Which way does the wind blow?

A laboratory experiment from the Little Shop of Physics at Colorado State University

Overview

Many people don't understand what makes the wind blow or why it blows in the direction that it does. They understand that a cold front brings colder air and that a warm front brings warmer air, but they don't understand why. This concept is important to understand a weather map and why the wind shifts occur when a front passes. This exercise should help explain the three forces that govern wind velocity (wind speed and direction).

Necessary materials:

- Simple maps representing different pressure gradients
- Internet access to obtain current weather maps
- A printer to make hard copies of the maps to hand out to students
- Red, blue, and green (or any 3 colors of your choice) colored pencils to differentiate between the different forces

Theory

We look at weather maps on television when the meteorologist is giving tomorrow's forecast, but where do those maps come from? Weather maps come from observations from the surface and from weather balloons that are released all around the world at two times each day. Lines are then drawn to interpolate the information and produce the map!

The pressure gradient force is what causes the wind to blow. It is a measure of how much air is in one location versus another and is what forces the air to move from regions of high pressure to regions of low pressure. Differing pressures are a result of density differences (measured as differences in temperature) and elevation. The pressure gradient force is determined only by the gradient in pressure (the stronger the difference in pressure the stronger the pressure gradient force)! At the surface, we generally look at maps of pressure so finding the gradient in pressure is easy. At higher levels, we generally look at isobaric maps (maps on a single pressure surface). In this case, there are no pressure lines and so we look at lines of geopotential height and think of them in the same way that we looked at pressure lines at the surface.

The Coriolis "force" is an apparent force due to the rotation of the Earth and doesn't force the air to move, but rather changes its direction. The Coriolis force depends upon the latitude and speed of the wind, being strongest at high latitudes and fast wind speeds. It acts to the right in the Northern Hemisphere (NH) and to the left in the Southern Hemisphere (SH).

Friction acts near the Earth's surface and acts opposite to the direction of the wind, acting to slow it down. Its strength depends upon the wind speed and the roughness of the surface. For instance, friction is greater over a forest and fast wind speeds than over calm water and slower wind speeds.

Far above the surface, the wind is a result of a force balance between the pressure gradient force and the Coriolis force. Near the surface, the force balance is between the pressure gradient force, the Coriolis force, and friction.

Doing the Experiment

The experiment goes like this:

Step 1

- As a group, practice drawing arrows to represent the three forces on the attached, simple plots before moving on to more complicated weather maps.
- Remember to first draw the arrow representing the pressure gradient force, pointing from lower to higher pressure. The tighter the gradient (the closer together the lines), the longer the arrow!
- Next, determine if the plot is at the surface or aloft.
- If the plot is aloft, draw an arrow representing the Coriolis force opposite (at an 180° angle to) the pressure gradient force.
- If the plot is at the surface, things are more complicated because we must also consider friction.
    - When friction is involved, the wind speed will be less than it would be if friction were not included. Since the Coriolis force is dependent upon the wind speed, a weaker wind speed will produce a weaker Coriolis force and the Coriolis force will not exactly balance the pressure gradient force.
    - Draw the arrow representing the Coriolis force at an angle somewhat less than 180° to the pressure gradient force. In the NH, the angle will be to the right of the pressure gradient force. In the SH, the angle will be to the left. Remember, the Coriolis force arrow will be smaller than the arrow for the pressure gradient force.
    - The arrow representing friction is at a 90° angle to the Coriolis force. It is to the right in the NH and to the left in the SH.
- Now it's time to draw the wind arrow! You can find it using vector addition.
- Aloft, the wind is parallel to the isolines, at a 90° angle to both the pressure gradient force and the Coriolis force. In the NH, the wind will be to the right of the pressure gradient and will be to the left in the SH.
- At the surface, the wind is 180° opposite the friction, 90° from the Coriolis force, and less than 90° from the pressure gradient force and will point toward lower pressure.
- Ask what difference exist between the surface and the 500mb plots and what happens when the pressure gradient becomes stronger.

Step 2

- Go to http://www.cdc.noaa.gov/Composites/Day/
- Under variables, select Geopotential height (sea level pressure) at 500mb (surface)
- At the first OR, select your date as both the first and second options (for a single day analysis) and also your year of interest
- Under color, select Black and White; shading type select Contours (Black and White only)

- Scale plot size is 500%, plot contour labels = yes, state boundaries = yes, region of globe = USA
- Click Create plot
- Copy the plot to some program (such as power point) where you can edit it. Add several dots in interesting locations and label them as 1,2,3… (Or you can do this manually)
- On a 500mb map, have the students
  - Label trough axes (where the isolines dip) with a solid line and ridge (where isolines have a bump) with a dashed line
  - Draw arrows representing the pressure gradient force and the Coriolis force.
  - Draw arrows representing the wind.
  - Where do you expect the fastest winds to occur?
- On a surface map, have the students
  - Label the surface lows and highs
  - Draw arrows representing the pressure gradient force, the Coriolis force, and friction.
  - Draw arrows representing the wind.
  - Where do you expect the greatest wind speed and why?
  - What 2 forces alter the wind speed?
  - Which force does not change the wind speed?
  - Which force does not change the wind direction?

Summing Up

This exercise explains wind speed and direction by looking at real weather maps and identifying important features and forces that determine the wind. Knowing where the air is coming from helps identify how the temperature will change because colder air comes from the direction of the poles and warmer air from the tropics.

For More Information

CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

Little Shop of Physics: http://littleshop.physics.colostate.edu