Fundamentals of synoptic meteorology

Lecture 17

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Why Care about Upper-Air?

Talked about surface pressure and what winds we expect to see at the surface.

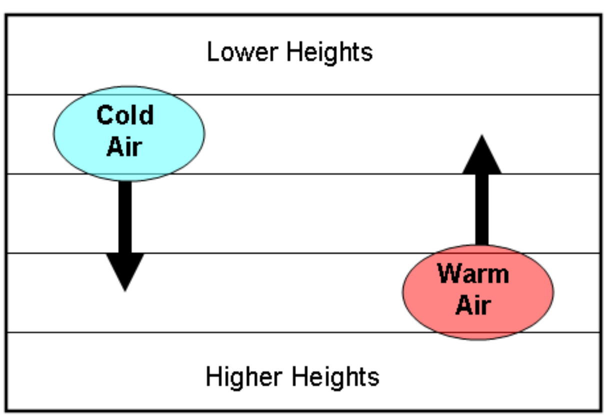
Lots of atmosphere not at the surface that affects weather conditions at the surface.

Need to have ways to observe and analyze the atmosphere kilometers from the surface.

Upper-air charts are important for weather forecast; upper-level winds determine the movement of surface air pressure systems, as well as whether these surface systems will intensify or weaken

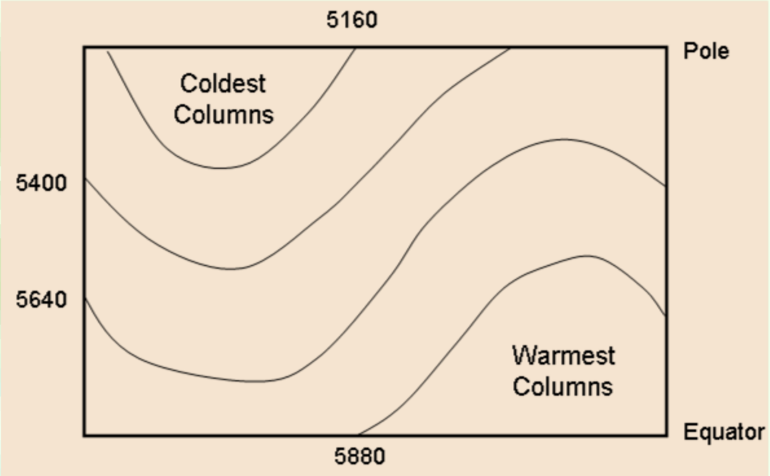
Forming upper-level troughs/ridges

Cold air masses move south, warm air masses move north…forming upper-level troughs/ridges.



Pole

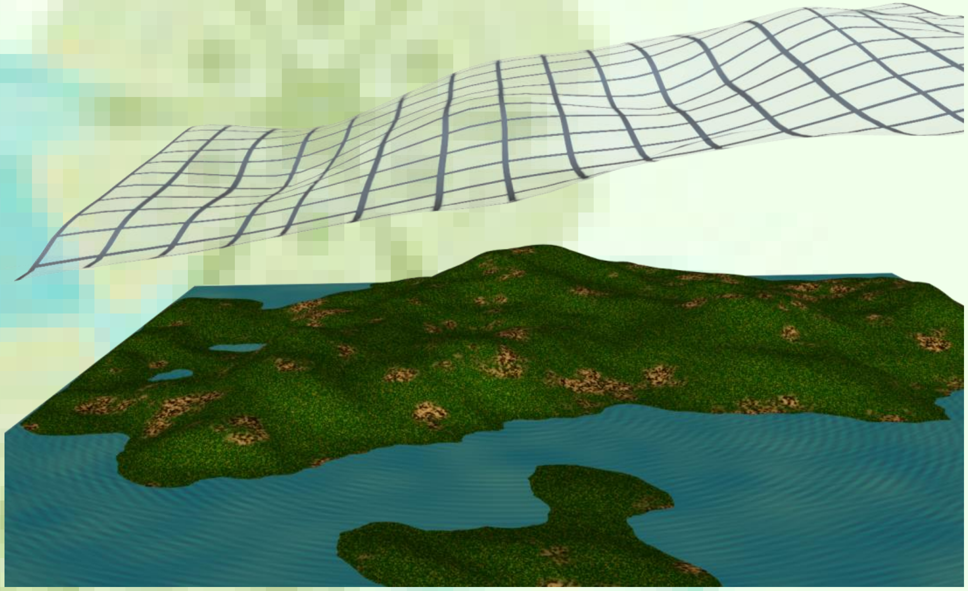
Equator



Relationship between heights and pressure

On a constant pressure map, a minimum in height corresponds to a low pressure center on a constant height surface on an altitude equal to that height

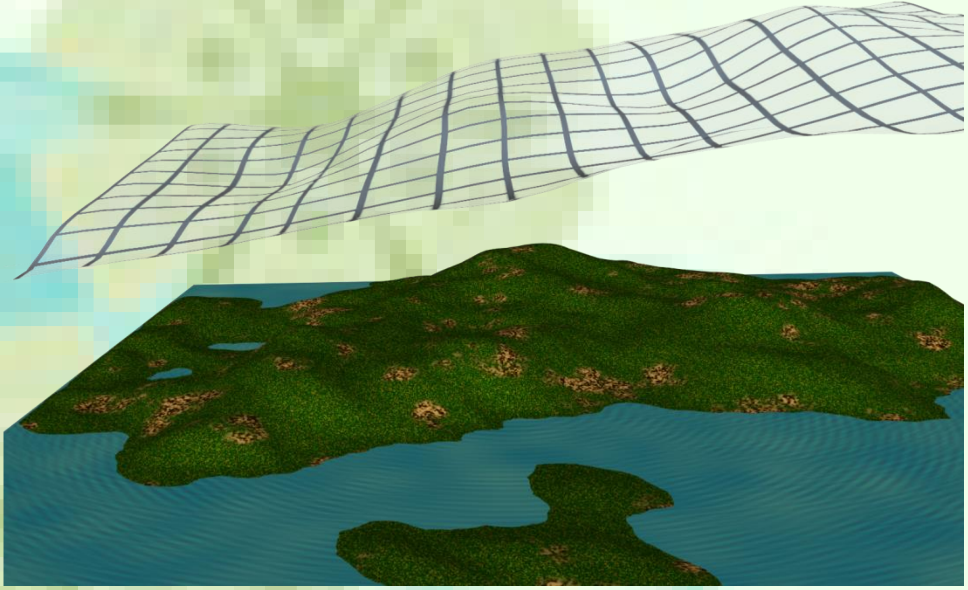
Treat a center of low heights on a constant pressure surface as if it were a center of low pressure



On a constant pressure map, a maximum in height corresponds to a high pressure center on a constant height surface at an altitude equal to that height

Treat a center of high heights on a constant pressure surface as if it were a center of high pressure

Height gradients a pressure gradients



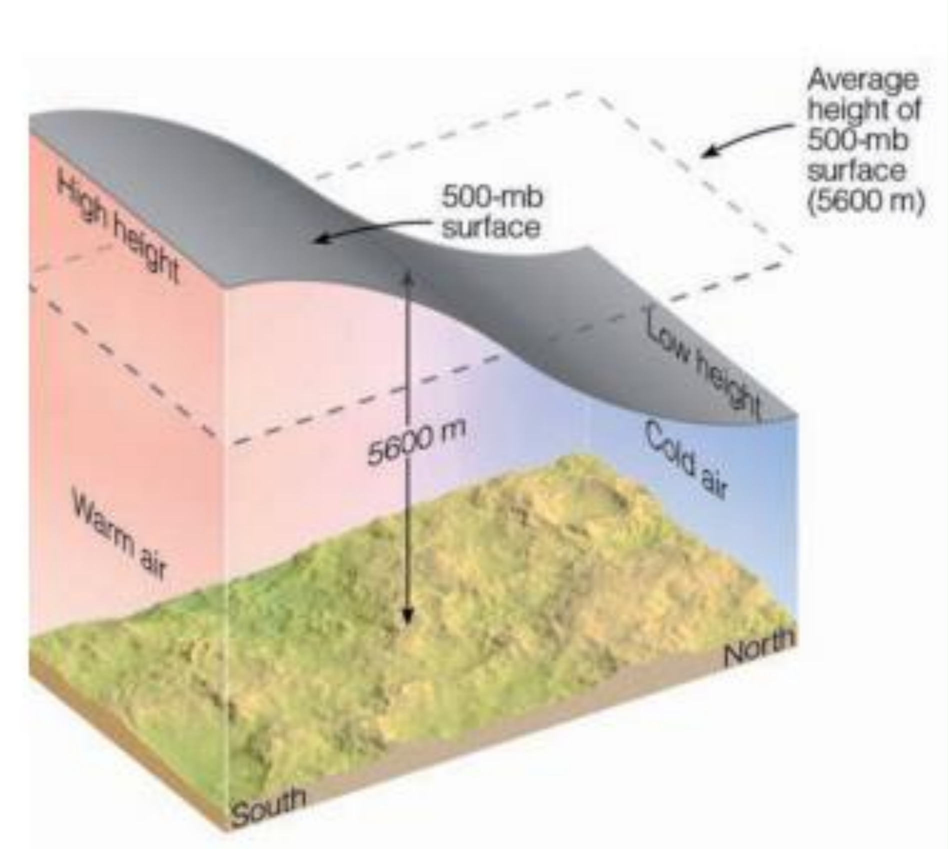
Upper Level Charts-Isobaric Charts

The tropospheric depth is proportional to the mean tropospheric temperature

The area shaded gray in the diagram represents a surface of constant pressure, or isobaric surface.

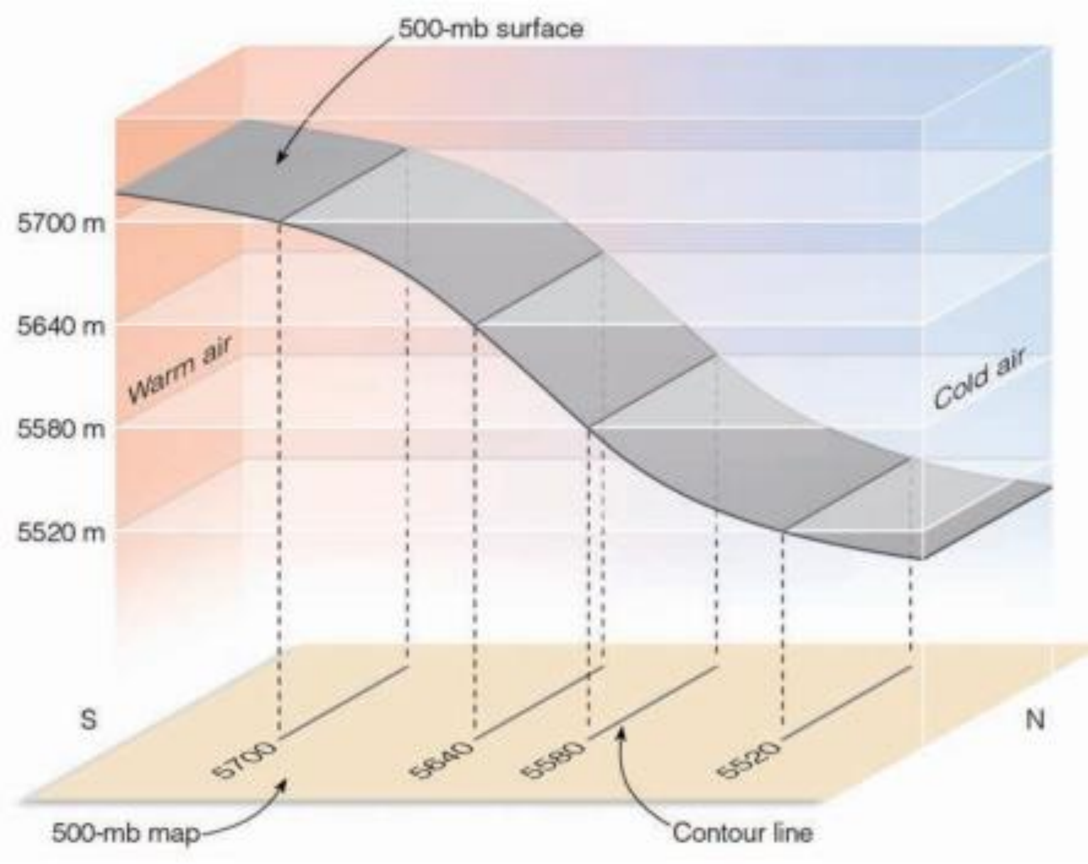
Because of the changes in air density, the isobaric surface rises in warm, less dense air and lowers in cold, more-dense air.

Where the horizontal temperature changes most quickly, the isobaric Surface changes elevation most rapidly.

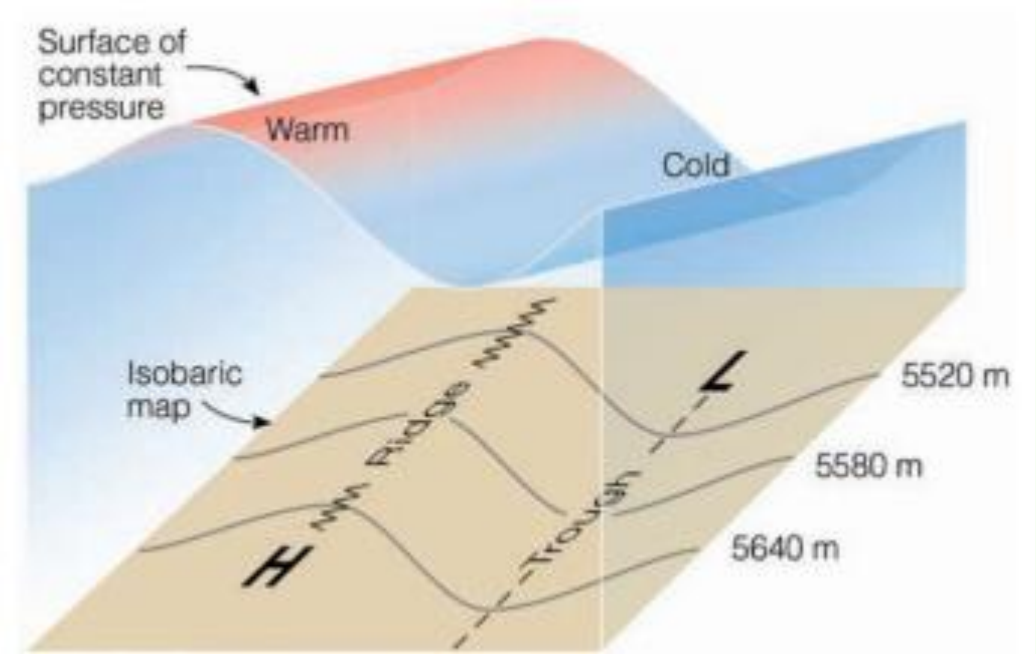


Hence, on an isobaric chart (e.g., 500 mb) we plot isopleths of the height of the surface.

Changes in elevation of an isobaric surface (500 mb) show up as contour lines on an isobaric (500 mb) map. Where the surface dips most rapidly, the lines are closer together.

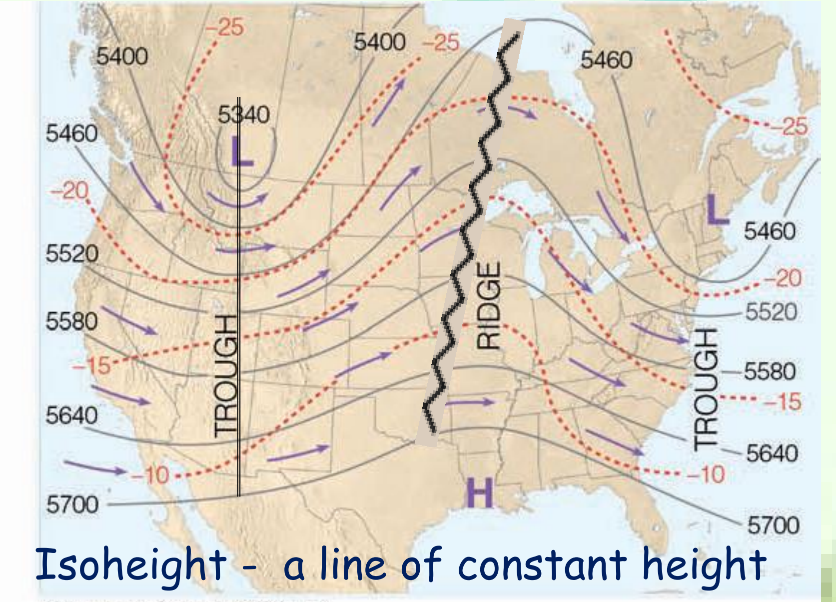


Isoheight - a line of constant height



The wavelike patterns of an isobaric surface reflect the changes in air temperature.

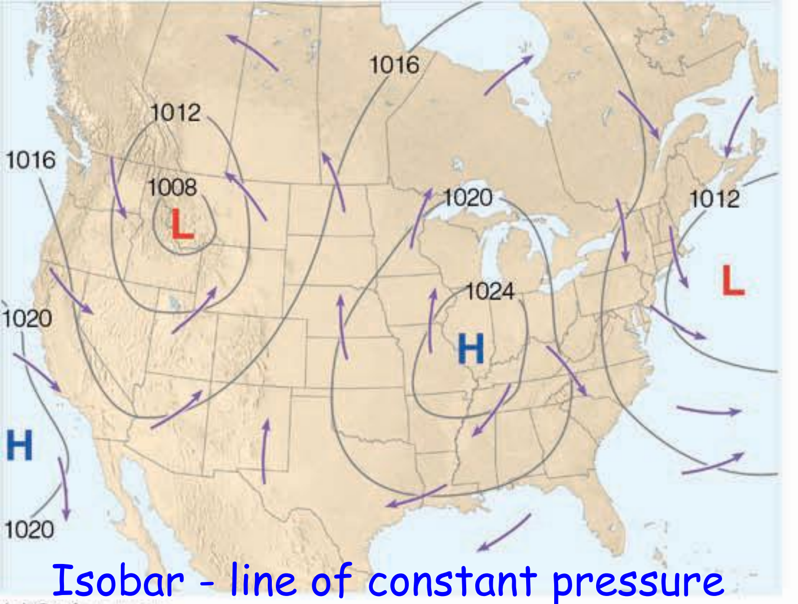
An elongated region of warm air aloft shows up on an isobaric map as higher heights and a ridge; the colder air shows as lower heights and a trough.



Isoheight - a line of constant height

(b) Upper-air map (500 mb)

Isotherm - line of constant temperature



Isobar - line of constant pressure

(a) Surface map

Notice that the height lines are NOT oriented E-W

In fact, one can see a wave-type pattern in the height lines with:

Notice that the higher heights are towards the south where it is warmer

lower heights are found further north where it is colder.

There is warm air aloft associated with a ridge.

There is cold air aloft associated with a trough.

Notice that ridges aloft are associated with Highs at the surface (anticyclon)

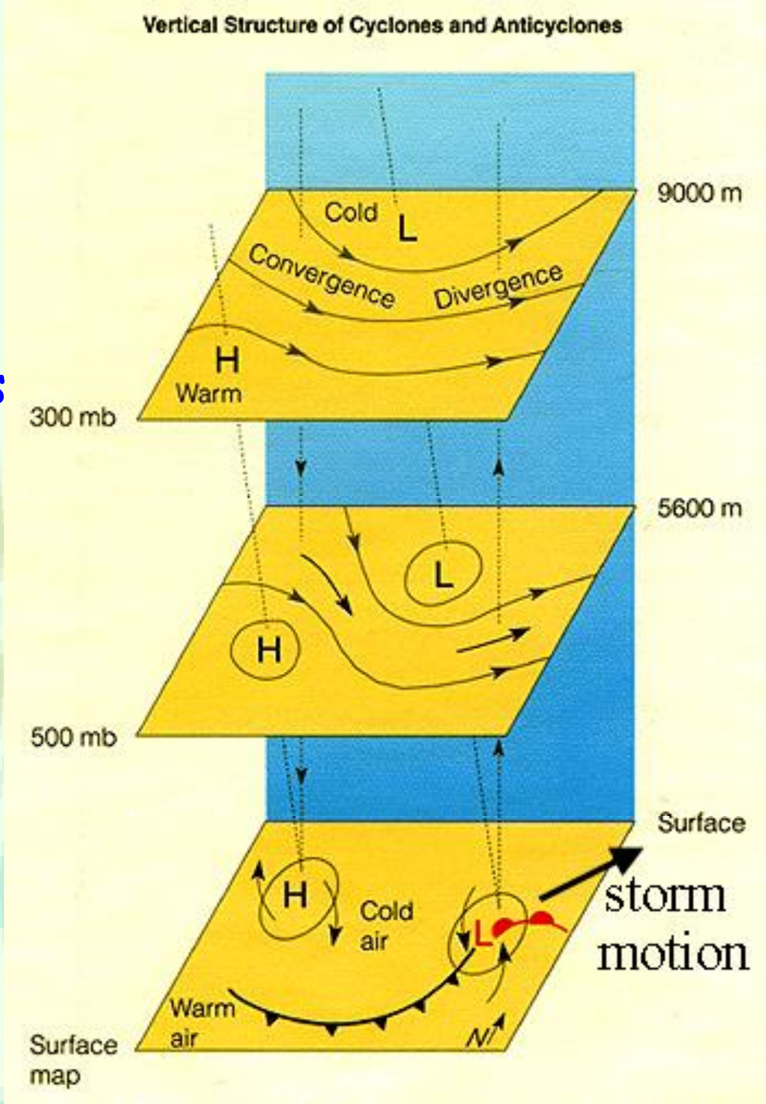
Troughs aloft are associated with Lows at the surface (cyclones). BUT NOT ALWAYS

Vertical Structure of Cyclones

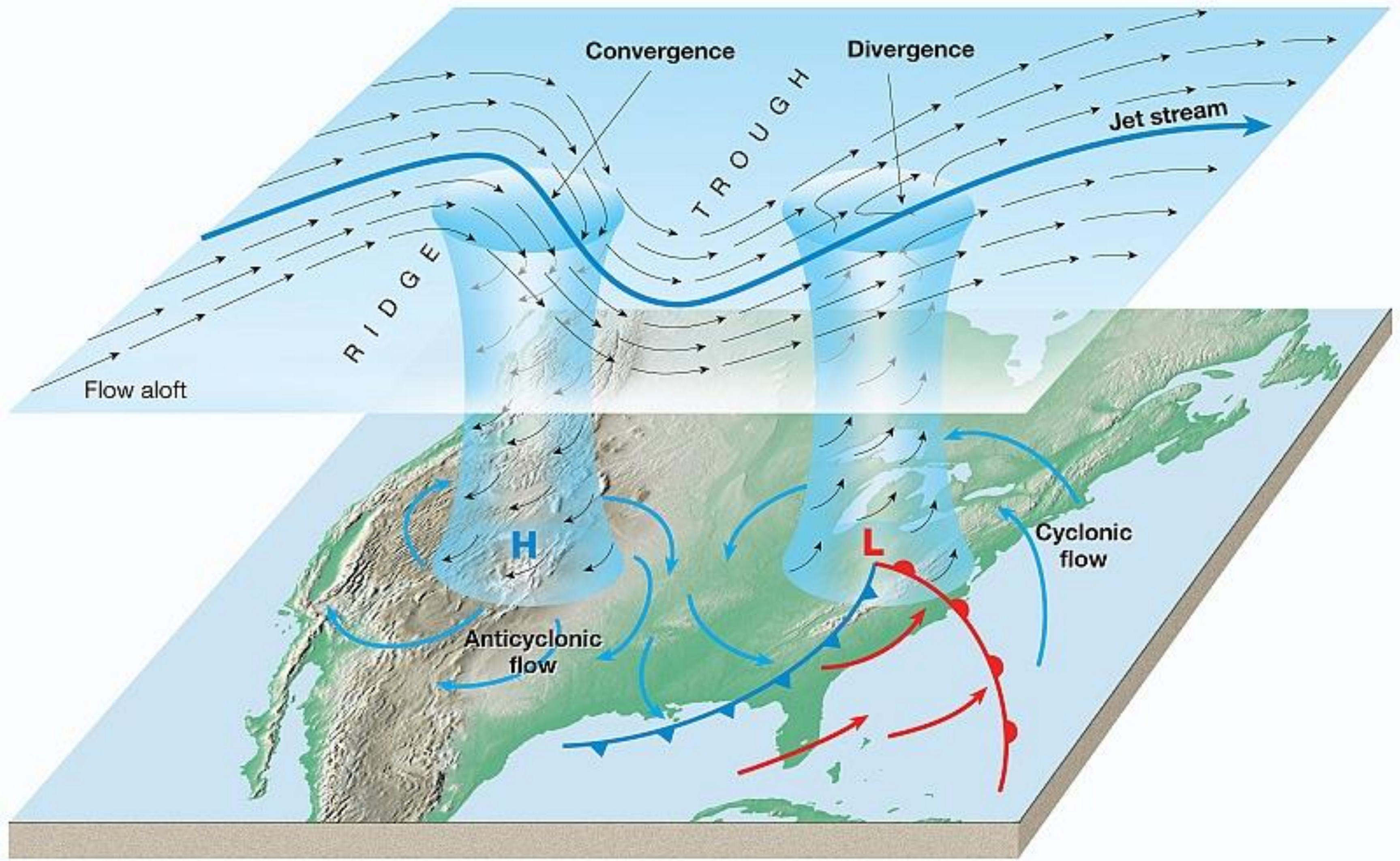
What else do these diagrams tell us?

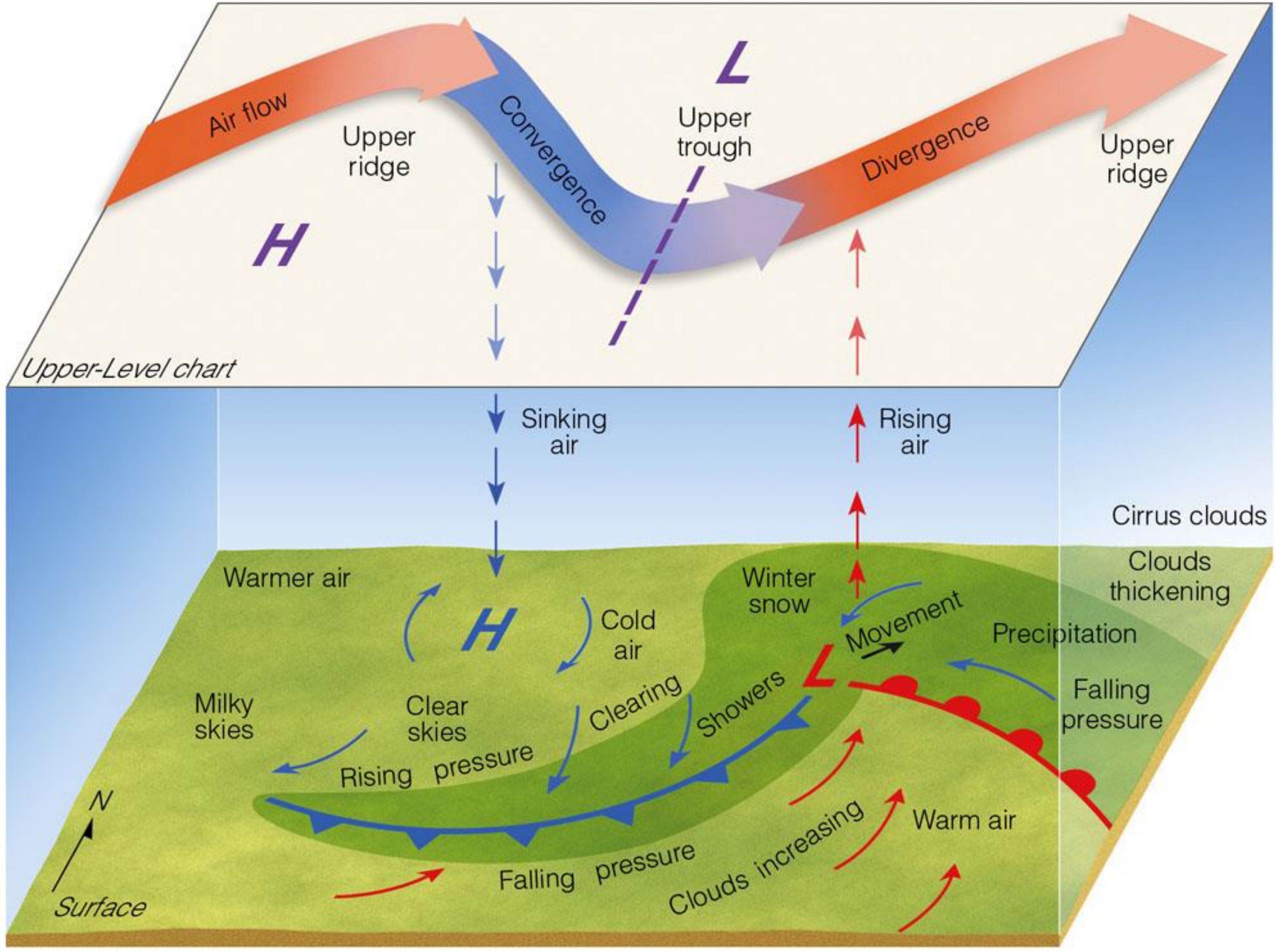
Surface cyclone is downstream from the upper tropospheric (~500 mb) trough axis

Mid-latitude cyclones generally tilt westward with height!



Cyclone and Anticyclone Flows





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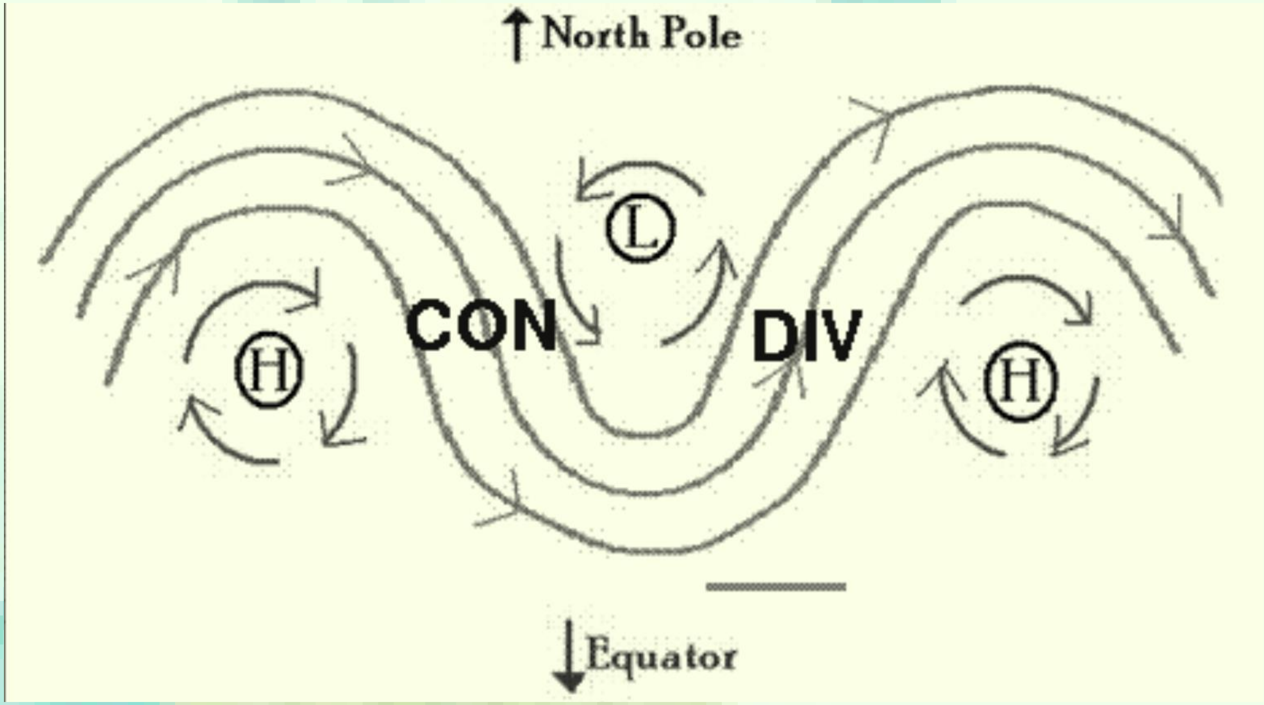
Upper Tropospheric Flow and Convergence/Divergence



Downstream of an upper tropospheric ridge, there is convergence, resulting in subsidence (downward motion).

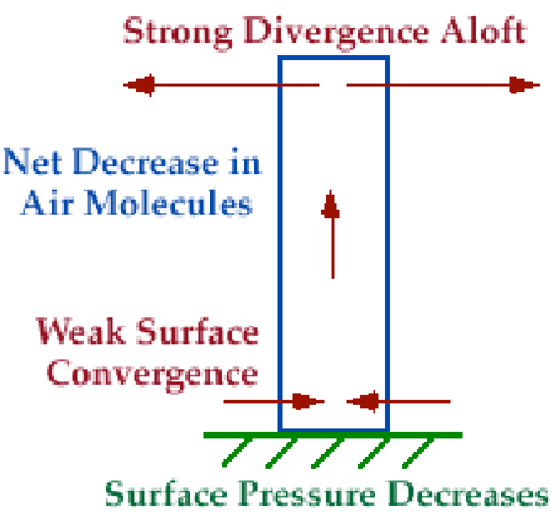
Likewise, downstream of an upper tropospheric trough, there is divergence, resulting in ascent (upward motion).

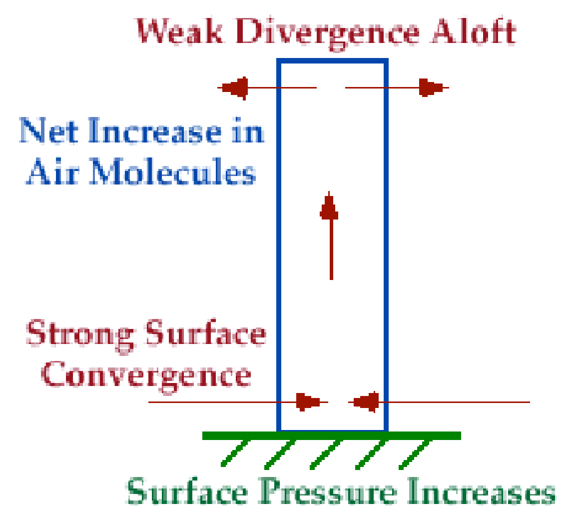
Cyclone Intensification/Weakening

How do we know if the surface cyclone will intensify or weaken?

If upper tropospheric divergence > surface convergence, the cyclone will intensify (the low pressure will become lower)

If surface convergence > upper tropospheric divergence, the cyclone will weaken, or "fill."



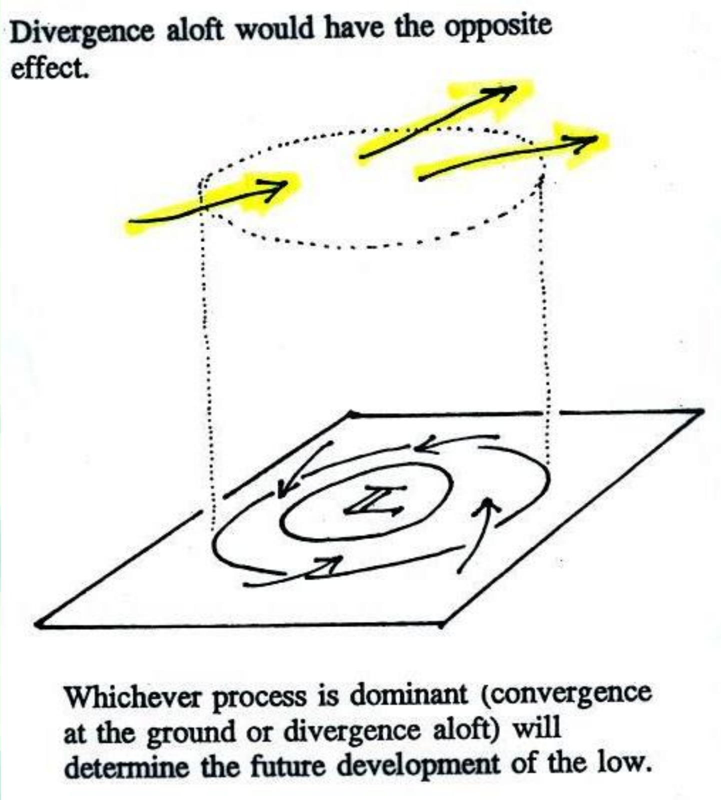


Think of an intensifying cyclone as exporting mass, and a weakening cyclone as importing mass.

There may be some upper level divergence (more arrows leaving the cylinder at some point above the ground than going in).

Upper level divergence removes air from the cylinder and would decrease the weight of the cylinder (and that would lower the surface pressure)

We need to determine which of the two (converging winds at the surface or divergence at upper levels) is dominant. That will determine what happens to the surface pressure.

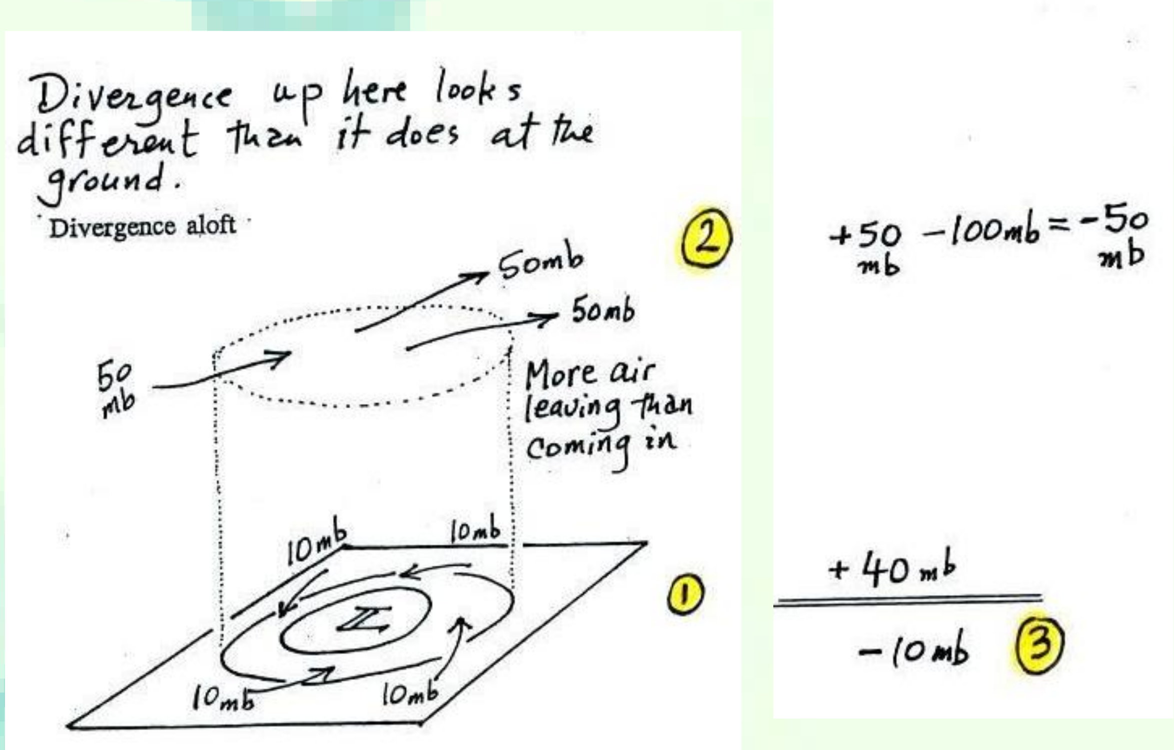


Divergence aloft would have the opposite effect.

Whichever process is dominant (convergence at the ground or divergence aloft) will determine the future development of the low.

Again some actual numbers might help

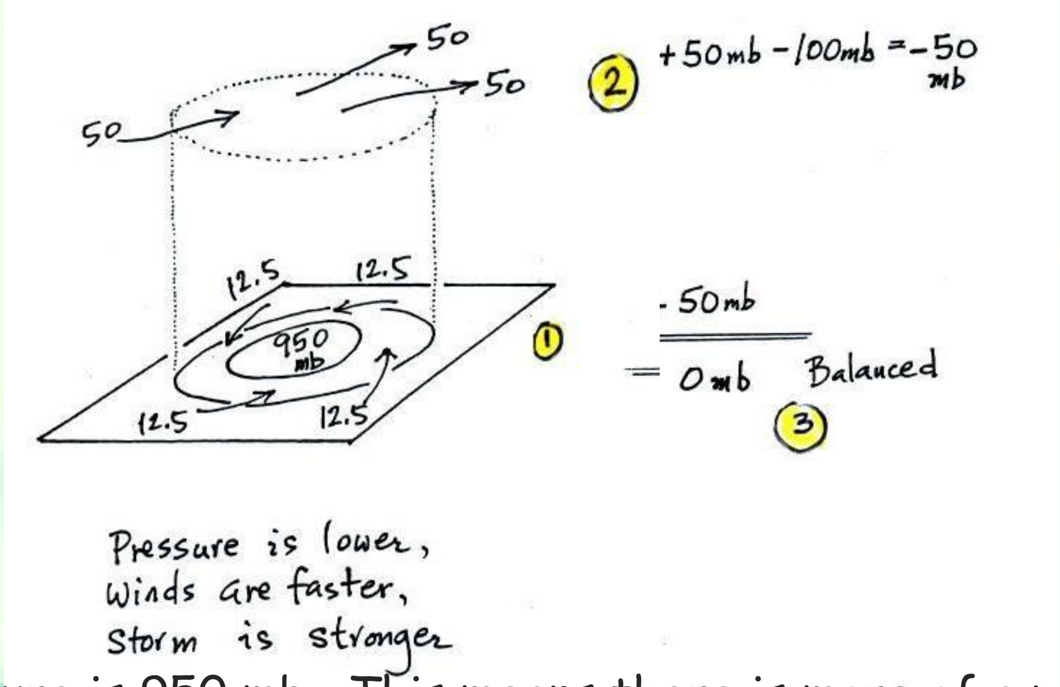
http://www.atmo.arizona.edu/students/courselinks/fall12/atmo170a1s2/coming_up/week_3/lect9_upper_level_charts.html



Divergence up here looks different than it does at the ground.

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. That change is reflected in the next picture.

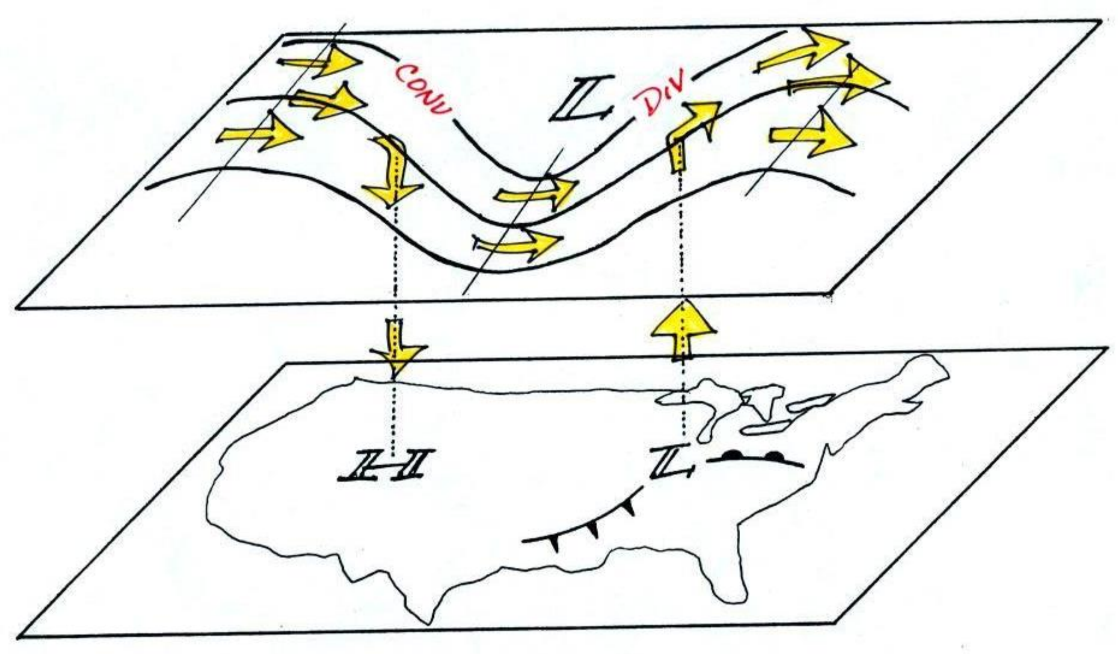


The surface pressure is 950 mb. This means there is more of a pressure difference between the low pressure in the center of the storm and the pressure surrounding the storm.

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). The storm won't intensify any further.

Now that you have some idea of what upper level divergence looks like (more air leaving than is going in) you are in a position to understand another one of the relationships between the surface and upper level winds.



One of the things we have learned about surface LOW pressure is that the converging surface winds create rising air motions.

The figure above gives you an idea of what can happen to this rising air (it has to go somewhere).

Note the upper level divergence in the figure: 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).

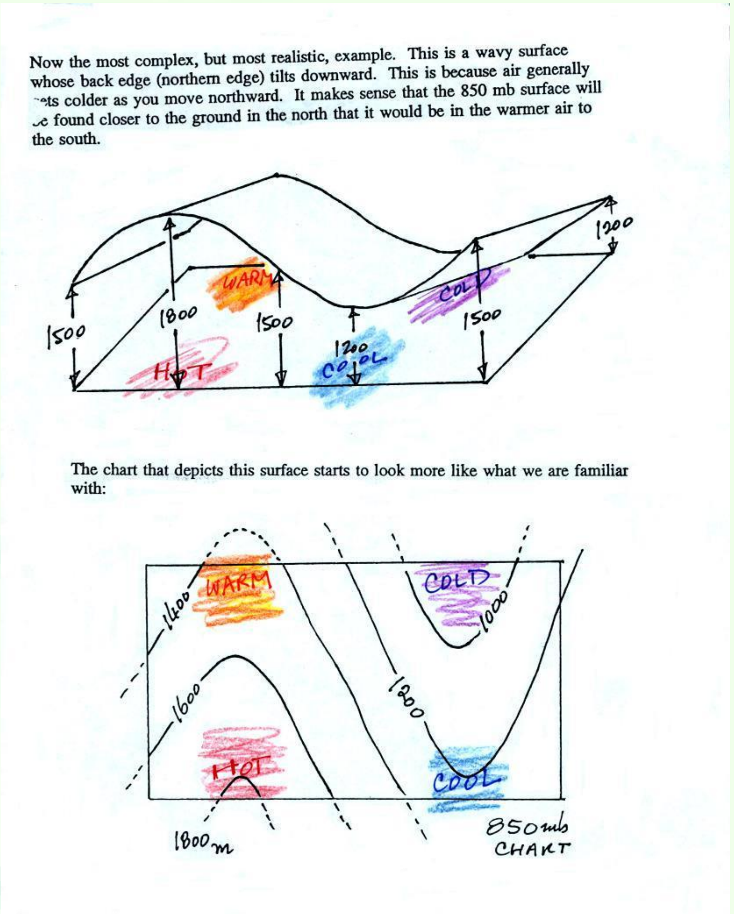
What happens to the extra arrow? It sinks, it is the source of the sinking air found above surface high pressure.

It's the wavy surface that we had in the previous example (where there was just a west to east temperature change) with the northern edge tilted downward because there is colder air in the north.

That's not much of a change. But look at how the map has changed. We now 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.

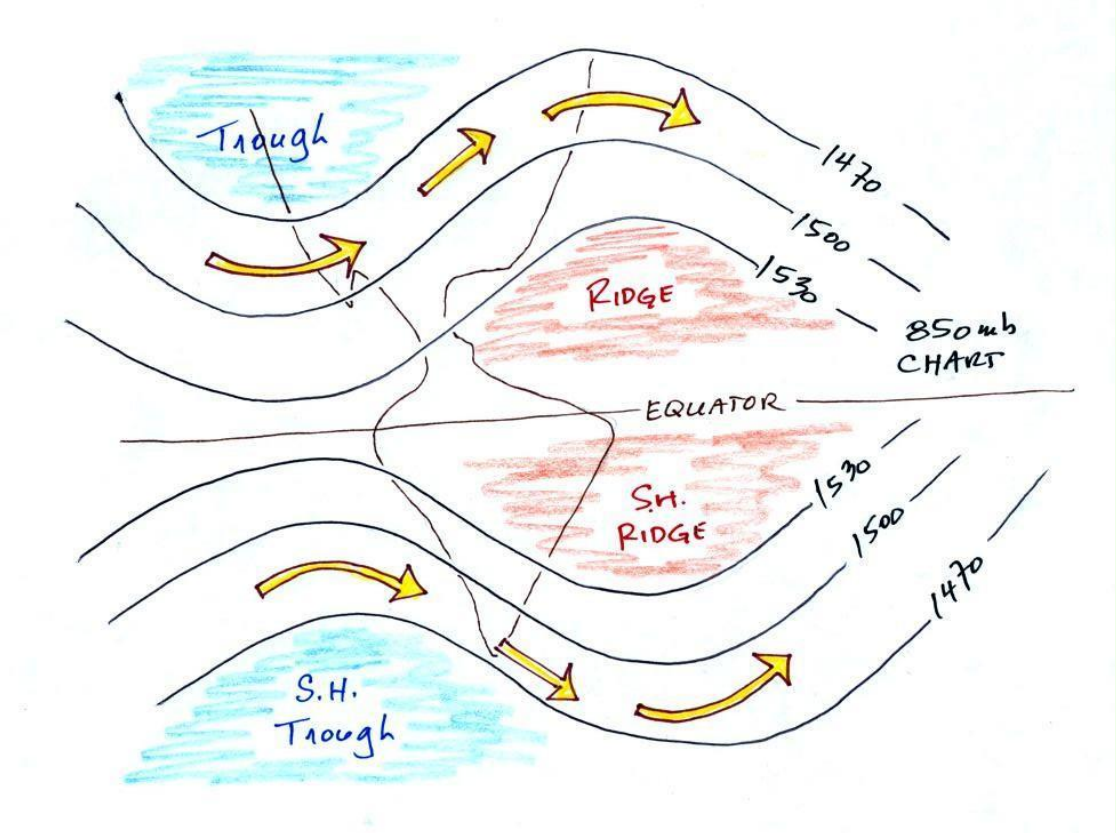
Now let's go back to the figure that we started this section with.



Now the most complex, but most realistic, example. This is a wavy surface whose back edge (northern edge) tilts downward. This is because air generally gets colder as you move northward. It makes sense that the 850 mb surface will be found closer to the ground in the north that it would be in the warmer air to the south.

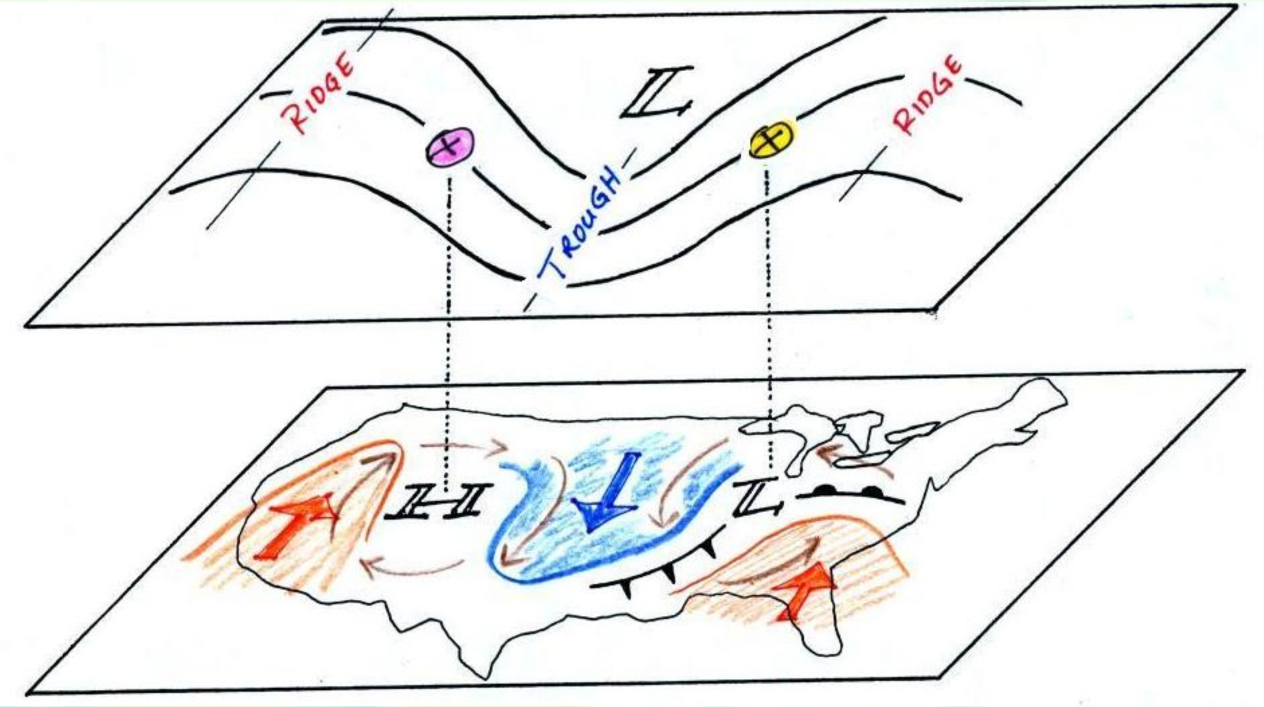
The chart that depicts this surface starts to look more like what we are familiar with:

Here is a quick comparison of upper level charts in the northern and southern hemispheres.



he contour values get smaller as you move toward colder air. The cold air is in the north in the northern hemisphere and in the south in the southern hemisphere (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'll finish this lecture by looking, in a little more detail, at how upper level winds can affect the development or intensification of a surface storm.
This material might be a little difficult and confusing at this point.
Don't worry if that is the case

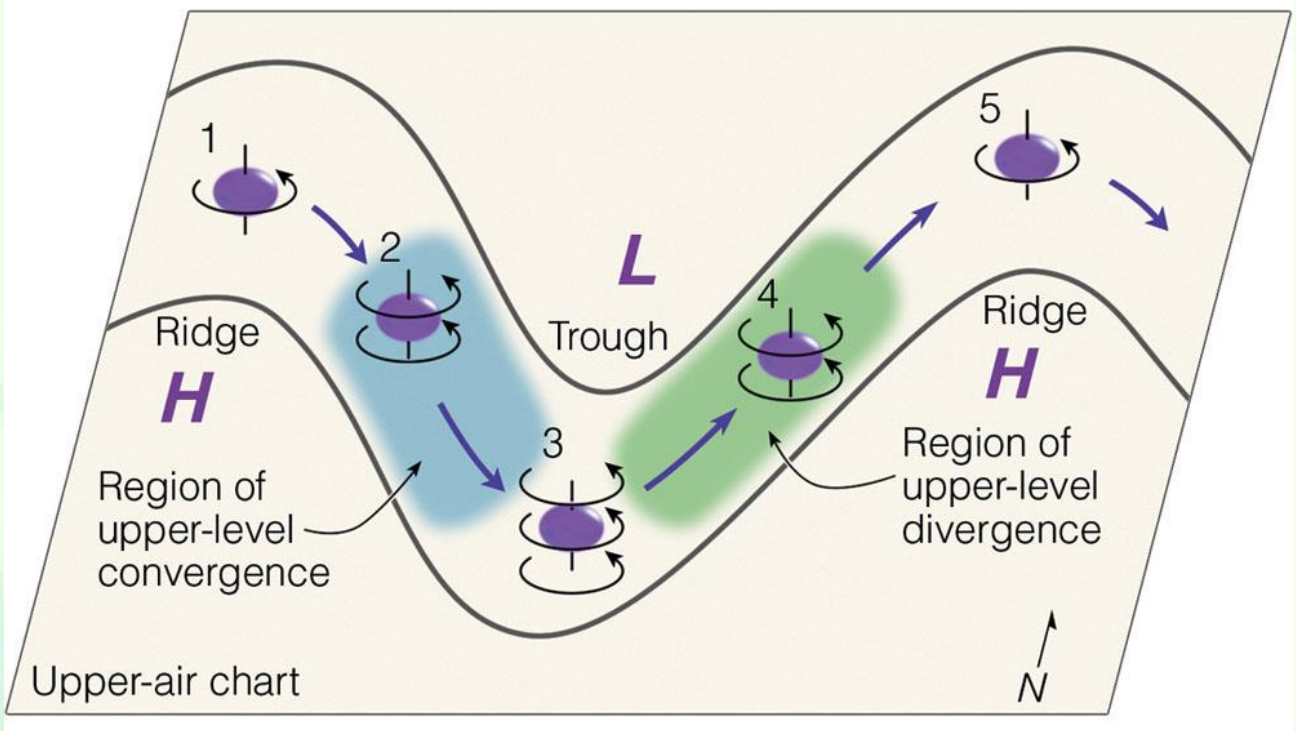


urface and upper level maps are superimposed in the figure above. On the surface map you see centers of HIGH and LOW pressure. The surface low pressure center, together with the cold and warm fronts, is a middle latitude storm.

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. The surface winds are shown with thin brown arrows on the surface map.

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. This cold air is being moved into the middle of the US by the northerly winds that are found between the HIGH and the LOW.

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 for this is that the yellow X is a location where there is often upper level divergence. Similary the pink X is where you often find upper level convergence. This could cause the pressure in the center of the surface high pressure to get even higher.



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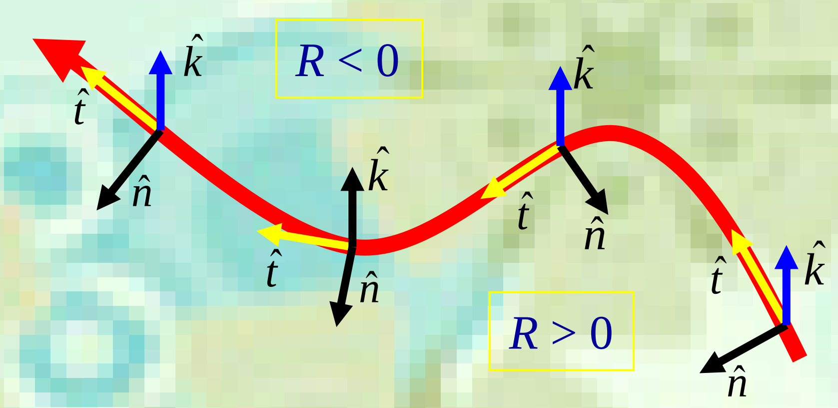
The vorticity of an air parcel changes as we follow it through a wave. From position 1 to position 3, the parcel's absolute vorticity increases with time.
In this region (shaded blue), we normally experience an area of upper-level converging air.

As the air parcel moves from position 3 to position 5, its absolute vorticity decreases with time.
In this region (shaded green), we normally experience an area of upper-level diverging air.

Natural Coordinates

Natural coordinates are defined by a set of mutually orthogonal unit vectors whose orientation depends on the direction of the flow.

if air parcels turn toward right



if air parcels turn toward left

Unit vector $\hat{t}$ points along the direction of the flow.

Unit vector $\hat{n}$ is perpendicular to the flow, with positive to the left.

Unit vector $\hat{k}$ points upward.

Vorticity in natural coordinates:

$$\zeta = -\frac{\partial V}{\partial n} + \frac{V}{R}$$

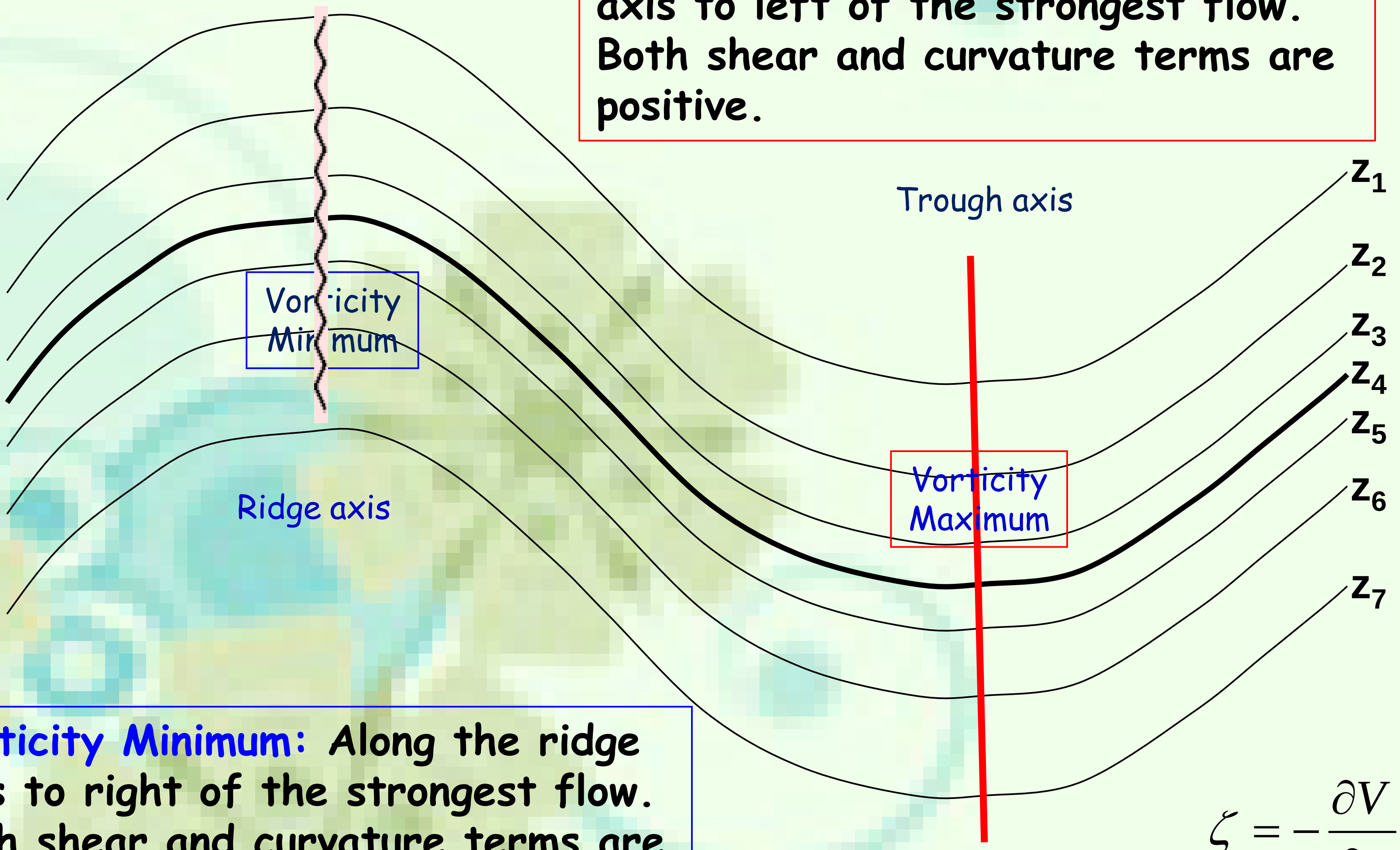
The relative vorticity is the sum of two parts:

$-\frac{\partial V}{\partial n}$ The rate of change of wind speed normal to the direction of flow, which is called the shear vorticity.

$\frac{V}{R}$ The turning of the wind along a streamline, which is called the curvature vorticity.

Vorticity On The Weather Map

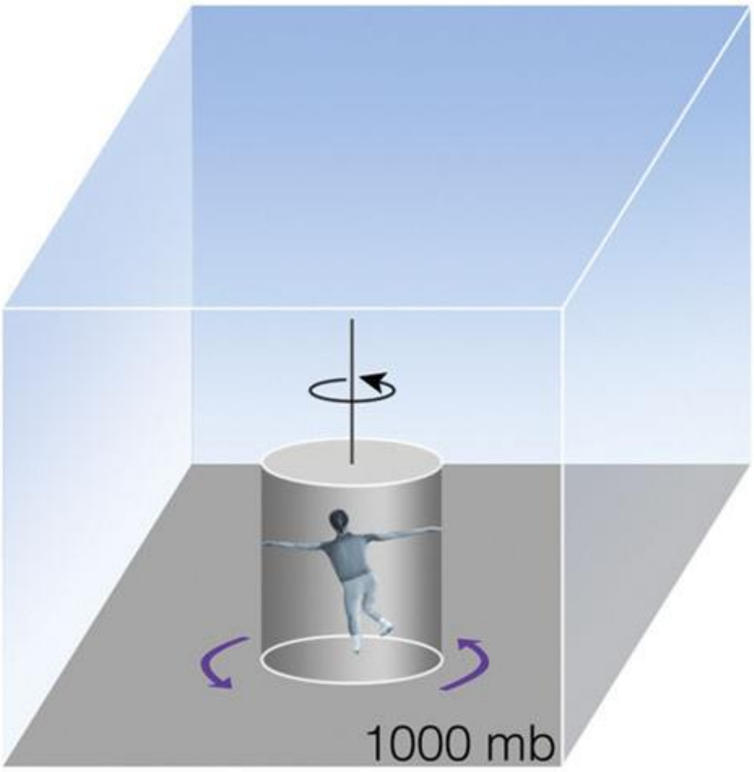
Vorticity Maximum: Along the trough axis to left of the strongest flow. Both shear and curvature terms are positive.



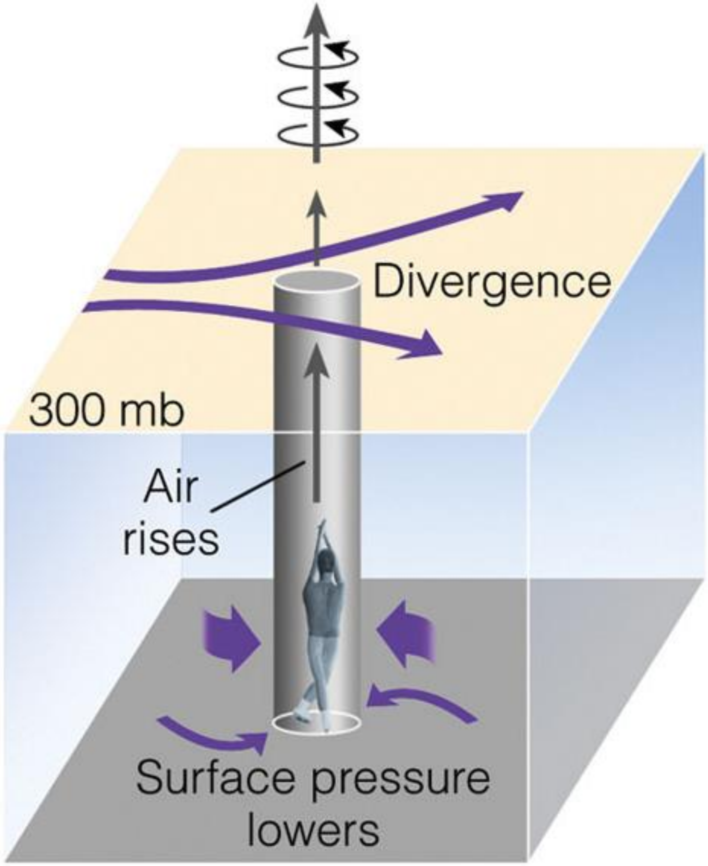
Vorticity Minimum: Along the ridge axis to right of the strongest flow. Both shear and curvature terms are negative.

$$\zeta = -\frac{\partial V}{\partial n} + \frac{V}{R}$$

When upper-level divergence moves over an area of weak cyclonic circulation, the cyclonic circulation increases (that is, it becomes more positive), and air is forced upward.



Cyclonic vorticity



Cyclonic vorticity increases

Circulation and Vorticity

Two primary measures of rotation in a fluid

By convention, both circulation and vorticity are positive in the counterclockwise direction.

(cyclonic in the Northern Hemisphere)

Circulation: Macroscopic measure of rotation for a finite area of the fluid = integration of the tangential component of velocity around a closed path

Vorticity: The tendency to spin about an axis; Microscopic measure of rotation at any point in the fluid

Circulation: The tendency for a group of air parcels to rotate
If an area of atmosphere is of interest, you compute the circulation

Vorticity: The tendency for the wind shear at a given point to induce rotation
If a point in the atmosphere is of interest, you compute the vorticity

Thanks

For your

Attention