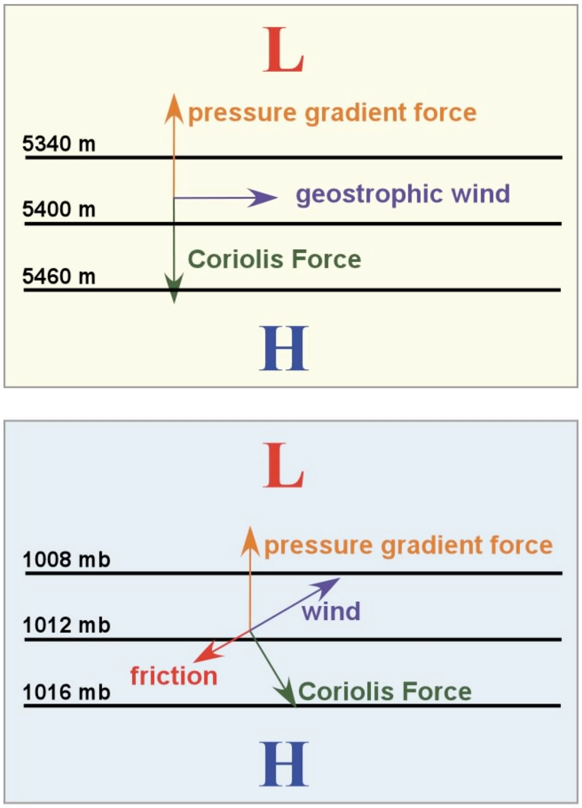


Chapter 7 Forces and Force Balances

Forces that Affect Atmospheric Motion

Why does air move and what controls the speed and direction of this movement?

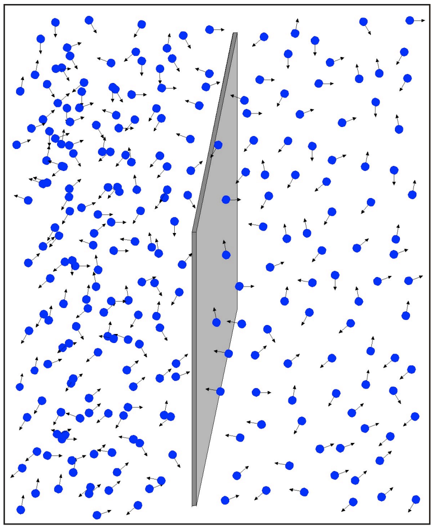
There are four forces that control the movement of air:

Pressure gradient Force
Gravitational Force
Frictional Force
Coriolis Force

A force can be thought of as a push or a pull.

The Pressure Gradient Force

Pressure gradient – the rate at which pressure changes with distance



©Kendall/Hunt Publishing

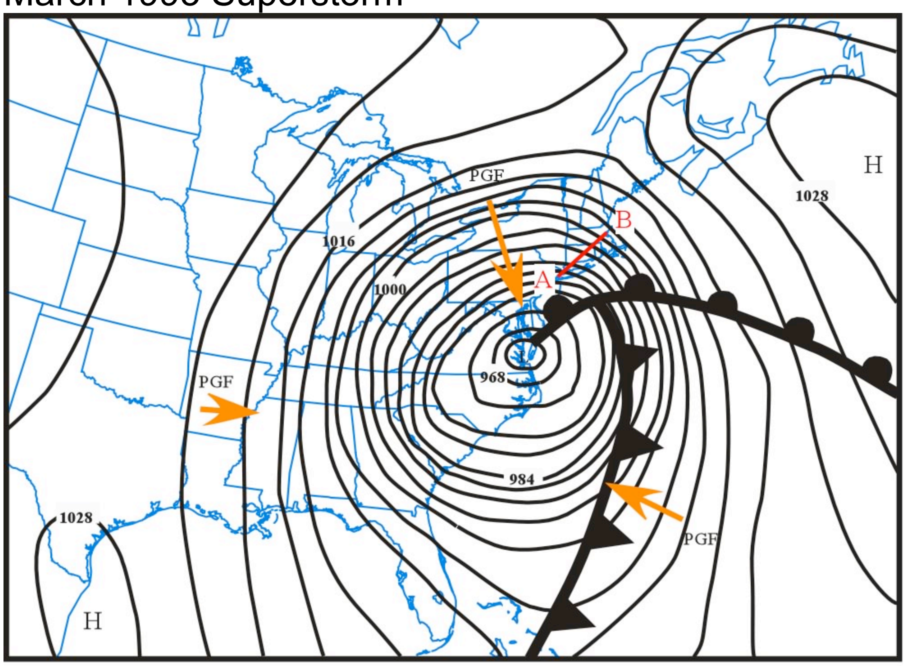
How is a pressure gradient created?

What happens to an air parcel that exists in the presence of a pressure gradient?

Pressure gradient force (PGF) – the force applied on an air parcel due to pressure differences

On a surface weather map the PGF is always perpendicular to the isobars and points from high to low pressure. The PGF is large when the isobars are closely spaced and small when the isobars are spaced far apart.

March 1993 Superstorm



©2002 Kendall/Hunt Publishing

Where is the PGF largest on this map?

In what direction does the PGF act?

The PGF increases as the pressure gradient becomes larger (isobars are close together).

The wind speed will increase as the horizontal pressure gradient, and horizontal PGF, increases.

Some sample horizontal pressure gradients:

Storm	**Pressure gradient**	**Sustained Winds**
Hurricane eyewall	1.9 mb / km	98 to 132 mph
March Superstorm	0.1 mb / km	29 to 46 mph

Vertical pressure gradient

We can consider both horizontal and vertical pressure gradients.

How large is the vertical pressure gradient?

How does the magnitude of the vertical pressure gradient compare to the magnitude of the sample horizontal pressure gradients listed above?

In what direction does the vertical PGF act?

Why doesn't the vertical PGF cause all of the air to accelerate away from the surface of the earth?

The Gravitational Force

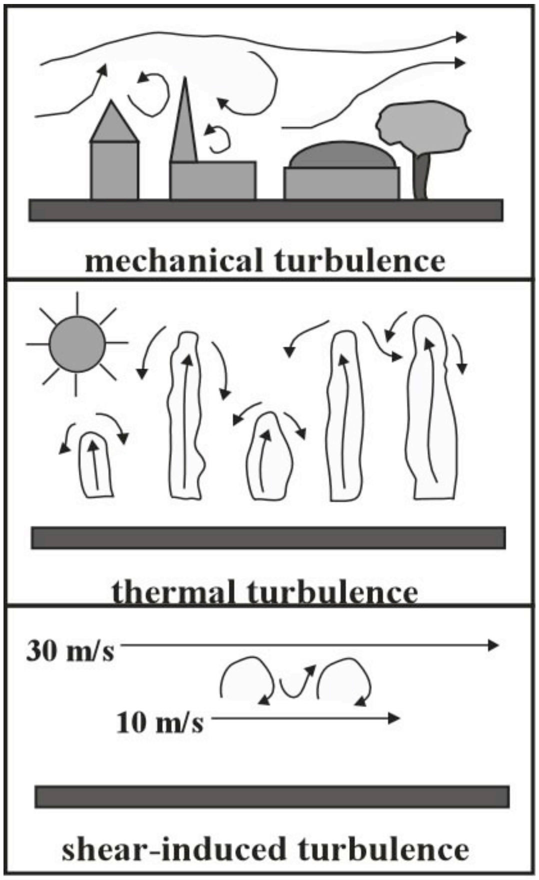
The earth exerts a gravitational pull on the atmosphere that is always directed down towards the center of the earth.

The Frictional Force

Frictional force – a drag force acting in a direction opposite the motion of the air

We can think of the frictional force as being caused by the mixing of air parcels moving at different speeds. This mixing is referred to as turbulence.

What causes turbulence in the atmosphere?



Mechanical turbulence occurs when air encounters obstructions on the surface.

Mechanical turbulence is larger over a rough surface than over a smooth surface.

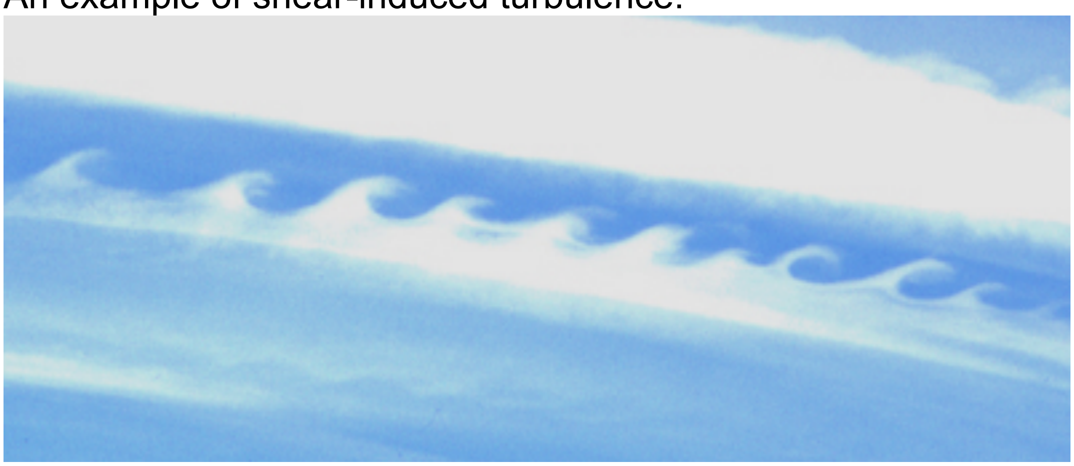
Thermal turbulence occurs when heated air rises and mixes with the air above.

Thermal turbulence is most common during the day.

Shear induced turbulence occurs when the wind speed changes rapidly over a short distance.

Shear induced turbulence is largest when the wind shear is large.

An example of shear-induced turbulence:

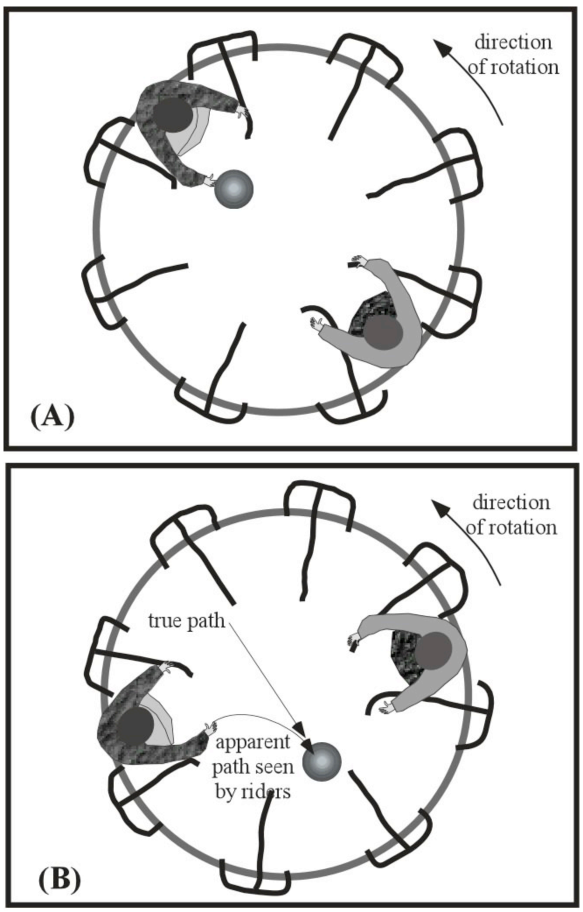


Turbulence, and thus the frictional force, tends to be most important near the surface of the earth, and rapidly decrease as you move away from the surface.

Friction layer (boundary layer) – the atmospheric layer in which friction is an important force

How deep is the friction layer?

The Coriolis Force



To an observer not sitting on the playground merry-go-round the ball appears to move in a straight line, and this is the true path followed by the ball.

To the two observers on the merry-go-round the ball appears to curve to the right.

To these observers there is an apparent force that acts on the ball.

The Coriolis force is an apparent force that arises due to the rotation of the earth.

The Coriolis force is due to conservation of angular momentum and the effects of the centrifugal force.

Important facts about the Coriolis force:

1. The Coriolis force causes objects to turn to the right of their direction of motion in the Northern hemisphere (left in the Southern hemisphere).

2. The Coriolis force can affect the direction of motion of an object, but cannot change the speed of the object.

3. The Coriolis force is strongest for fast moving objects and zero for objects that are not moving.

4. The Coriolis force is zero at the equator and increases to a maximum at the poles.

5. The Coriolis force is most important for air movement over large distances and becomes insignificant for small scale circulations.

Newton's Laws of Motion

Newton's First Law of Motion – an object at rest will remain at rest and an object in motion will remain in motion traveling at a constant speed in a straight line as long as no force is exerted on the object.

Acceleration – a change in speed and/or direction

Newton's Second Law of Motion – the force exerted on an object equals its mass times its acceleration ($F = m \times a$)

> A push on a light object causes a large acceleration.
> A push on a heavy object causes a small acceleration.

In the atmosphere multiple forces act on the air. The sum of these forces gives the net acceleration of the air.

For our discussion of the atmosphere we will consider the forces that result in horizontal and vertical accelerations of the air separately.

Vertical motion:

Acceleration = vertical PGF + gravitational force

Horizontal Motion:

For horizontal motions we will think about air within the boundary layer and air above the boundary layer separately.

Horizontal motion above the boundary layer:

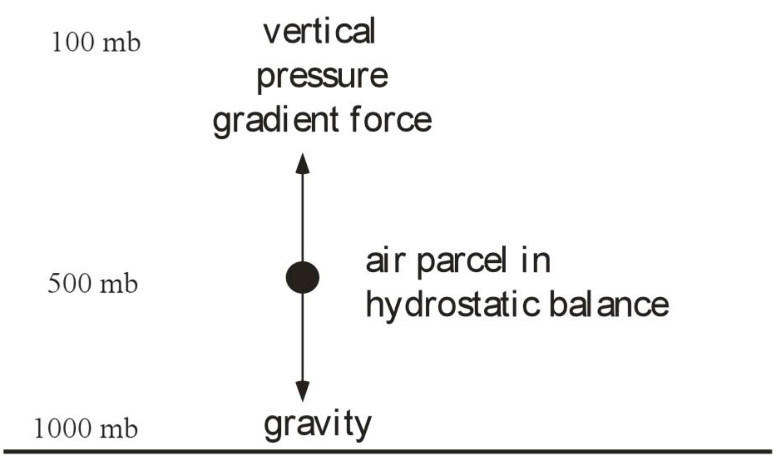
Acceleration = horizontal PGF + Coriolis force

Horizontal motion within the boundary layer:

Acceleration = horizontal PGF + Coriolis force + frictional force

Force Balances

Hydrostatic Balance



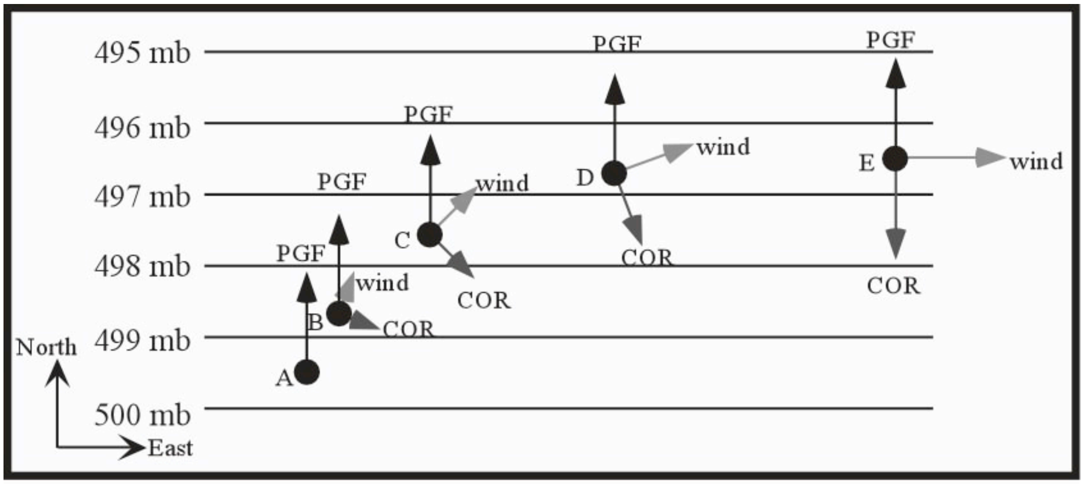
Hydrostatic balance – the upward directed PGF is exactly balanced by the downward directed gravitational force

The atmosphere is almost always in hydrostatic balance.

The most common exception is in strong thunderstorms.

Geostropic balance

How does air, that is initially at rest, come into geostrophic balance?



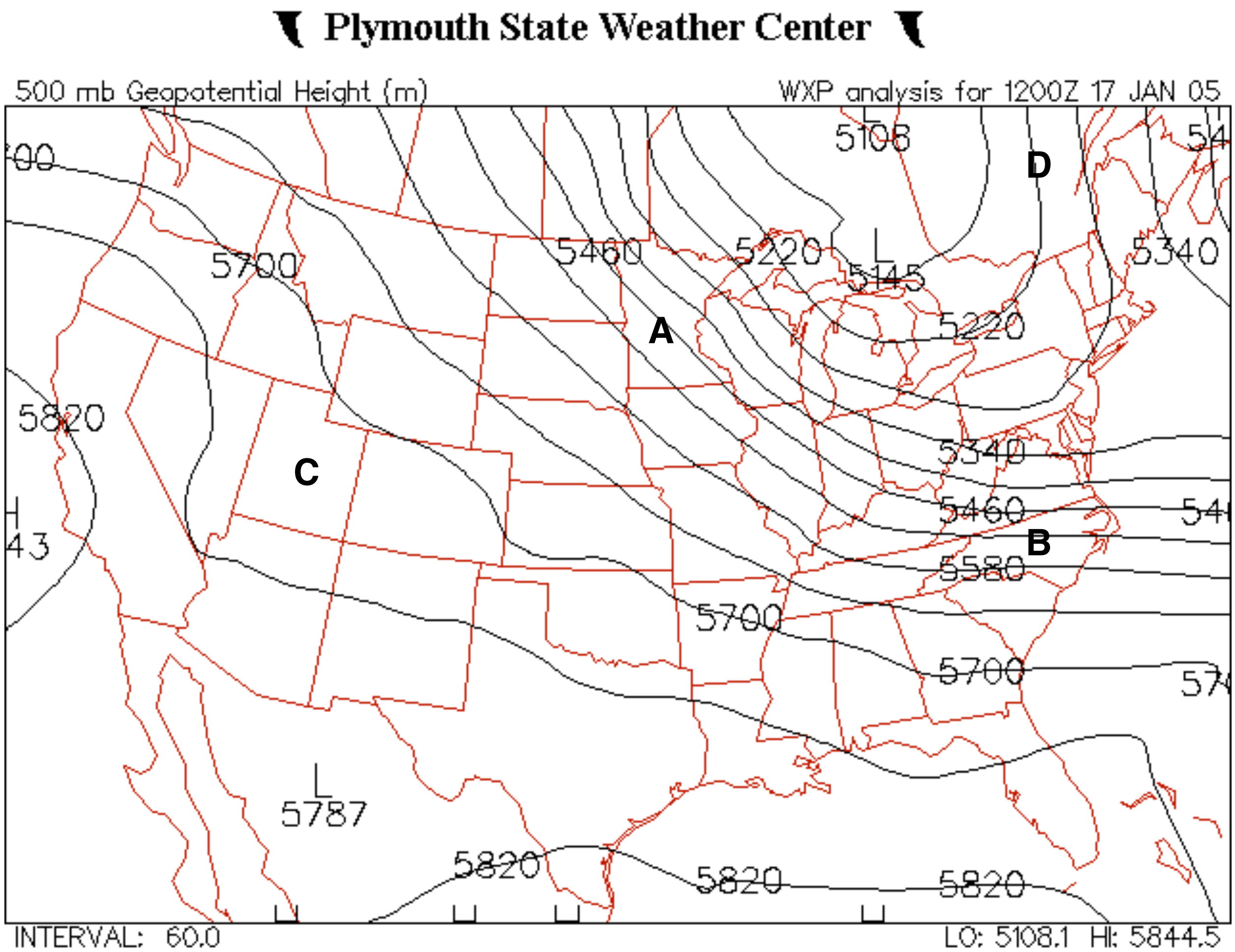
Geostrophic balance – the PGF is exactly balanced by the Coriolis force

Geostrophic wind – the wind that would exist if the atmosphere were in geostrophic balance.

The geostrophic wind flows parallel to straight isobars (or height contours on a constant pressure map) and its speed increases as the pressure gradient increases.

In the Northern hemisphere the geostrophic wind is directed such that higher pressure (or higher heights on a constant pressure map) are to the right of the geostrophic wind direction.

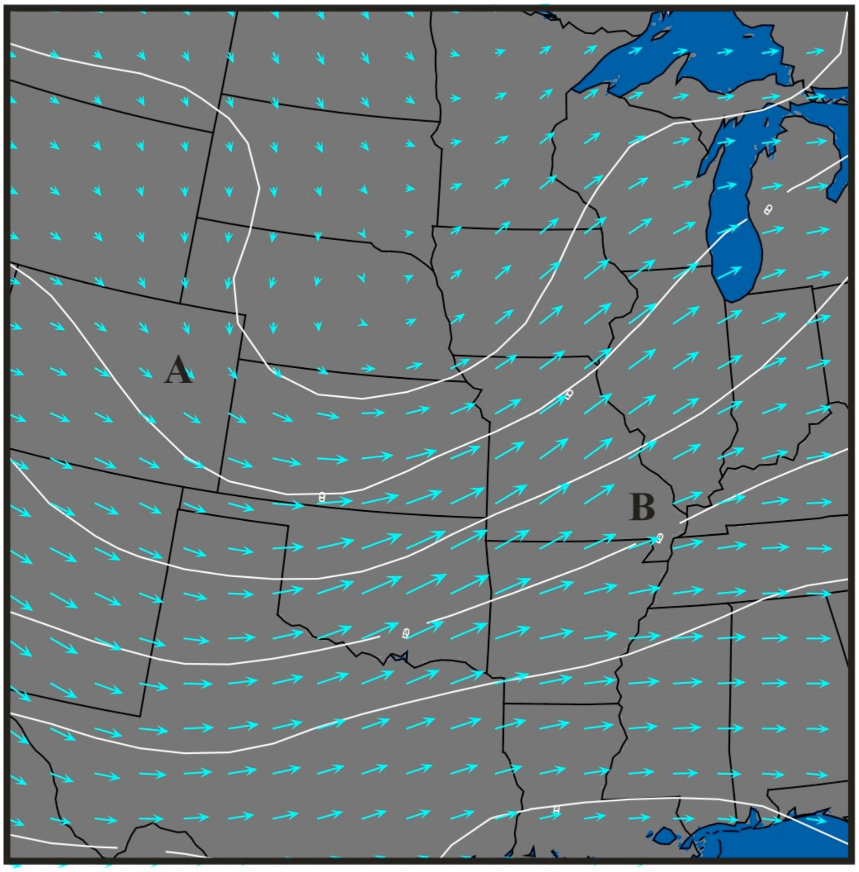
Determining the geostrophic wind from an upper level weather map:



What is the geostrophic wind direction at point A?
What is the geostrophic wind direction at point B?
What is the geostrophic wind direction at point D?

Is the geostrophic wind larger at point A or point C?

Above the boundary layer the atmosphere is nearly in geostrophic balance, but rarely exactly in geostrophic balance.



Courtesy of the Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign

Is the atmosphere in geostrophic balance at point A in this figure?

What about at point B?

What conditions are required for the atmosphere to be in exact geostrophic balance?

Geostrophic Balance and the Jet Stream

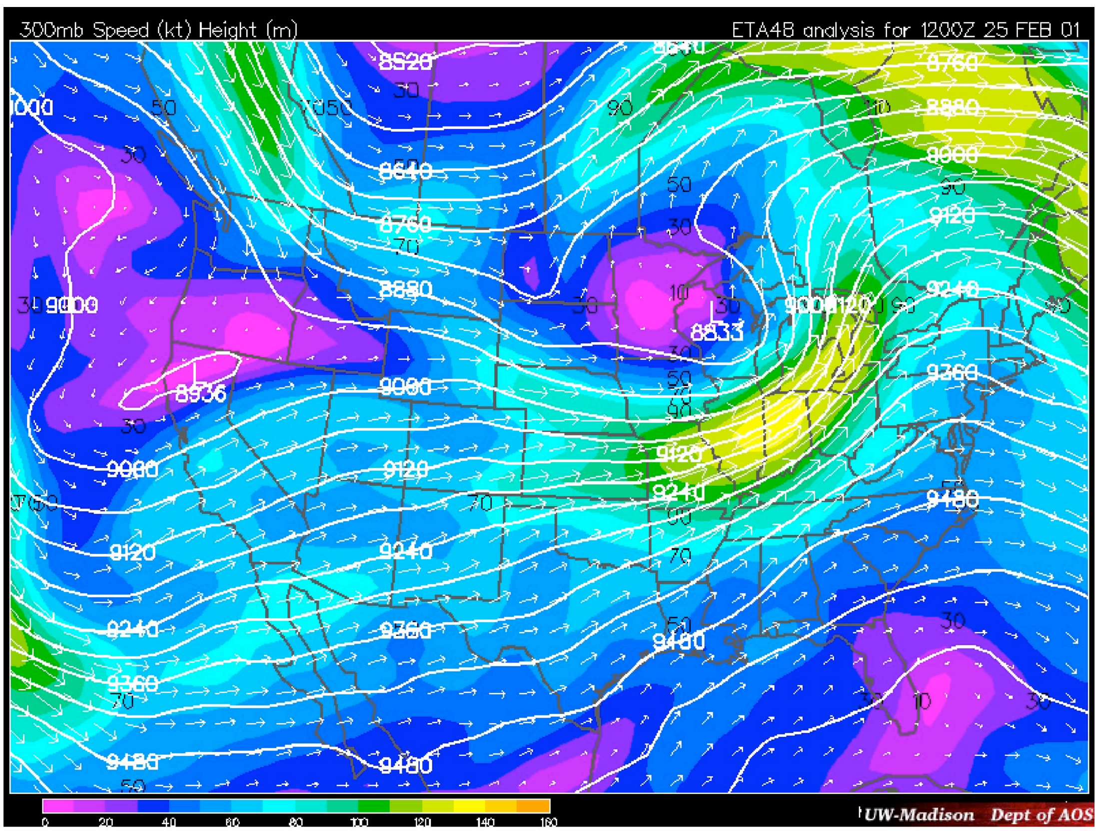
Jetstream – a narrow band of strong winds that encircle the earth in the mid-latitudes.

The jetstream is typically 200 to 300 miles wide and located between 250 mb and 500 mb.

Up to 3 jetstreams can exist between the equator and the pole:

- Subtropical jetstream
- Polar jetstream
- Arctic jetstream

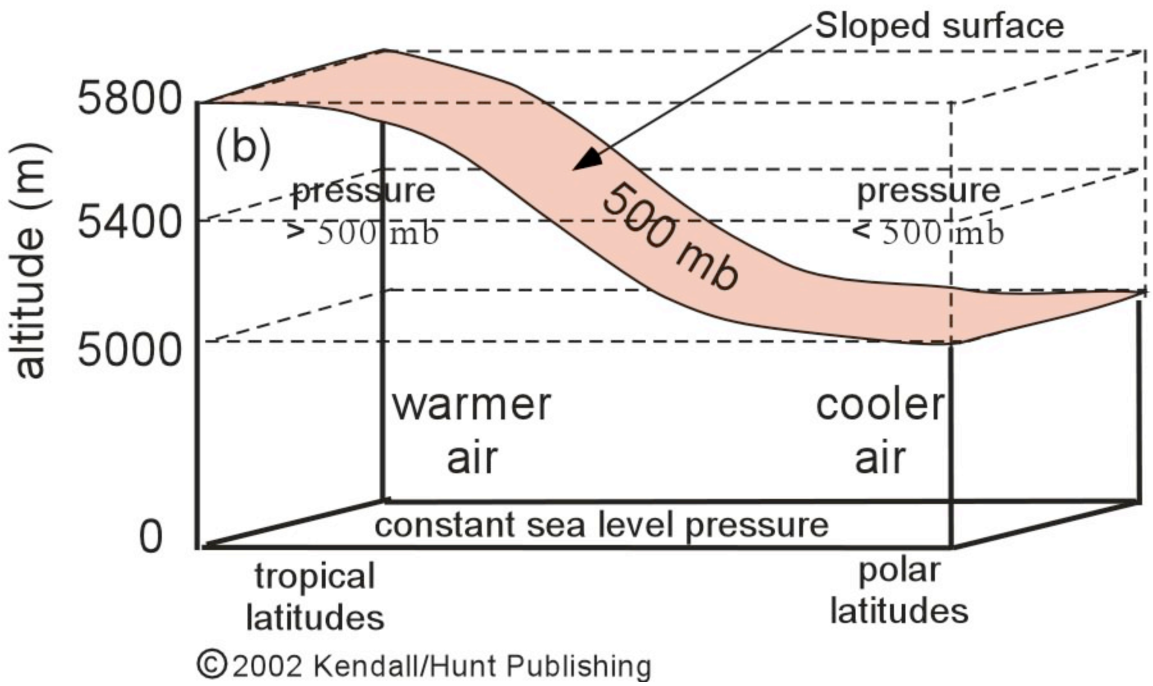
Jetstreak – a region of exceptionally strong winds in the jetstream.



Courtesy of the Department of Atmospheric and Oceanic Sciences
University of Wisconsin-Madison

Where is the jetstream on this map?

How does the height of a constant pressure surface change as you move from warm to cold air?



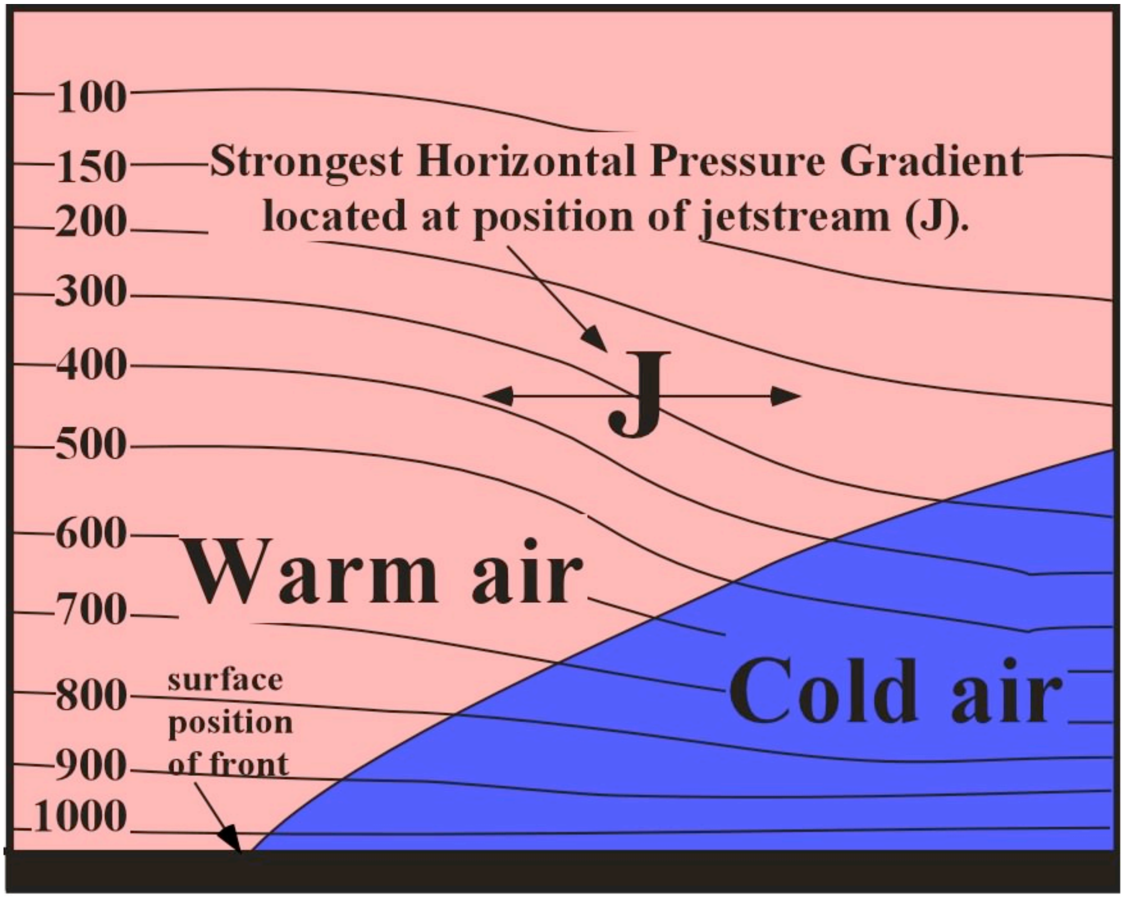
How does the pressure change as you move from left to right in this figure, at an altitude of 5400 m?

The slope of a constant pressure surface, and thus the horizontal pressure gradient, is largest in the upper troposphere above the region of largest horizontal temperature gradient.

The geostrophic wind speed will increase as the slope of the constant pressure surface increases.

Constant pressure surfaces, in the upper troposphere, generally slope downward from the equator to the pole.

In what direction will the geostrophic wind blow in the mid-latitudes if the constant pressure surfaces slope downward from the equator to the pole?



How does the slope of the constant pressure surfaces change as you move up from 1000 mb to 300 mb?

Relative to the warm and cold air, in what direction does the 300 mb surface slope down towards?

Why is the jetstream (marked by the J) located where it is in this picture?