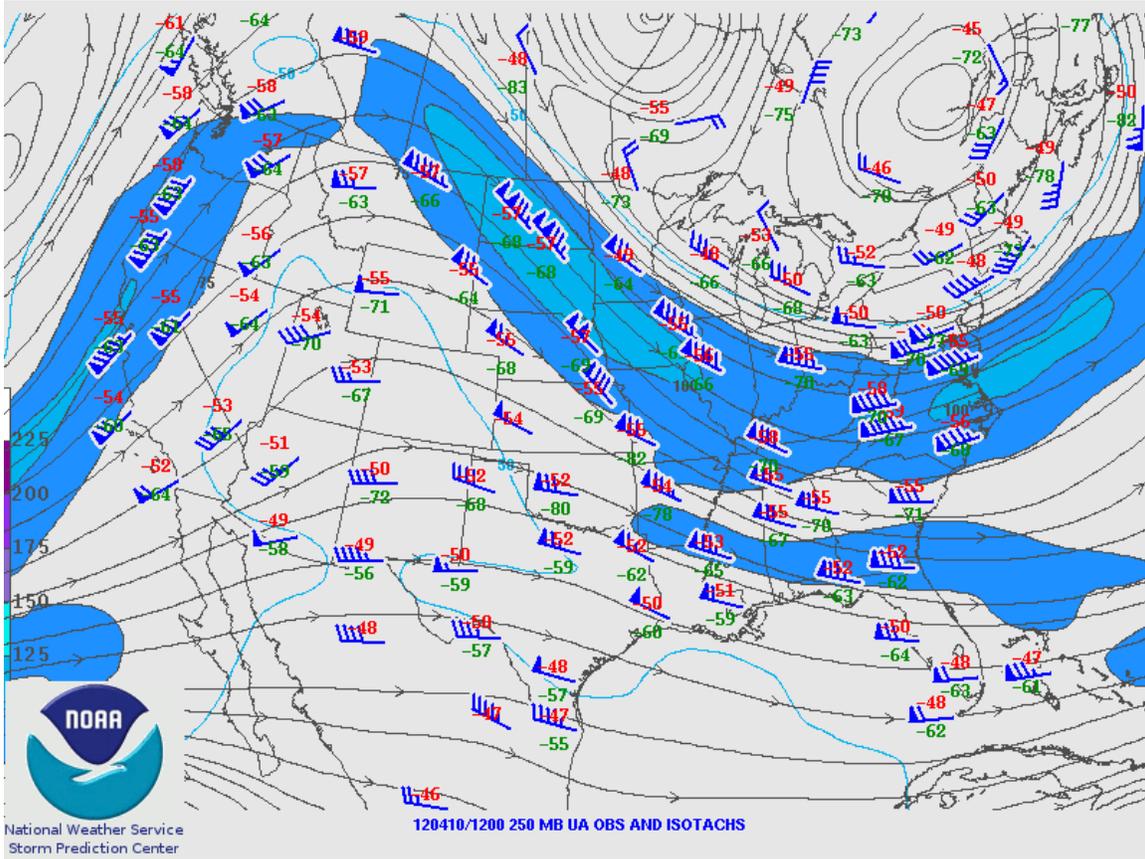6. The 250-mb flow pattern displayed on the map is most like that of **[(*Figure 1*) (*Figure 2*)]** of Activity 1 in this module.

Figure C. 250 mb map for 12Z 10 APR 2012 (NOAA SPC).