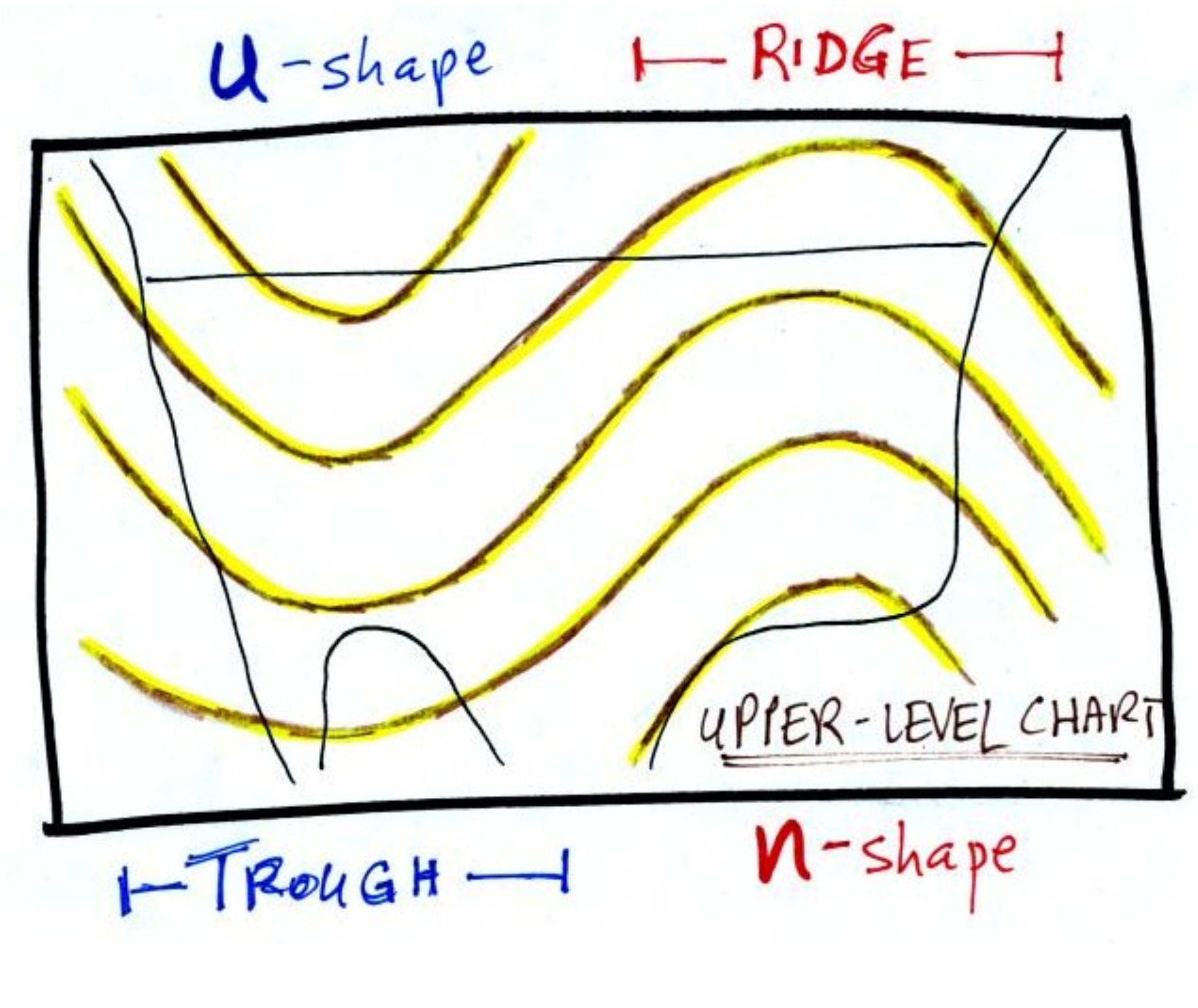
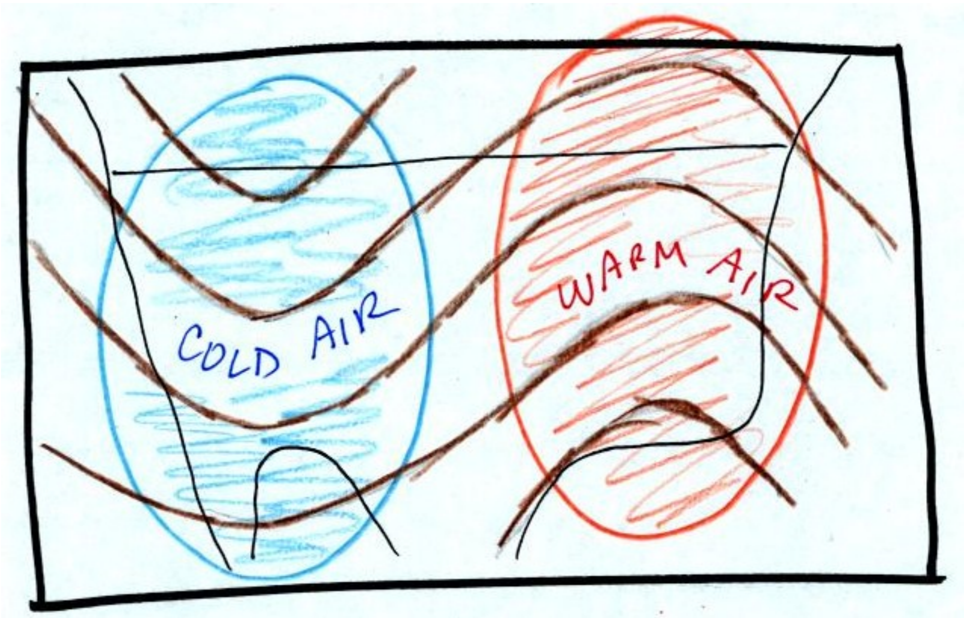
Module 3: Lecture 9

In addition to surface weather maps, maps showing conditions at various altitudes above the ground are routinely made. We will spend some time learning about these upper level charts. Upper level conditions are important because they affect the development and movement of surface features (and vice versa).

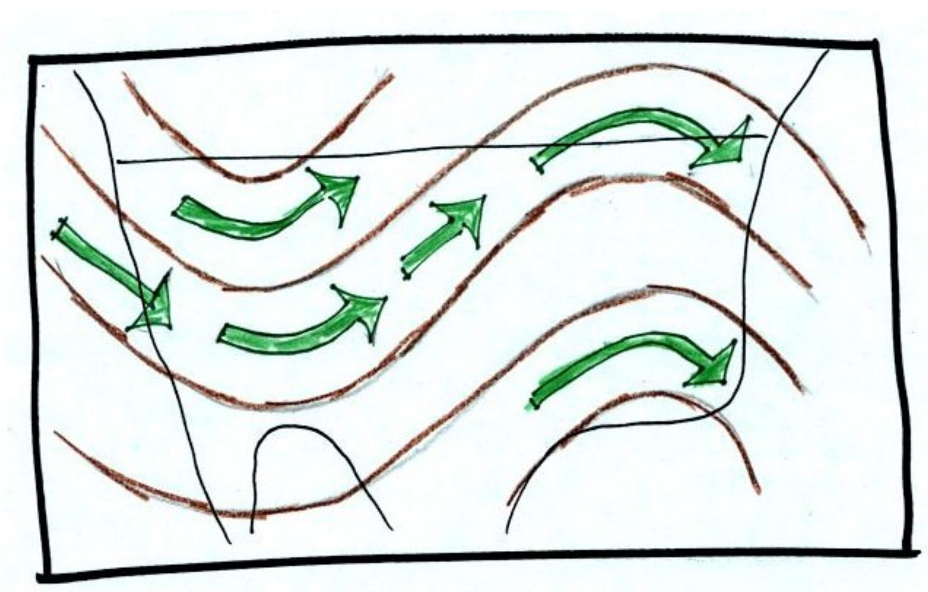
We will start with some basic features and then take a more careful and detailed look at upper level charts. The overall appearance of an upper level chart is somewhat different from a surface weather map. The patterns on a surface map tend to be complex and you generally find circular (more or less) centers of high and low pressure. Circular, closed high and low pressure centers are occasionally found above the surface. However usually you will find a relatively simple wavy pattern similar to what is sketched below.



The **u**-shaped portion of the pattern is called a trough and the **n**-shaped portion is called a ridge. Troughs are produced by large volumes of cool or cold air (the cold air is found between the ground and the upper level that the map depicts). The western half of the country in the map above would probably be experiencing colder than average temperatures. Large volumes of warm or hot air produce ridges. The eastern half of this map is experiencing warmer than average temperatures.



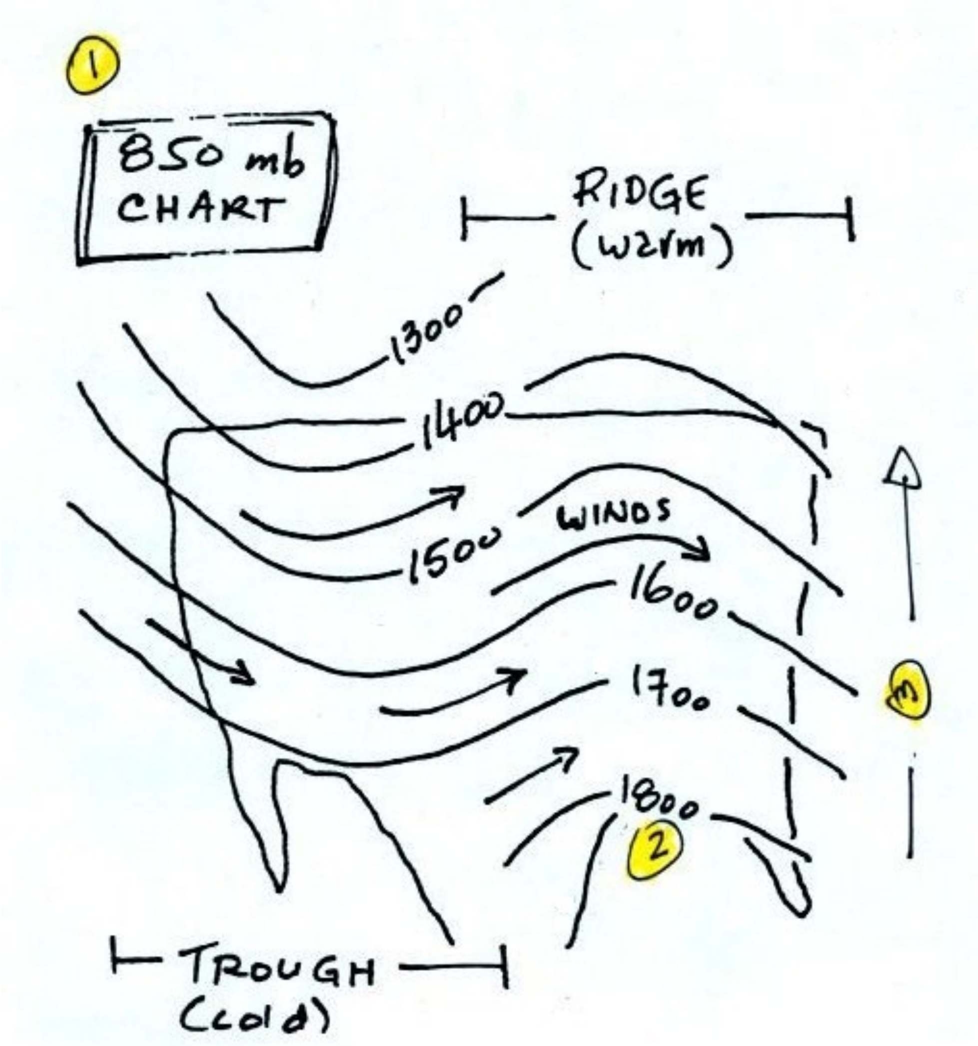
The winds on upper level charts blow parallel to the contour lines. On a surface map the winds cross the isobars slightly, spiraling into centers of low pressure and outward away from centers of high pressure. **The upper level winds generally blow from west to east.**



Now we will discuss upper-level charts in more depth.

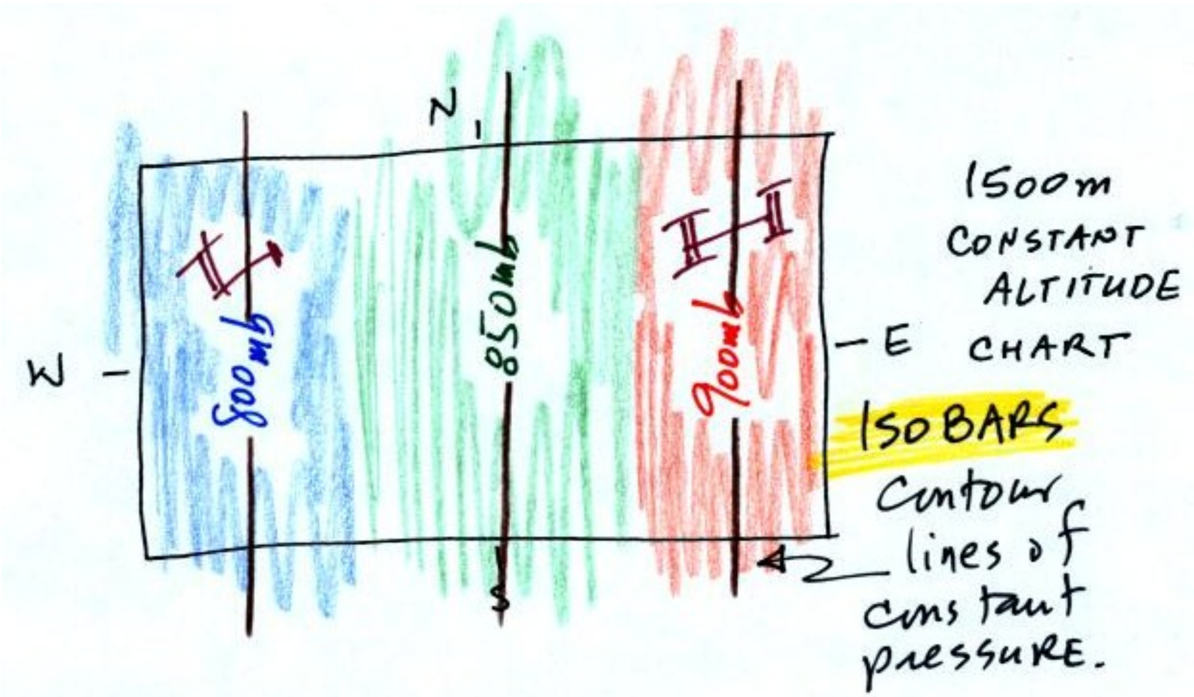
Below is a typical upper-level chart. By the end of this section you should better understand what the title "850 mb Chart" on the upper level map above refers to. You will also understand what the numbers on the contour lines mean. You will also have a better idea of where the names trough and ridge come from and why they are associated with cold and warm air masses, respectively. Note that the values on the contours decrease as you move from the equator toward higher latitude. You should be able to explain why that happens.

You really only need to remember two very important concepts from earlier in the course: (1) pressure decreases with increasing altitude, and (2) pressure decreases more rapidly in cold high-density air than it does in warm low density air.



Isobars on constant altitude upper level charts

Surface weather conditions are plotted by showing pressures at a constant altitude (sea level). The same method could be used to map upper level conditions. We could draw an upper level chart by plotting pressure at various altitudes above sea level, just as we do for surface maps. For example, the figure below shows how the pressure varies at a **constant altitude** of 1500 meters. Note that the lowest pressures are found in the cold air while higher pressures would be found in the warm air. At 1500 meters, the pressure drops from 1000 mb to 800 mb but only decreases 100 mb in the warm, low density air.

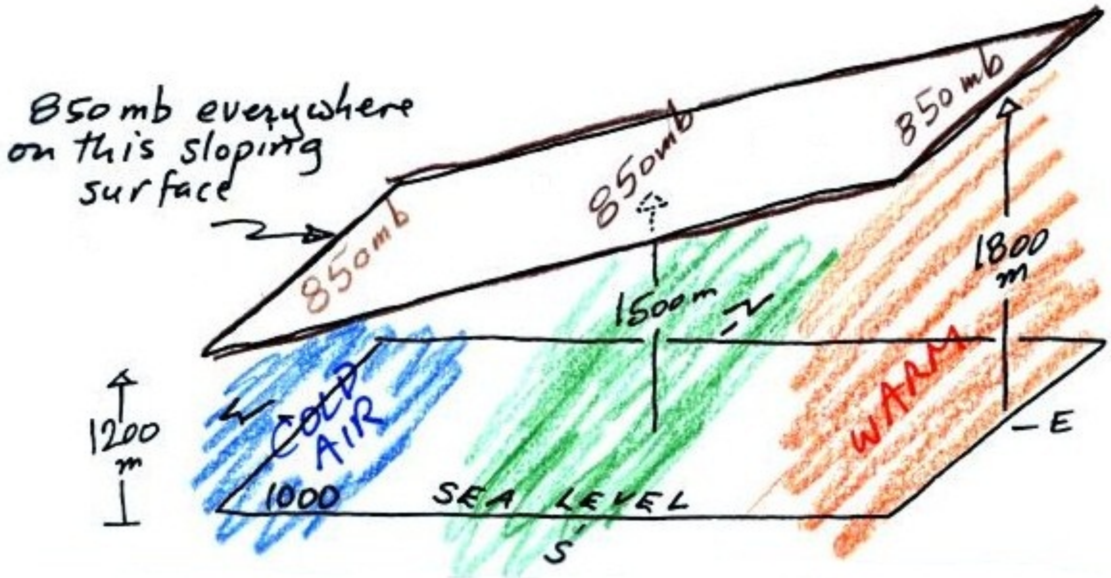


Height contours on constant pressure (isobaric) upper level charts

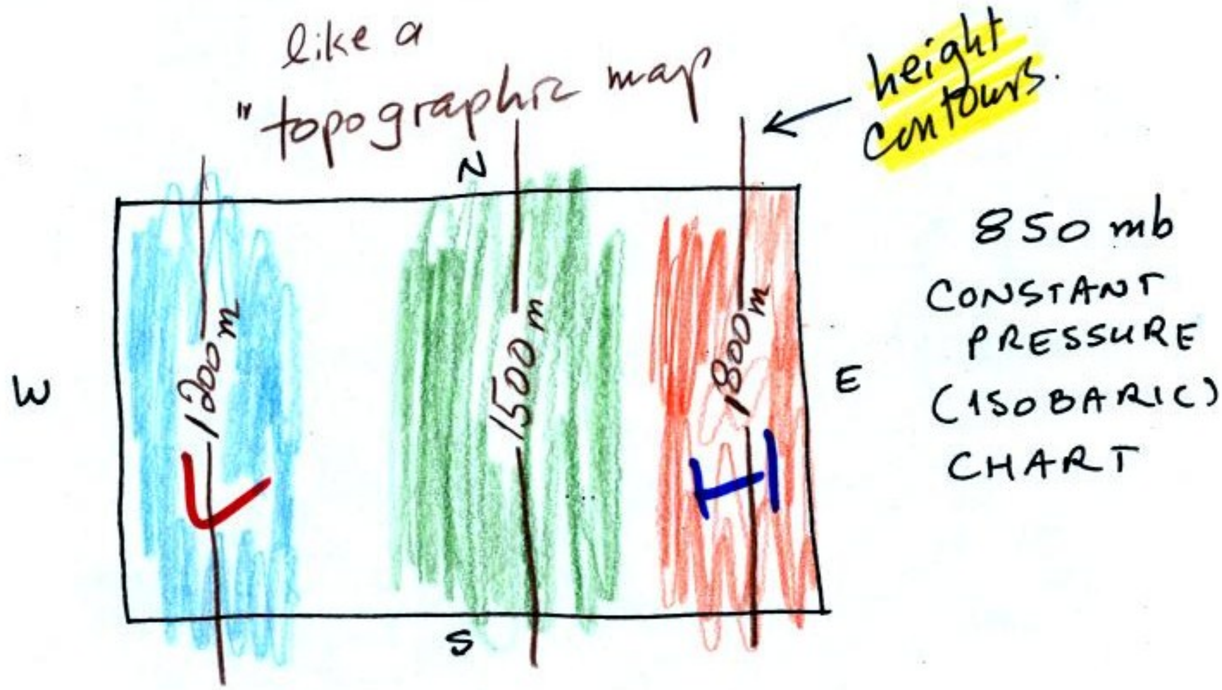
The method above would seem to be a logical way of mapping upper level atmospheric conditions. Unfortunately that is not how things are done. Just to make life difficult, meteorologists do things differently. **Rather than plotting conditions at a constant altitude above the ground, meteorologists measure and plot conditions at a particular reference pressure level above the ground.**

In the picture below you start at the ground (where the pressure is corrected to 1000 mb) and travel upward until you reach a pressure of 850 mb. You make a note of the altitude at which a pressure of 850 mb occurs. In cold, dense air the pressure decreases rapidly so you may only need to rise 1200 meters to reach a pressure of 850 mb. In warm and less dense air the pressure decreases more slowly and you would expect to travel higher to reach a pressure of 850 mb.

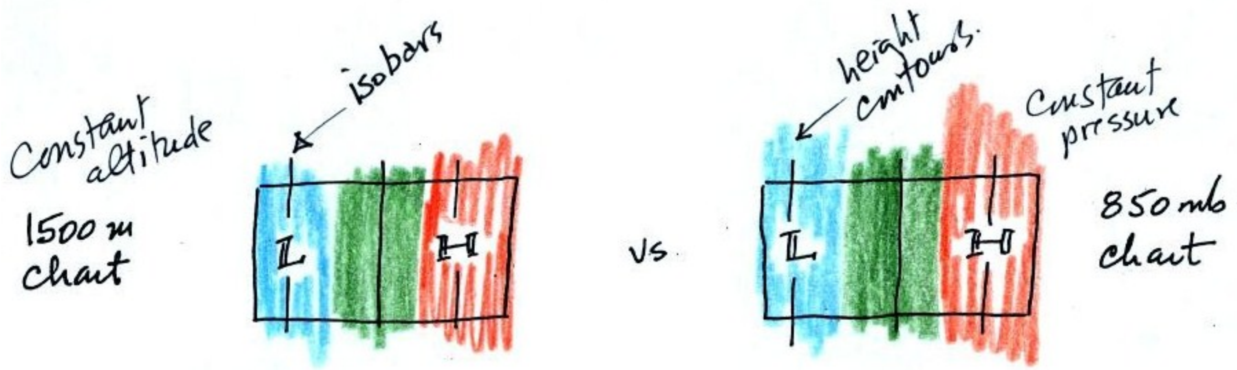
As shown in the figure below, every point on the on the map has a pressure of 850 mb. What changes is the altitude above the ground.



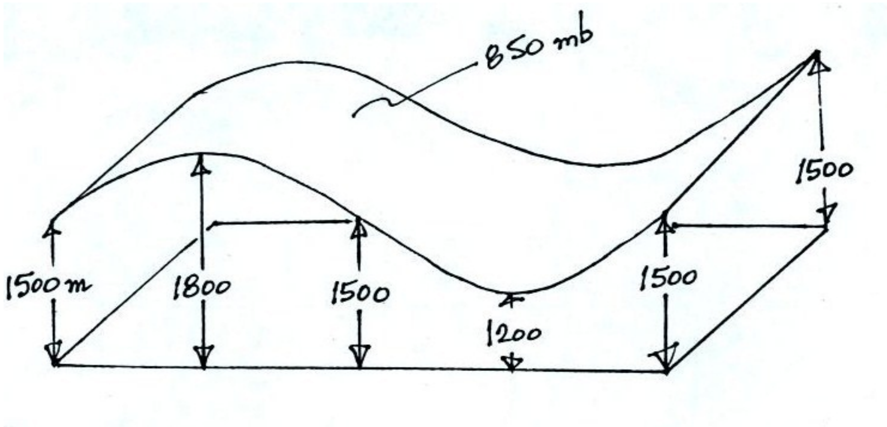
You could draw a topographic map of the sloping **constant pressure** surface by drawing contour lines of altitude or height. The L and H on this map represent low and high altitude, respectively.



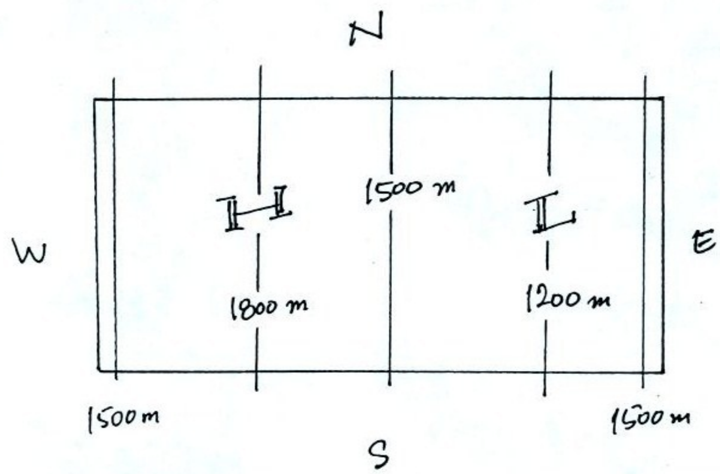
The two kinds of charts (constant altitude and constant pressure) are redrawn below. The numbers on the contour lines have been left off in order to demonstrate that both types of maps have the same overall pattern. They should be similar because they are both depicting the same upper level atmospheric conditions.



In the example above, the temperature changed smoothly from cold to warm as you move from left to right (west to east). See if you can figure out what temperature pattern is producing the wavy 850 mb constant pressure surface below.

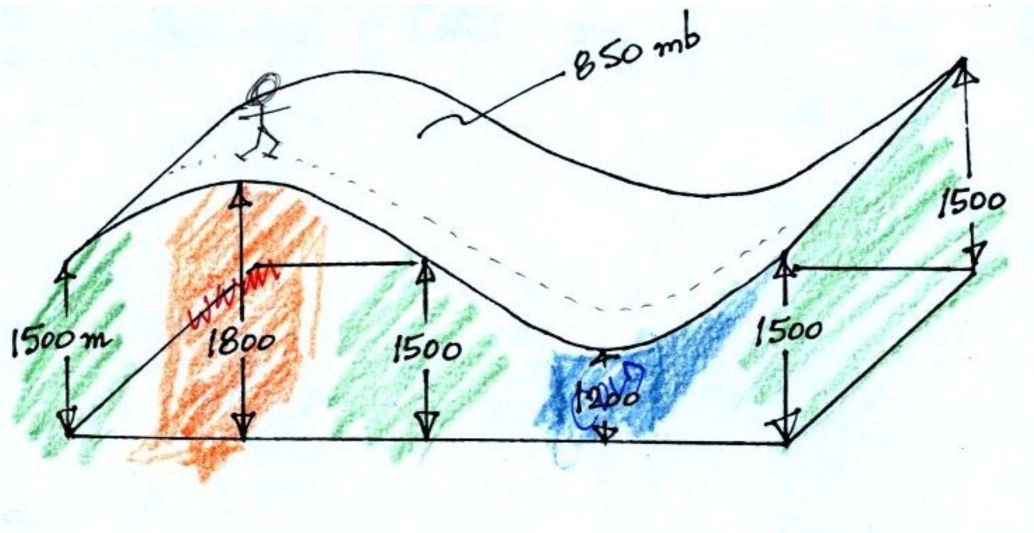


The chart for this wavy 850 mb surface would look like:



The key is remembering that the 850 mb level will be found at higher altitudes in the warm air, where pressure decreases slowly with increasing altitude. The 850 mb level will be found at lower altitudes in cold air, where pressure decreases rapidly with increasing altitude. The temperature pattern is shown below.

If you imagine hiking along the 850 mb surface you can begin to understand where the term ridge comes from. In a ridge the reference pressure is found at higher altitude. A trough is in effect a valley where the reference pressure is found at lower altitude.



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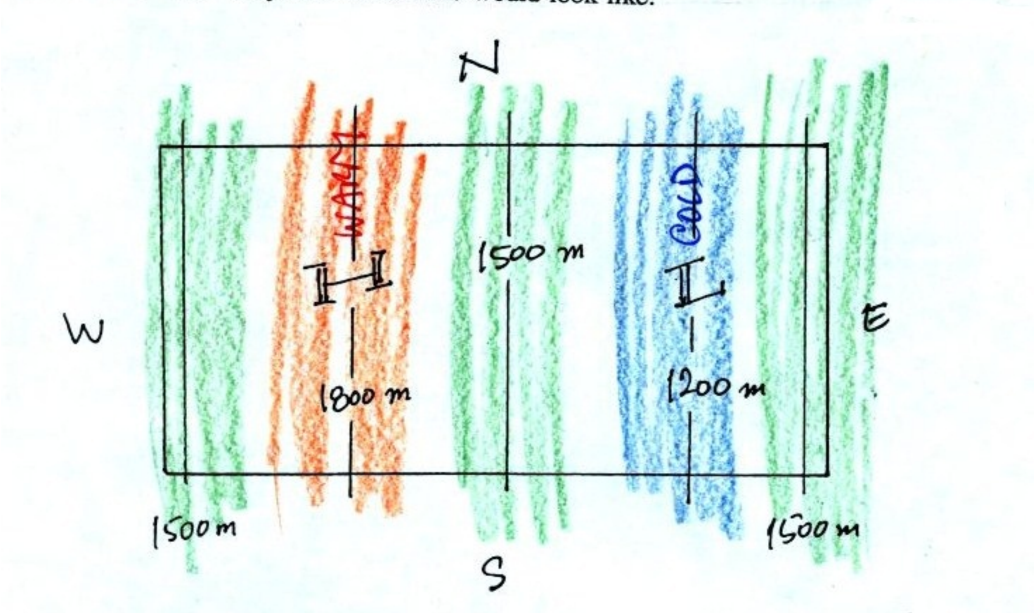
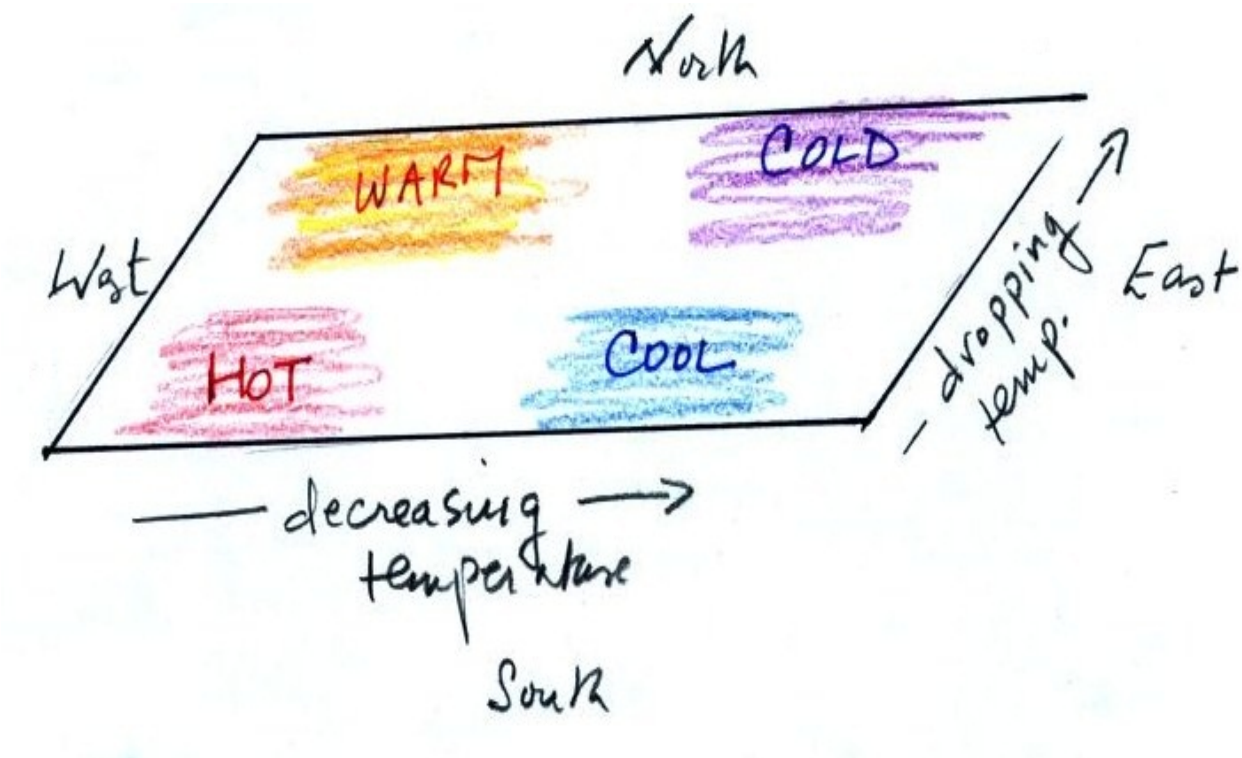
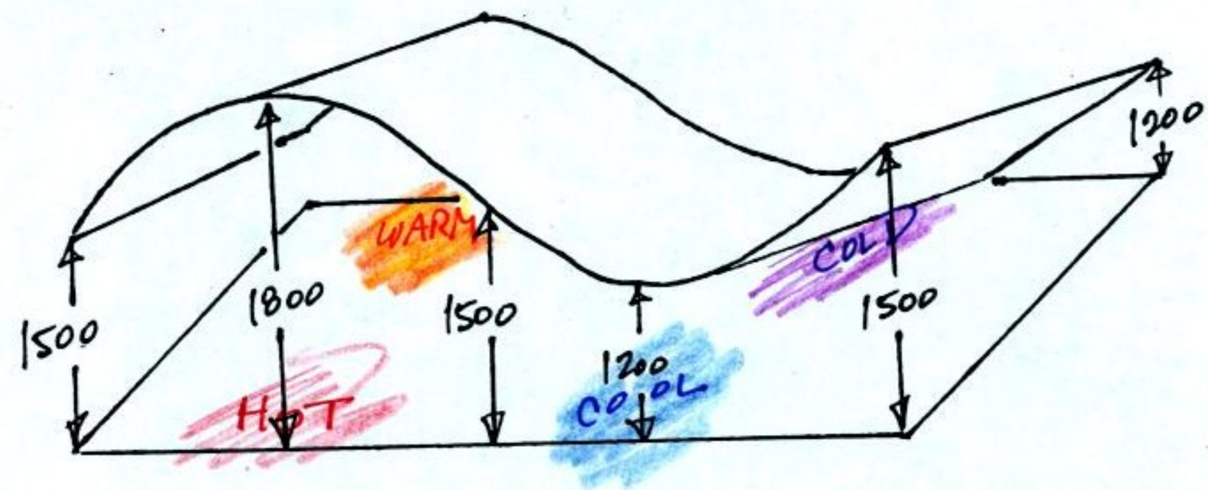


In the next figure we will add south to north temperature changes in addition to the west to east temperature gradient. Here is what the temperature pattern will look like.

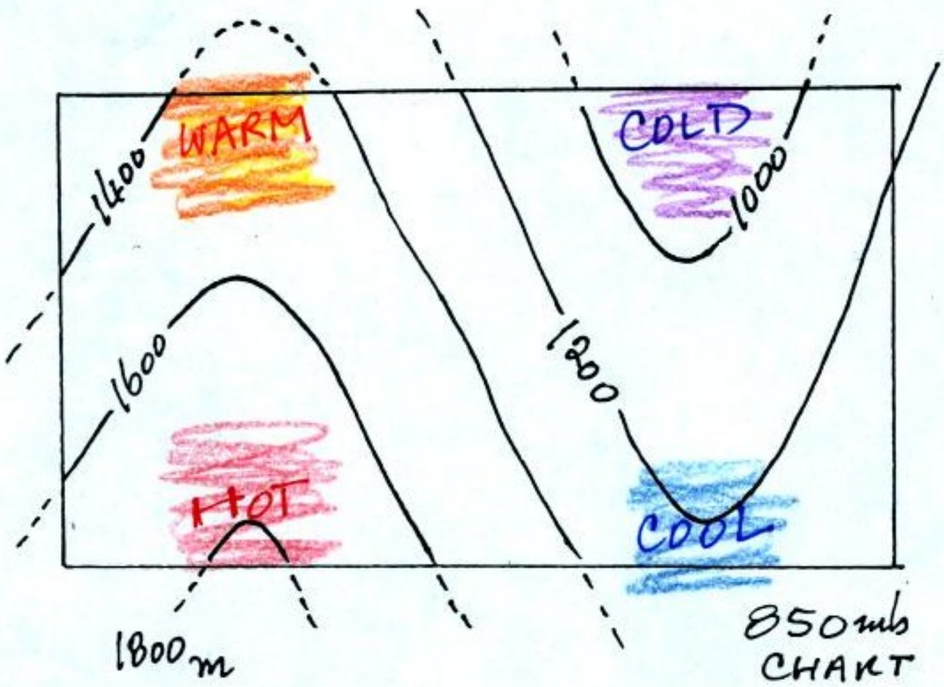


The temperature decreases as you move from west to east (as it did in the previous pictures) and now it also decreases as you move from south to north. What will the wavy 850 mb constant pressure surface look like now? It is the wavy surface that we had in the previous example (where there was just a west to east temperature change). Now the northern edge is tilted downward because there is colder air in the north.

Now look at how the map has changed. We see an "n" shaped ridge and a "u" shaped trough. The highest point on the 850 mb surface (1800 meters or so) is found above the hot air near the SW corner of the picture. The lowest point (a little less than 1000 meters) is found in the coldest air near the NE corner of the picture.



The chart that depicts this surface starts to look more like what we are familiar with:

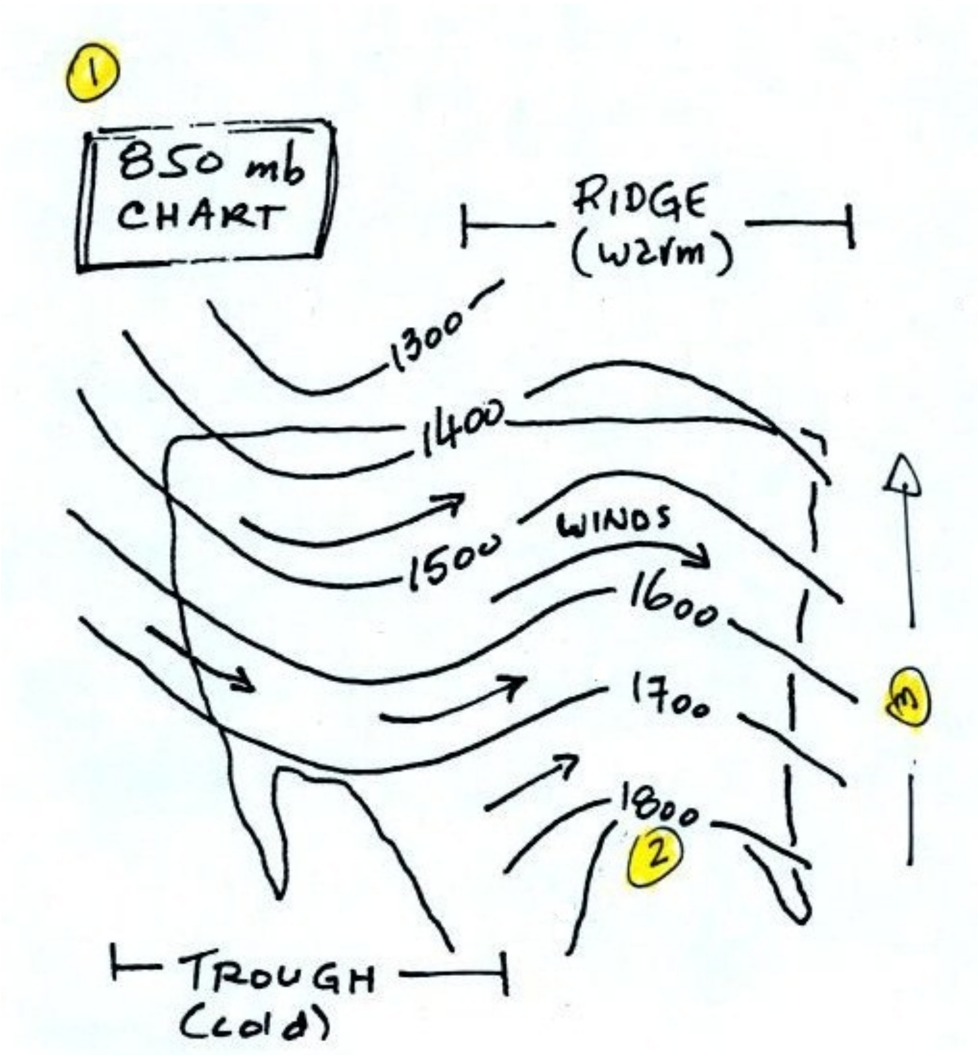


Now let us go back to the figure that we started this section with.

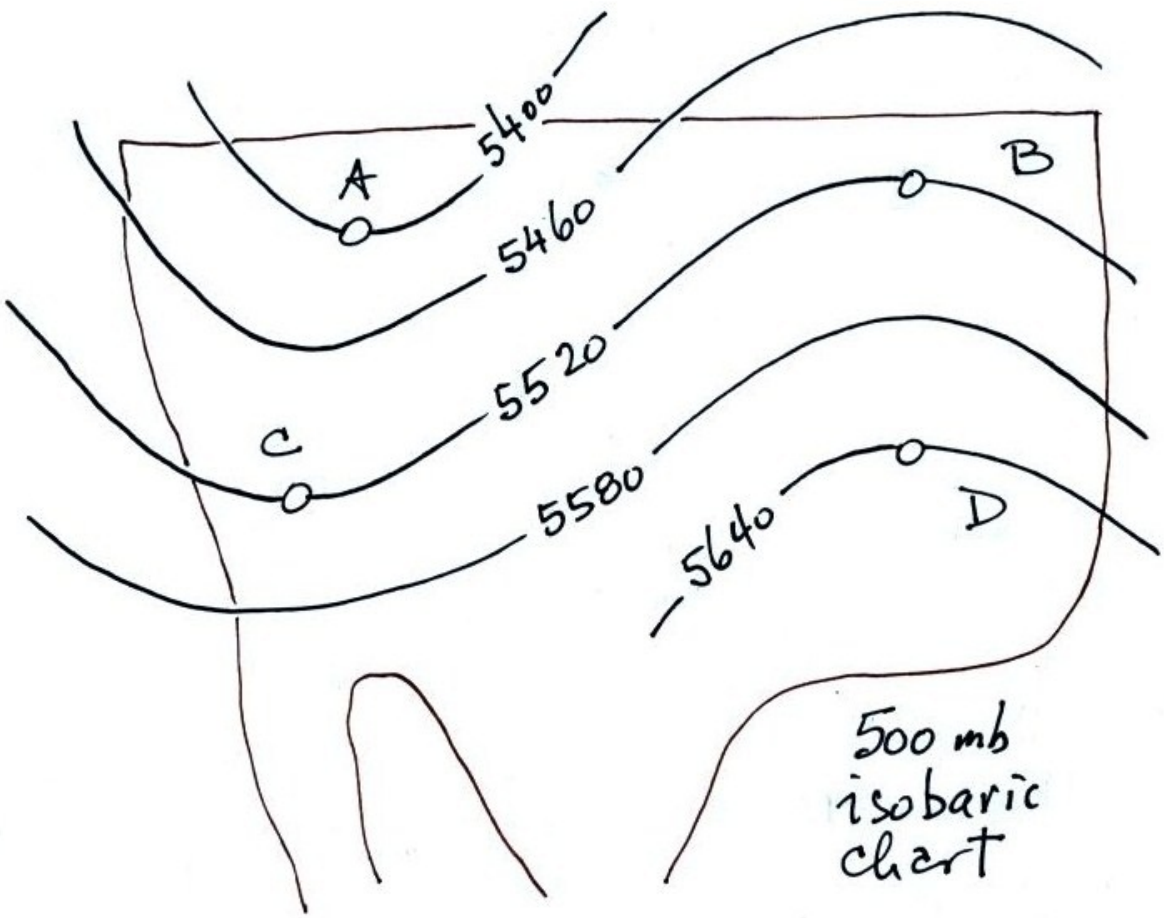
1. The title tells you this is a map showing the altitude of the 850 mb constant pressure level in the atmosphere.

2. Height contours are drawn on the chart. They show the altitude, in meters, of the 850 mb pressure level at different points on the map.

3. The numbers become smaller as you head north because the air is colder. The 850 mb level is lower in the north where the air is colder, denser, and where pressure decreases more rapidly with increasing altitude.



Here is a figure with some questions to test your understanding of this material. You will find the answers at the end of this lecture. Unlike the previous examples, this is a 500 mb constant pressure chart instead of a 850 mb chart. The 500 mb pressure occurs at a higher altitude than the 850 mb level.



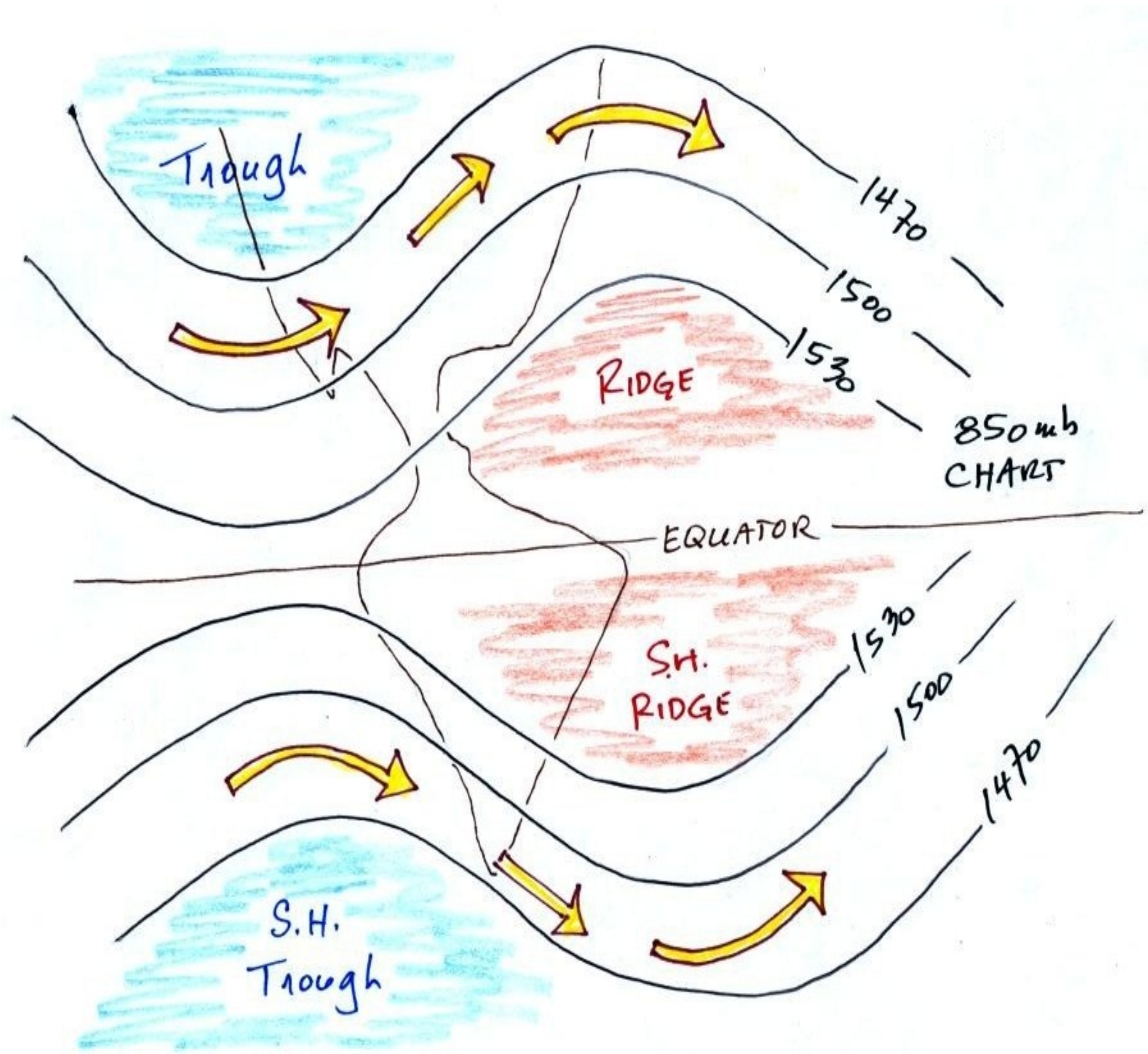
Is the pressure at Point C greater than, less than, or equal to the pressure at Point D (you can assume that Points C and D are at the same latitude)? How do the pressures at Points A and C compare?

Which of the four points (A, B, C, or D) is found at the lowest altitude above the ground, or are all four points found at the same altitude?

The coldest air would probably be found below which of the four points? Where would the warmest air be found?

What direction is the wind blowing at Point C?

Here is a quick comparison of upper level charts in the northern and southern hemispheres. The cold air is in the north in the northern hemisphere and in the south in the southern hemisphere. Essentially the pattern is effectively flipped in the southern hemisphere compared to the northern hemisphere. The winds blow parallel to the contour lines and from west to east in both hemispheres.

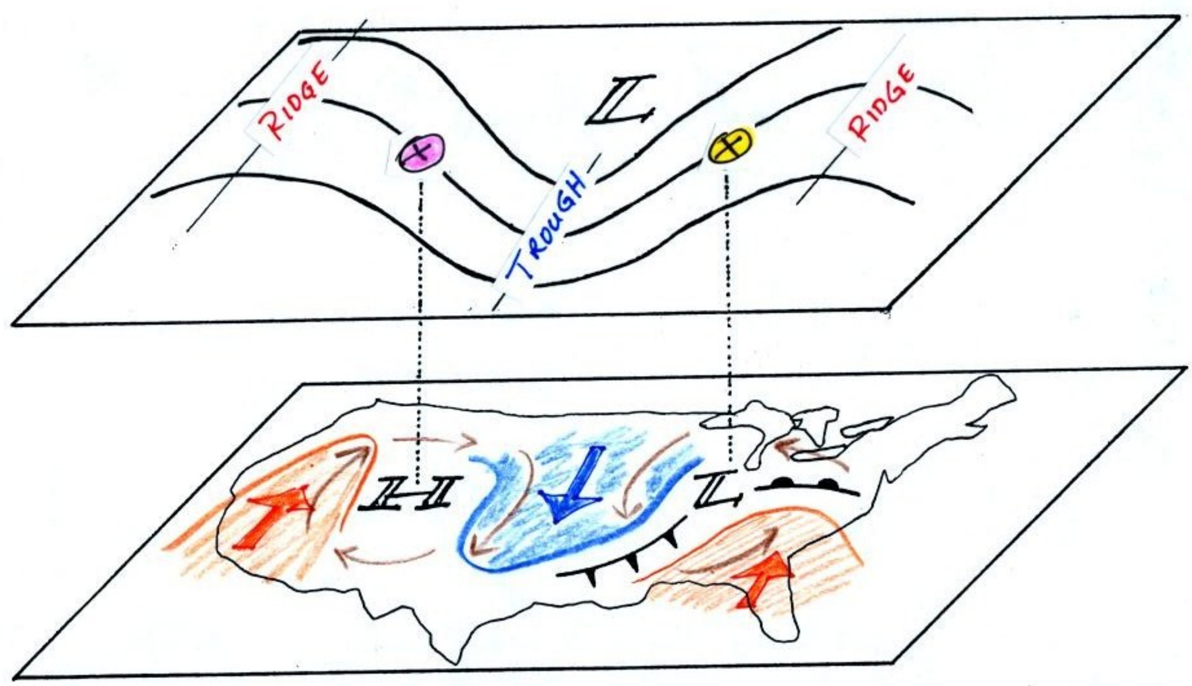


We will finish this lecture by looking in more detail at how upper level winds can affect the development or intensification of a surface storm. Do not worry if you find this material a little difficult and confusing at this point.

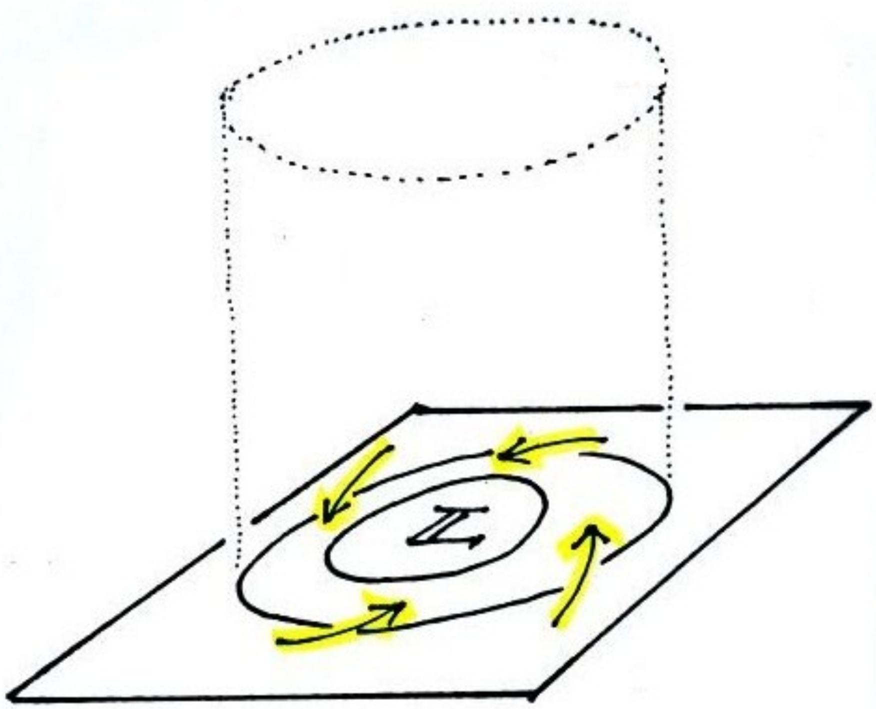
Surface and upper level maps are superimposed in the figure below. On the surface map you see centers of high and low pressure. The surface low pressure center, together with the cold and warm fronts, is a middle latitude storm. The surface winds are shown with thin brown arrows on the surface map. Note how the counterclockwise winds spinning around the low move warm air northward (behind the warm front on the eastern side of the low) and cold air southward (behind the cold front on the western side of the low). Clockwise winds spinning around the high also move warm and cold air.

Note the ridge and trough features on the upper level chart. We learned that warm air is found below an upper level ridge. Now you can begin to see where this warm air comes from. Warm air is found west of the high and to the east of the low. This is where the two ridges on the upper level chart are also found. You expect to find cold air below an upper level trough. The northerly winds found between the high and the low are moving cold air into the middle of the country.

Note the yellow X marked on the upper level chart directly above the surface low. This is a good location for a surface low to form, develop, and strengthen (strengthening means the pressure in the surface low will get even lower; this is also called "deepening"). The reason is that the yellow X is a location where there is often upper level divergence. The pink X is where you would expect to find upper level convergence, which could cause the pressure in the center of the surface high pressure to get even higher.

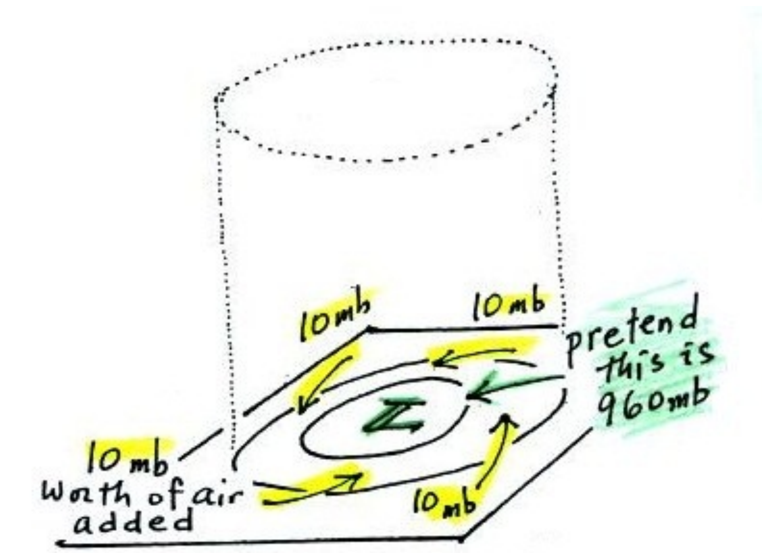


This figure shows a cylinder of air positioned above a surface low pressure center. The pressure at the bottom of the cylinder is determined by the weight of the air overhead. The surface winds are spinning counterclockwise and spiraling in toward the center of the surface low. These converging surface winds add air to the cylinder, which makes the cylinder increase in weight. As the low fills, you would expect the surface pressure at the bottom of the cylinder to increase over time.



Converging winds at the ground add weight to the column of air above the low. This would act to increase the pressure and weaken the low.

We will make up some numbers and perhaps this will make things clearer. We will assume the surface low has a pressure of 960 mb. Imagine that each of the surface wind arrows brings in enough air to increase the pressure at the center of the low by 10 mb. You would expect the pressure at the center of the low to increase from 960 mb to 1000 mb. This is just like a bank account. You have $960 in the bank and you make four $10 dollar deposits. You would expect your bank account balance to increase from $960 to $1000.



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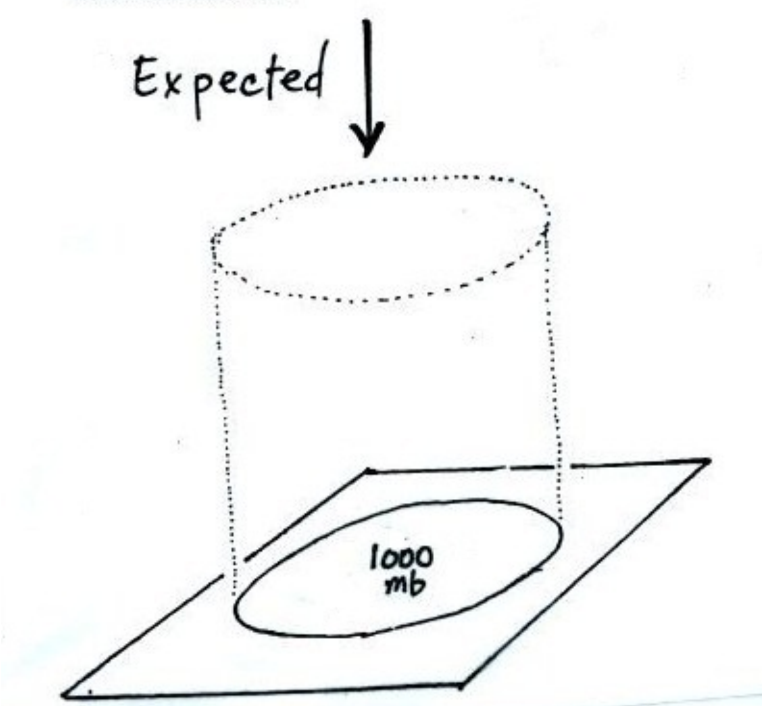
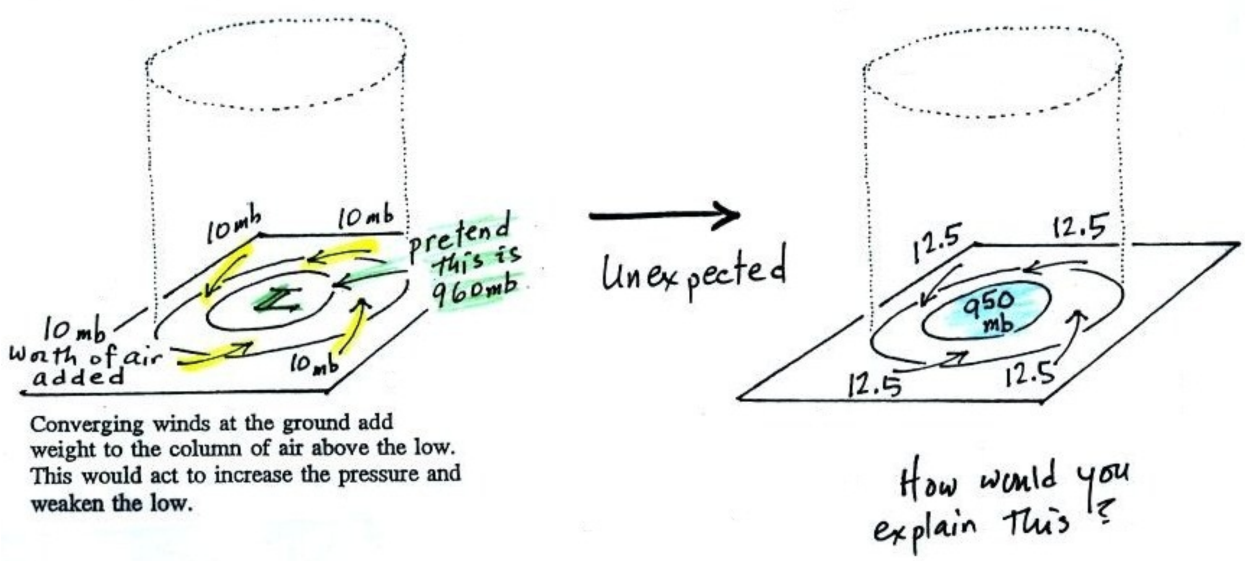
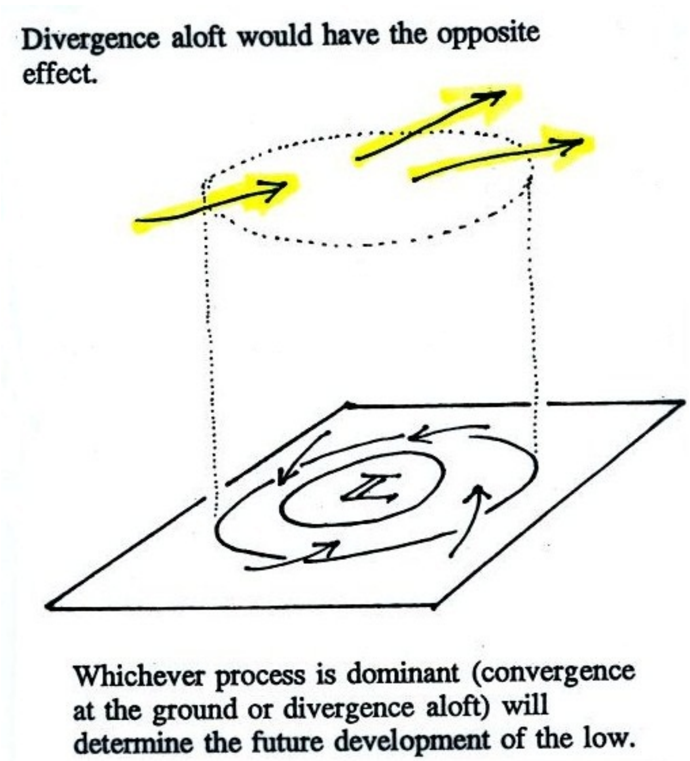


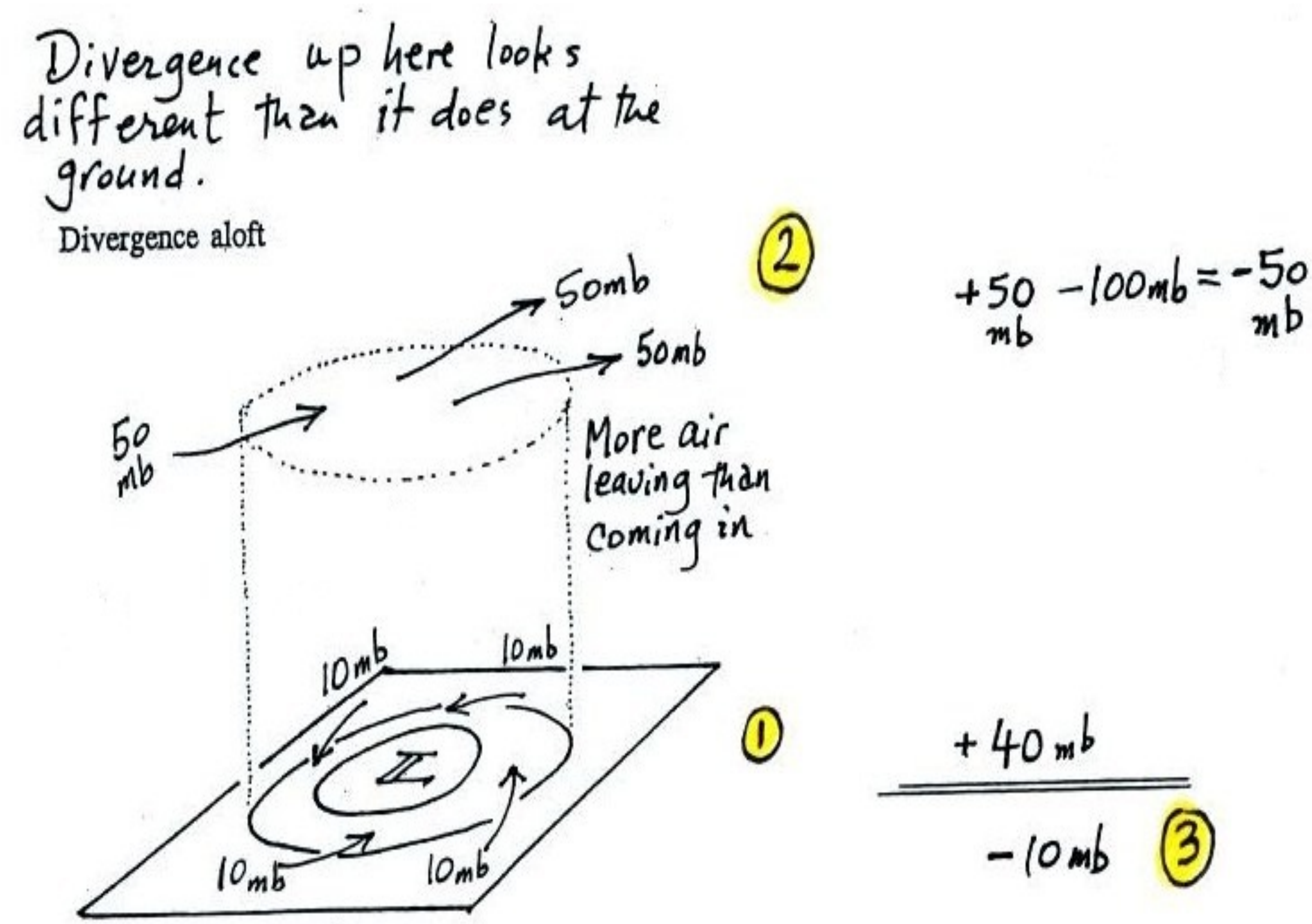
But what if the surface pressure decreased from 960 mb to 950 mb as shown in the following figure? Or in terms of the bank account, you would be very surprised if, after making four $10 dollar deposits, the balance went from $960 to $950.



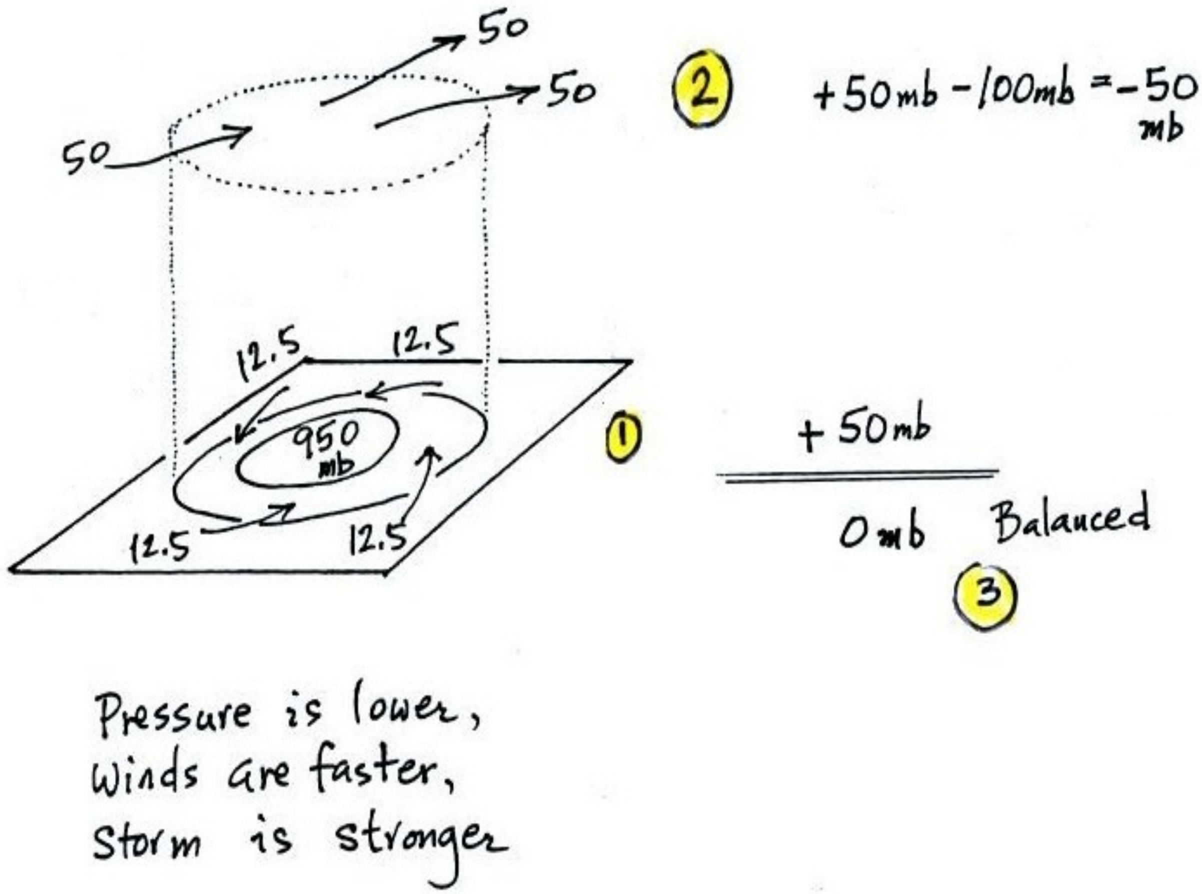
The next figure suggests that there may be upper level divergence. In other words, there are more arrows leaving the cylinder at some point above the ground than arrows of air entering the cylinder on the ground. Upper level divergence removes air from the cylinder and decreases the weight of the cylinder, which lowers the surface pressure.



We need to determine whether converging winds at the surface or diverging winds at upper levels have a greater effect. That will determine what happens to the surface pressure. Again some actual numbers might help. The 40 millibars worth of surface convergence is shown at Point 1. Up at Point 2 there are 50 mb of air entering the cylinder but 100 mb leaving. That is a net loss of 50 mb. At Point 3 we see the overall result, a net loss of 10 mb. The surface pressure should decrease from 960 mb to 950 mb.

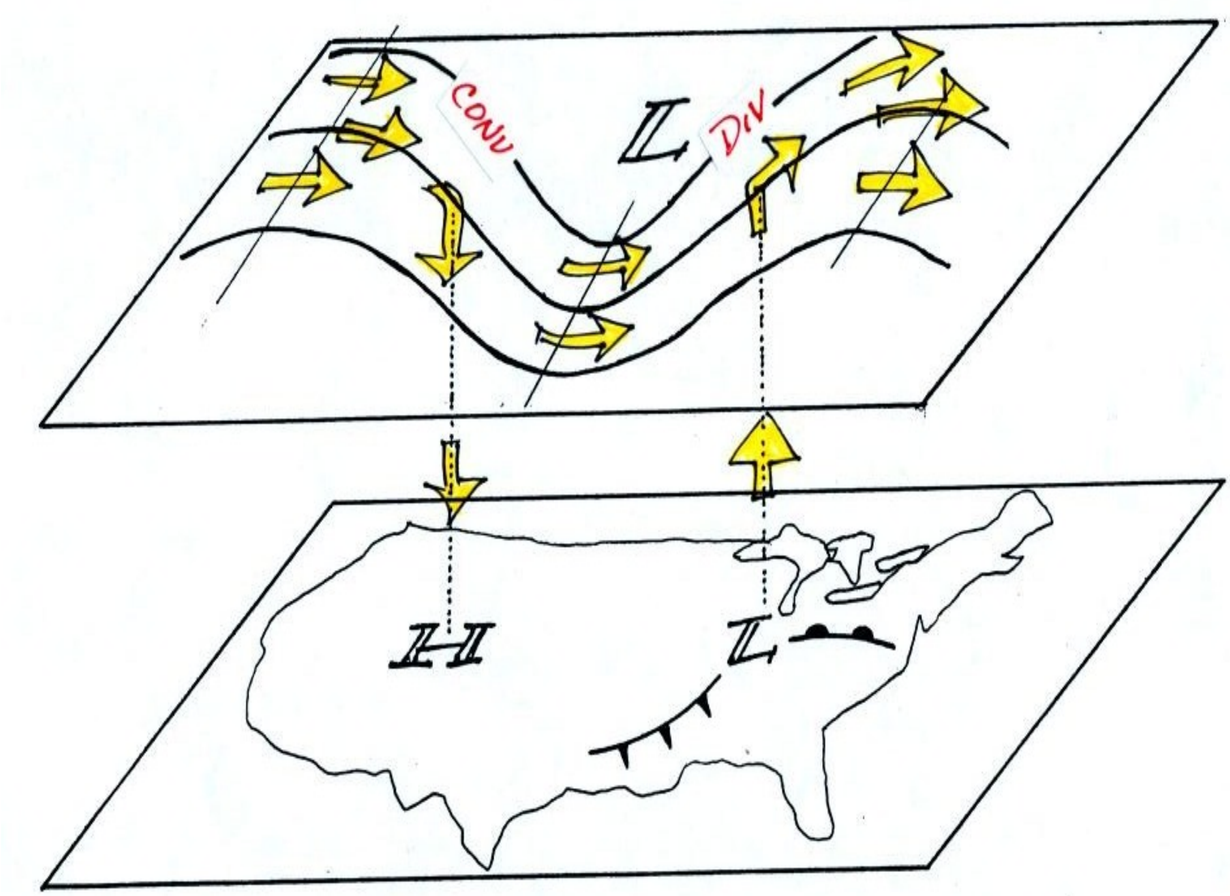


The surface pressure is 950 mb, which means there is more of a pressure difference between the center of the storm and the surrounding area. The surface storm has intensified and the surface winds will blow faster and carry more air into the cylinder (the surface wind arrows each now carry 12.5 mb of air instead of 10 mb). The converging surface winds add 50 mb of air to the cylinder (Point 1); the upper level divergence removes 50 mb of air from the cylinder (Point 2). Convergence and divergence are in balance (Point 3) and the storm will not intensify.

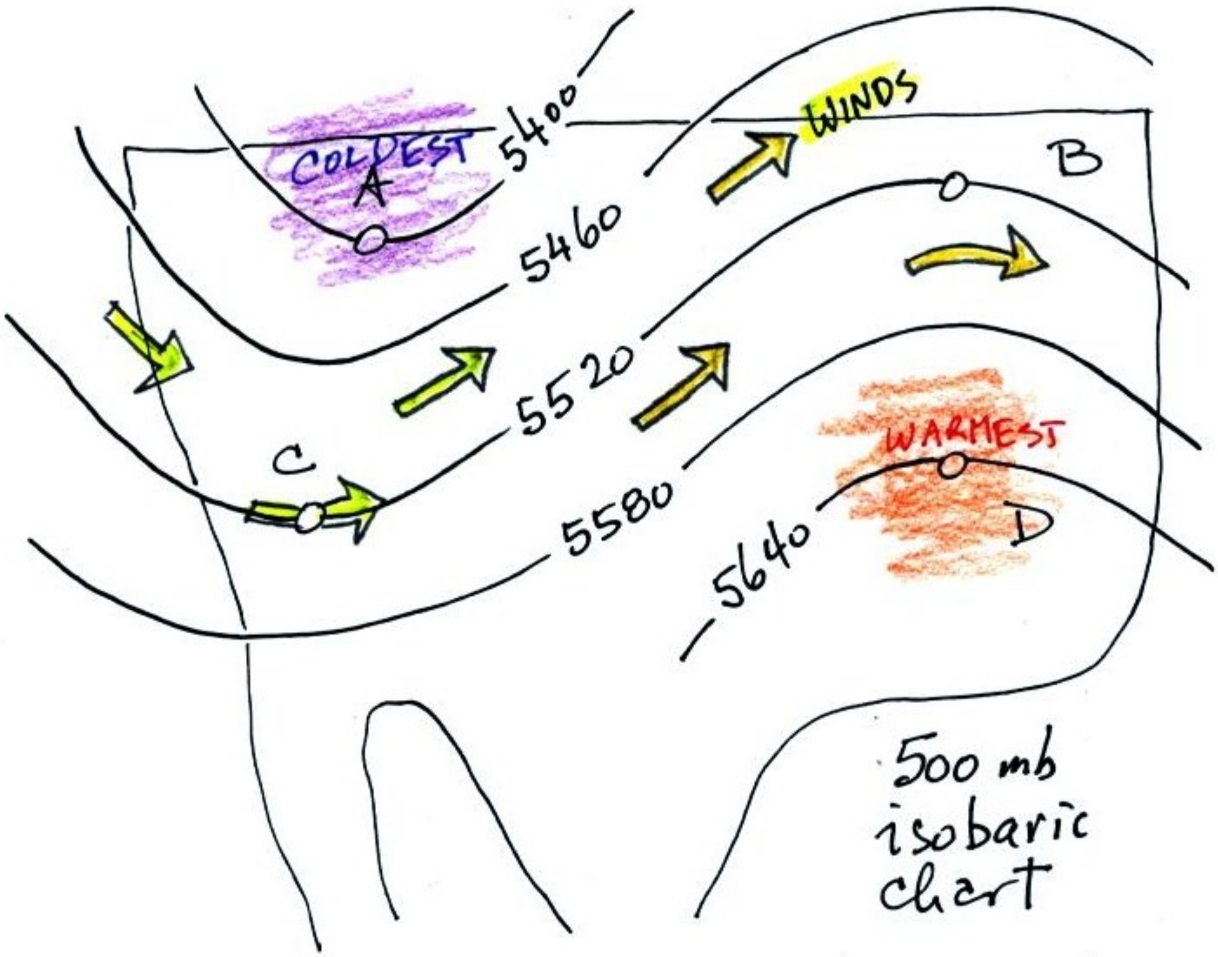


Now that you have some understanding of upper level divergence (more air leaving than coming in), you are in a position to understand another important relationship between the surface and upper level winds.

In the figure below, the words "DIV" and "CONV" show where there is upper air divergence and convergence, respectively. You will note that upper level divergence occurs above the surface wind convergence into the low pressure area. There are two arrows of air coming into the point "DIV" and three arrows of air leaving (more air going out than coming in is what makes this divergence). The rising air can, in effect, supply the extra arrow's worth of air. Three arrows of air come into the point marked "CONV" on the upper level chart and two leave (more air coming in than going out). What happens to the extra arrow? It is the source of the sinking air found above the surface high pressure.



Here are the answers to the "test your understanding" question found earlier in this lecture.



1. This is a constant pressure chart. The pressures at Points A, B, C, and D are all the same: 500 mb.

2. Point A is found at the lowest altitude: 5400 meters. Point D is found at the highest altitude: 5640 meters.

3. The coldest air is found below Point A and the warmest air is below Point D.

4. The winds blow parallel to the contours from west to east as shown on the map above. The winds at Point C are blowing from the west.