Why do storms often form along fronts?

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

Overview

If you have ever watched the TV weatherman closely, you may have wondered why rainstorms often accompany warm and cold fronts. Is it the temperature change that is so important, or is something else going on?

Necessary materials:

- Large clear fish tank/aquarium (the longer the better)
- Barrier to divide the tank into two sections
- Warm and cold water
- Ice or salt
- Red and blue food coloring

The experiment can be modified for use without the barrier.

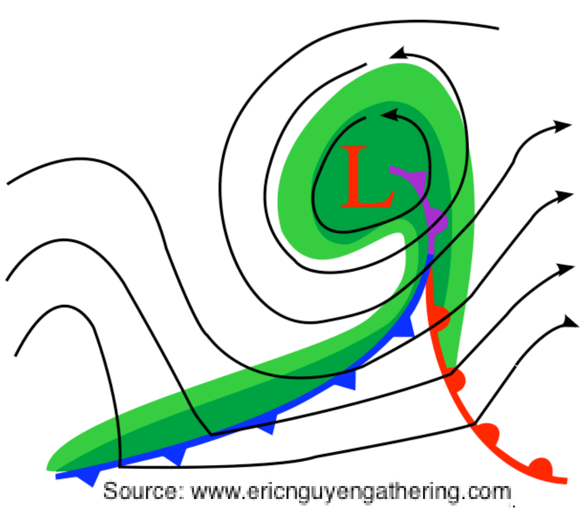
This experiment demonstrates the concept of density currents and explains why precipitation forms along air mass boundaries.

Theory

Actually, a change in temperature is important to make the rain, but perhaps not for the reasons that you might expect.

Of course, you know that when it gets cold, liquid water **freezes** into ice, and water vapor **condenses** into liquid water. So when air that contains water vapor gets cold, the water vapor can condense and form raindrops. Is that what's happening? Have we solved the problem already? What about the warm fronts? Warming means **evaporation** and **melting**, so there must be something else going on here.

First of all, we must realize that when a cold or warm front approaches, it does not change the temperature of the air that is already all around. Instead, cold and warm fronts represent the boundaries of warm and cold **air masses** that are in motion. So when a cold front approaches it is bringing new, cold air in behind it, displacing warmer air in front of it.



Rain (in green) always seems to accompany cold, warm, and occluded fronts like in this mid-latitude cyclone.

Now that we know that the air is moving, can we figure out why precipitation forms along the front? Well, we also already know that it takes some kind of cooling for the moisture in the air to condense into rain. Does the movement cause cooling?

Let's think about how the two types of air move. One is cold and one is warm. That means that one is more dense than the other, since when gases and liquids get colder, they get more dense. And since, dense air is heavier than warm air, it would sink beneath the warm air if they were put in the same place. This is like turning on the air conditioning in the summer if the air conditioning vents are near the top of a room. Once the cold, dense air begins blowing out of the vents it sinks beneath the warm, less dense air already in the room because the cold air has more **potential energy** due to its higher mass. This type of motion involving fluids of different densities is known as a **density current**.

Density currents (also called buoyancy or gravity currents) are fluid flows which arise from horizontal density differences within the fluid. In the atmosphere, gravity currents take the form of cold fronts, cold-air outflow from thunderstorms, and **katabatic** (downward) flow from mountain tops. During the passage of a density current, there is a sudden drop in temperature, and an increase in the wind speed.

When a cold front starts to push on the warm air ahead of it, it actually flows underneath the warm air and lifts the warm air higher in the atmosphere. Since air pressure get lower the higher you go in the atmosphere, as the warm air is lifted, it expands and becomes cooler. This is the cooling that we need to condense the water vapor into rain!

It works for warm fronts, too. As warm air tries to push on cold air ahead of it, it cannot flow underneath because it is less dense. Instead, it rises up over the top of the cold air, and as it rises, it expands and cools, making the water vapor inside condense into rain.

Doing the Experiment

This experiment can be done in a number of different ways, each with varying levels of detail. More advanced methods include testing the effects of various differences in density or using longer tanks to explore the speed of the density current or examining what happens when two high-density fluids are released from opposite ends of the tank and allowed to run in to one another.

The experiment goes like this:

- Use the divider to separate the container into two (preferably water-tight) sections.
- Fill one section (the larger if the sections are not of equal size) with warm water and a few drops of the red food coloring
- Fill the other section with cold water, ice, and the blue food coloring. Allow this to cool through if not already done. Alternatively, salt can be mixed into this section in place of the ice to make it more dense.
- Quickly remove the partition and watch the cold, dense water move underneath the warm, less dense water.

Be sure to make it clear that the water flow represents the flow along a cold front in the atmosphere. In addition to watching from the side of the tank, it is also interesting to watch the flow from the top with the omission of the red food coloring to watch the formation of **shear vortices** along the "front."

Further Exploration: Visit the following website and collect videos and images of large-tank density current experiments that were preformed in a university laboratory, http://www.meteo.physik.uni-muenchen.de/~robert/meteorologielabor/labor.html**.**

Summing Up

In this form, the experiment is largely qualitative, but it presents a good visual representation of how cold fronts and warm fronts move in the atmosphere. Additionally, while the experiment does not directly show the formation of precipitation within the tank, the extension to precipitation formation by lifting air is easy to include.