Lesson I: Which way does the wind blow?

Overview:

What makes the wind blow? What makes the wind blow in certain directions? Why does the wind shift after the passage of a weather front? Many people do not know the answers to these questions. This exercise will help explain the forces that govern wind velocity (wind speed and direction) and provide a better understanding of weather maps.

Necessary Materials:

- Maps representing different pressure gradients
- Internet access to obtain weather maps
- Printers to make hard copies of the maps
- Four colored pencils (red, green, blue, and **black**)

Theory:

Everyday we look at weather maps on television or on the Internet, but where do those maps come from? Weather maps come from observations at the surface and from weather balloons that are released worldwide (twice a day). Maps are then produced from these observations and lines are used to interpolate between data points.

The forces that govern **wind** velocity include the pressure gradient force, the Coriolis "force" (an apparent force due to Earth's rotation) and friction. The pressure gradient force is what causes the **wind** to blow. In the atmosphere, pressure differences are a result of changes in density due to warm and cold air. When warm and cold air are close together, we have a pressure gradient. The pressure gradient force is only determined by the gradient in the pressure (the stronger the difference in the pressure, the stronger the pressure gradient force). Finding the pressure gradient at the surface is easy because we look at maps of pressure. At higher levels, we look at isobaric surface maps. Isobaric surface maps do not have lines of pressure but have lines of geopotential height.

The Coriolis "force" is an apparent force due to the rotation of the Earth and does not cause the **wind** to blow, but changes its direction. The magnitude of the Coriolis force is dependent on the latitude and speed of the **wind** (maximized 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).

Near the Earth's surface, friction acts opposite to the direction of the **wind** and slows it down. The magnitude of friction depends on the speed of the **wind** and the roughness of the surface. For example, friction is stronger over a forest and fast **wind** speeds than over calm water and slower **wind** speeds.

High above the surface, the friction force is very small so the **wind** is a result of the force balance between the pressure gradient force and the Coriolis force. Near the Earth's surface, friction is no longer negligible and the **wind** is a result of the force balance between the pressure gradient force, the Coriolis force and friction.

Doing the Experiment:

Step 1

- As a group, practice drawing force diagrams using simple plots of pressure and geopotential height before using the weather maps. Assume Northern Hemisphere.
- First determine if the plot is at the surface or aloft.
- Locate and label high (**H**) and low pressure (**L**) (color coding does not relate high or low pressure to the Coriolis force or the pressure gradient force, but is used to be consistent with everyday weather maps).
- Draw a vector representing the pressure gradient force, pointing from higher to lower pressure. The tighter the pressure gradient, the longer the vector.
- If the plot is aloft, friction is negligible and we can draw a vector representing the Coriolis force opposite (at an 180° angle to) the pressure gradient force (recall geostrophic balance).
- In the upper levels of the atmosphere, the **wind** is called the geostrophic wind and it is parallel to isolines or at a 90° angle to both the pressure gradient force and the Coriolis force. In the NH the **wind** is to the right of the pressure gradient force and is to the left in the SH.
- If the plot is at the surface, friction is no longer negligible and we need to balance the pressure gradient force, Coriolis force and friction.
  - Friction decreases the **wind** speed. Since the Coriolis force is dependent on the **wind** speed, it also decreases and will not exactly balance the pressure gradient force (the pressure gradient force will not change).
  - Draw a vector representing the Coriolis force (smaller than the pressure gradient force) at angle that is less than 180° to the pressure gradient force. The angle should be to the right of the pressure gradient force in the NH and to the left in the SH.
  - Draw a vector representing the friction at a 90° angle to the Coriolis force. Friction is to the right of the Coriolis force in the NH and to the left in the SH.
- Using vector addition, we can see that the Coriolis force and friction balance the pressure gradient force, and can draw the resulting **wind** vector (in **black**).
- At the surface, the **wind** vector will point towards lower pressure and is 180° opposite the friction, 90° from the Coriolis force, and less than 90° from the pressure gradient force.

Step2

- Now we will apply these fundamentals to weather maps.
- Go to http://www.esrl.noaa.gov/psd/data/composites/day/
- Two plots are required for this exercise, select one plot at a time and continue with the following steps. For plot number one, select sea level pressure (surface analysis) for the

variable and select 1000 mb for the analysis level. For plot number two, select geopotential height for the variable and 500 mb for the analysis level.

- At the first OR, select the date of your choice for both the first and second options (for a single day analysis) and type in the year.
- Under color, select Black and White and for shading type select contours (Black and White).
- Scale plot size is 500%, plot contour label = yes, state boundaries = yes, region of globe = USA
- Click create plot
- Edit the plot by adding several dots in interesting locations manually or by copying the plot and pasting it to an editing program.
- **500 mb analysis:**
    - Label all upper-level highs, lows, trough axes (where isolines dip), and ridges (where isolines have a bump) using the symbols below.
    - For each dot draw vectors representing the pressure gradient force and the Coriolis force (remember friction is negligible aloft).
    - Draw the resulting **wind** vectors
- **Surface analysis:**
    - Label all surface highs and lows using the symbols below.
    - For each dot draw vectors representing the pressure gradient force, the Coriolis force, and friction.
    - Draw the resulting **wind** vectors
- **Some Questions:**
- What type of pressure gradient force would be associated with destructive winds?
- On the maps, where are the strongest winds aloft and at the surface?
- How does roughness change the magnitude of the wind speed?
- If we were in the Southern Hemisphere, how would the wind vectors on our weather maps (that we just marked) change?

Symbols:

H: Surface and upper level high (color does not relate high pressure to the Coriolis force, but is used to be consistent with everyday weather maps)

L: Surface and upper level low (color does not relate low pressure to the pressure gradient force, but is used to be consistent with everyday weather maps)

Upper level trough axis:

Upper level ridge axis:

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Summary:

This exercise explains the forces that govern wind velocity (speed and direction) and provides a better understanding of weather maps. Knowing what makes the wind blow and change directions is important for understanding the atmosphere.

Lesson Glossary:

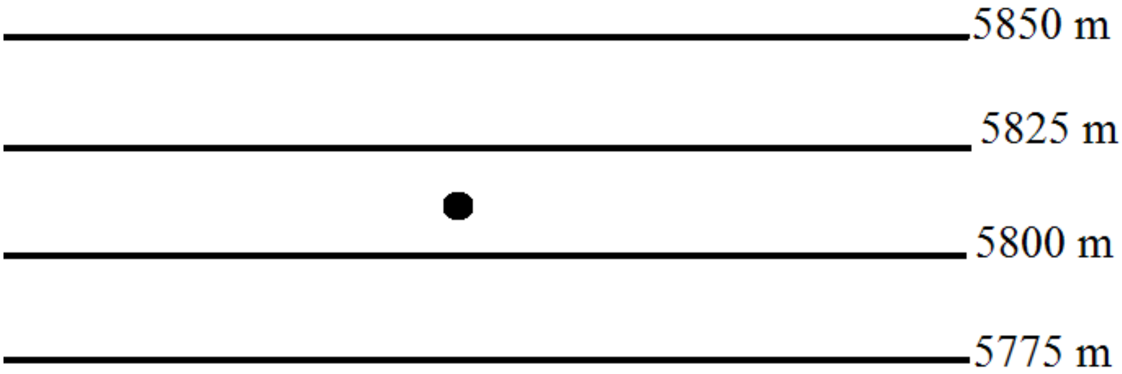
1. Geopotential Height: The approximate height above mean sea-level where a single pressure surface (like 500 mb) is observed.
2. Geostrophic Balance: Describes a balance between the horizontal pressure gradient force and the Coriolis force.
3. Geostrophic Wind: The horizontal wind velocity for which the Coriolis force exactly balances the horizontal pressure gradient force.
4. Isobaric Surface Maps: Maps of geopotential height for a single pressure surface (like 500 mb).
5. Isolines: Lines used on maps to represent points of equal value.

For More Information:

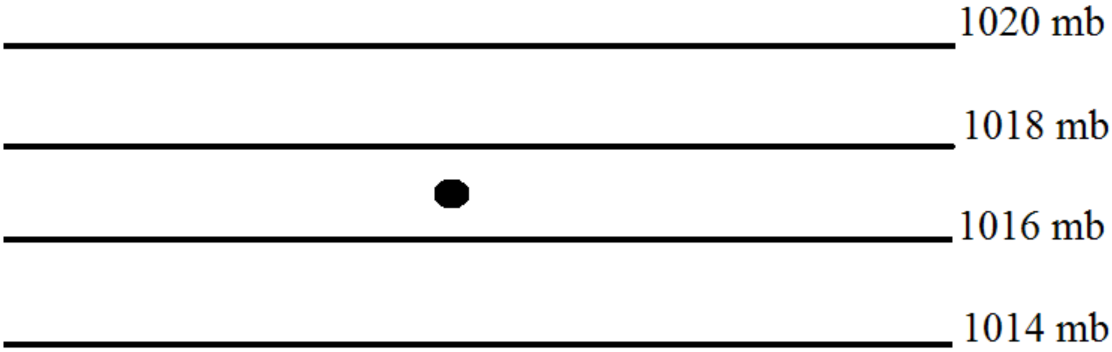
CMMAP, the Center for Multi-Scale Modeling of Atmospheric Processes: http://cmmap.colostate.edu

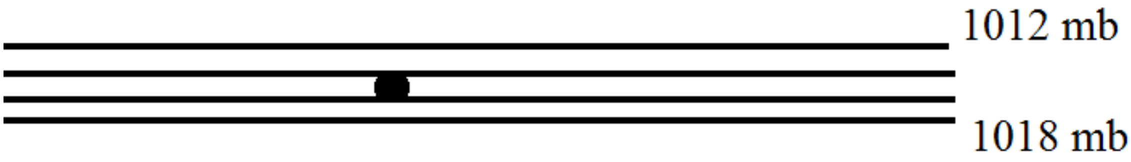
Little Shop of Physics: http://littleshop.physics.colostate.edu

500 mb Heights

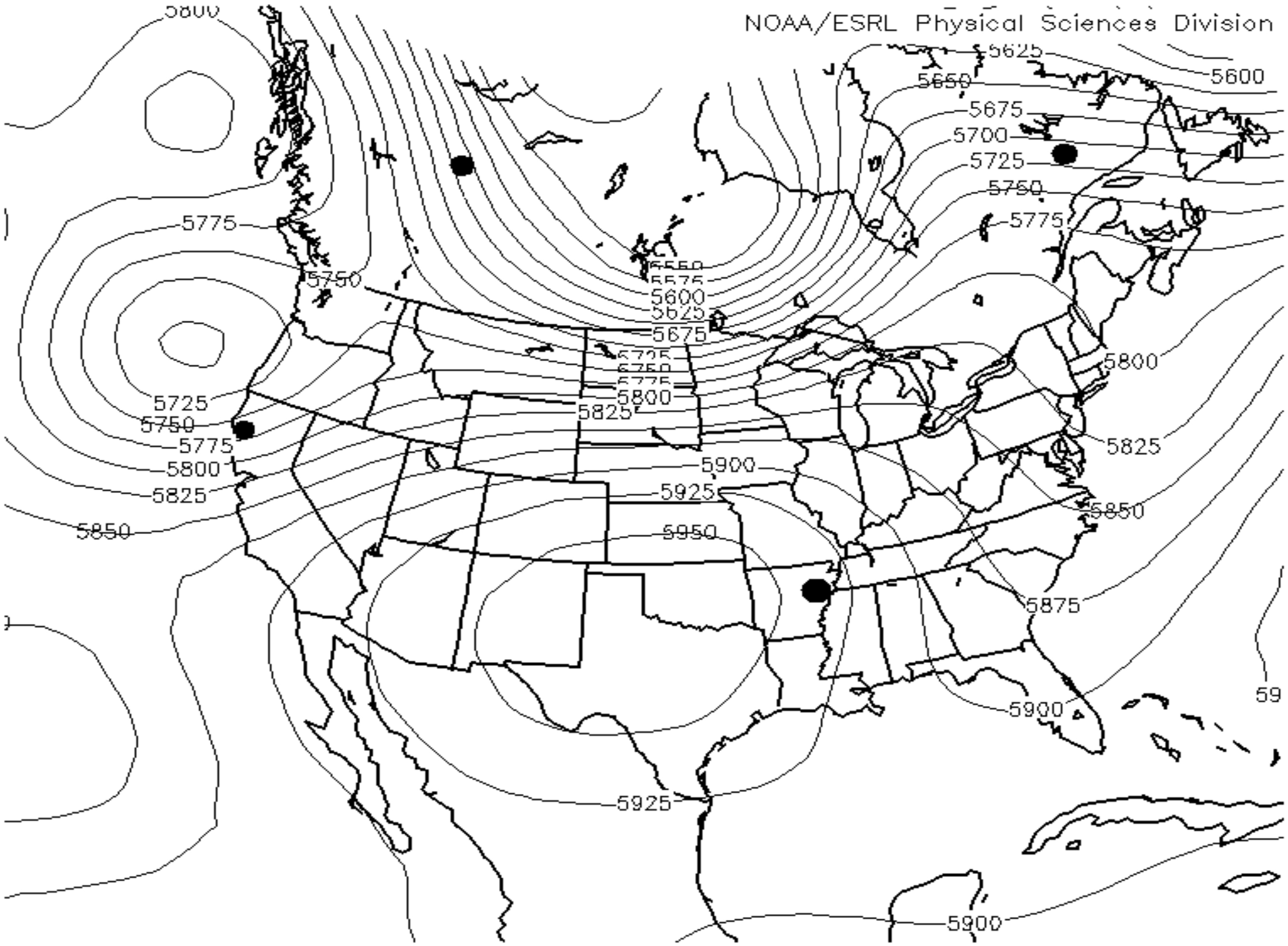


Sea Level Pressure





500mb Isobaric Surface Map

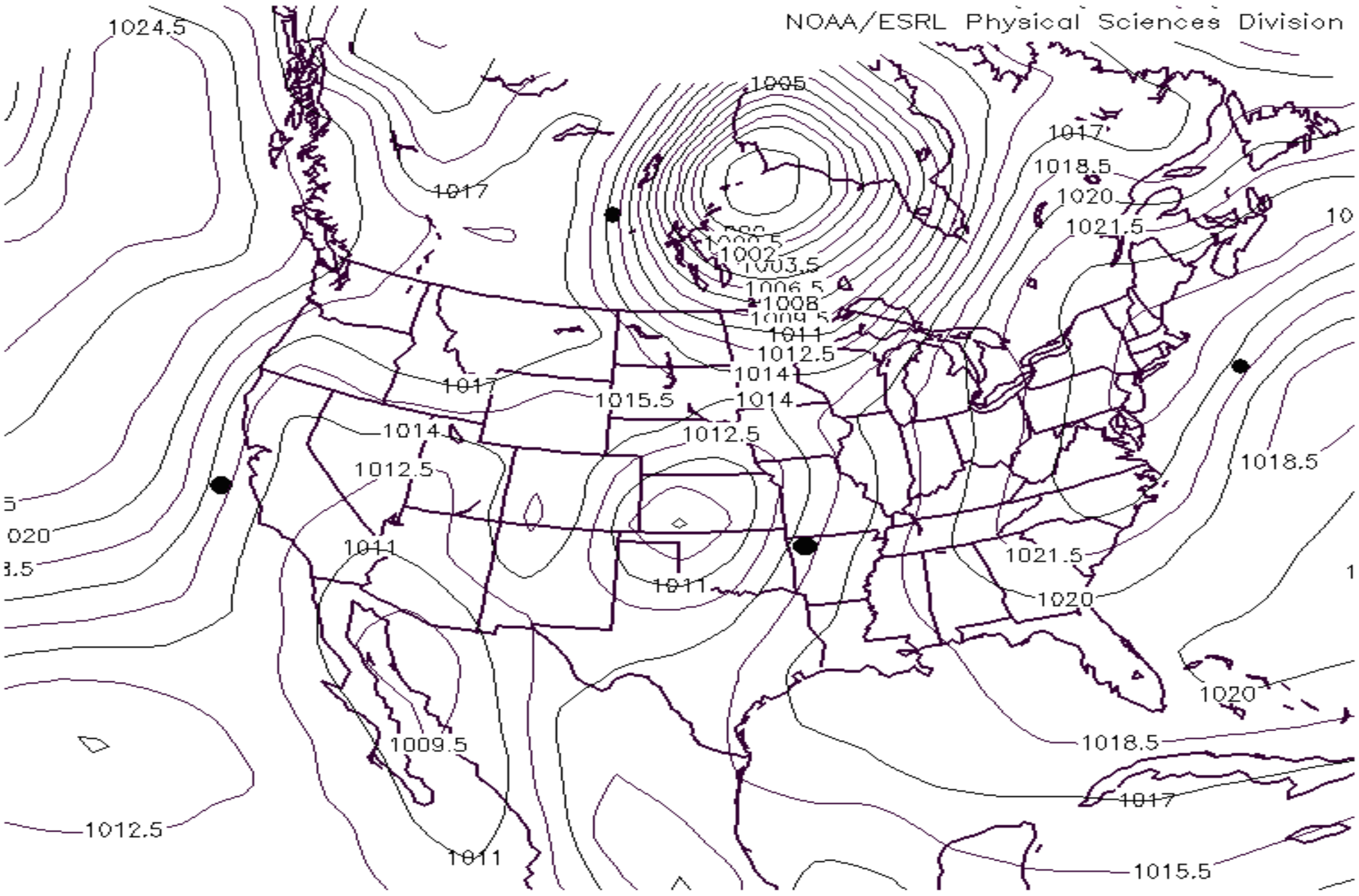


NOAA/ESRL Physical Sciences Division

500mb Geopotential Height (m) Composite Mean
7/10/09 to 7/10/09

NCEP/NCAR Reanalysis

Sea Level Pressure Map



Sea Level Pressure (mb) Composite Mean
7/10/09 to 7/10/09
NCEP/NCAR Reanalysis

SOLUTIONS

The pressure gradient force makes the air move.

The Coriolis force rotates the wind.

Friction tries to slow the wind down.

Wind is what results.

Upper level ridge axis:

Upper level trough axis:

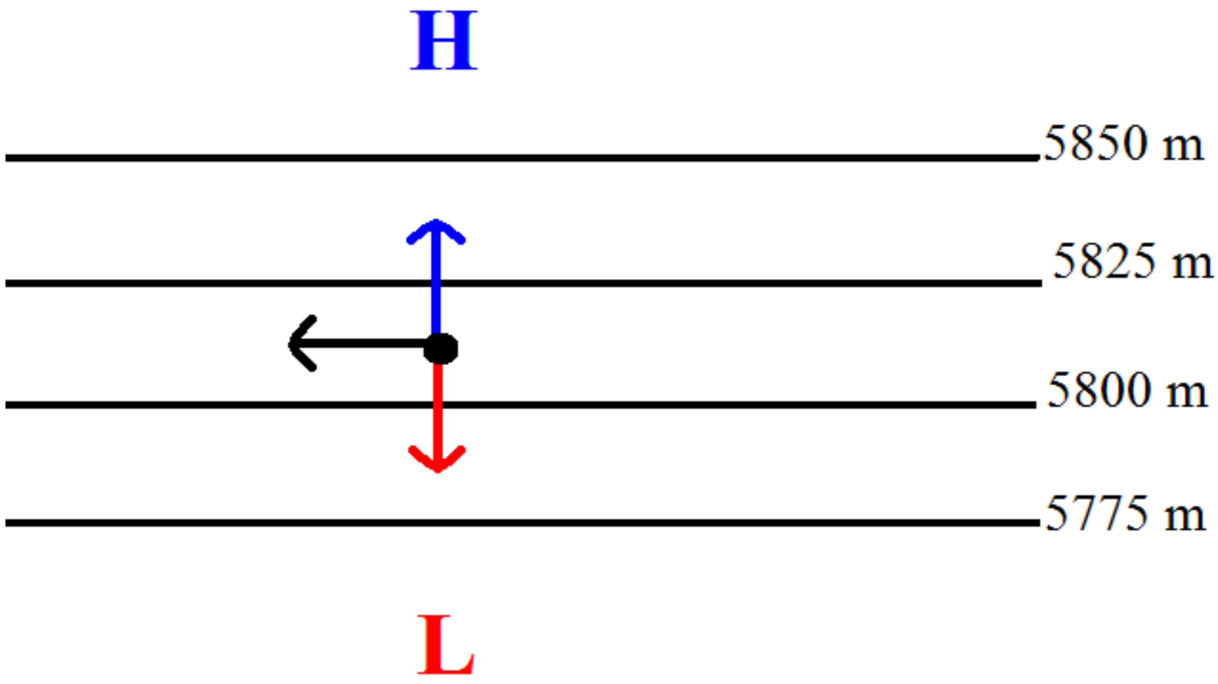
Surface and upper level low:

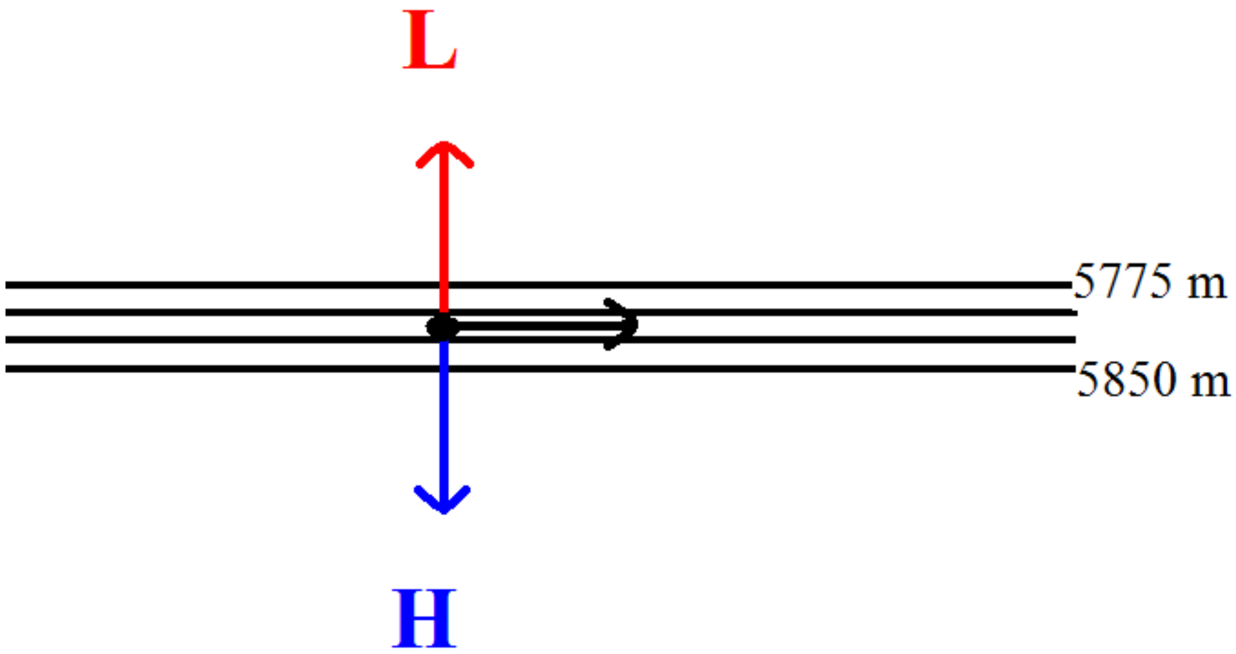
L

Surface and upper level high:

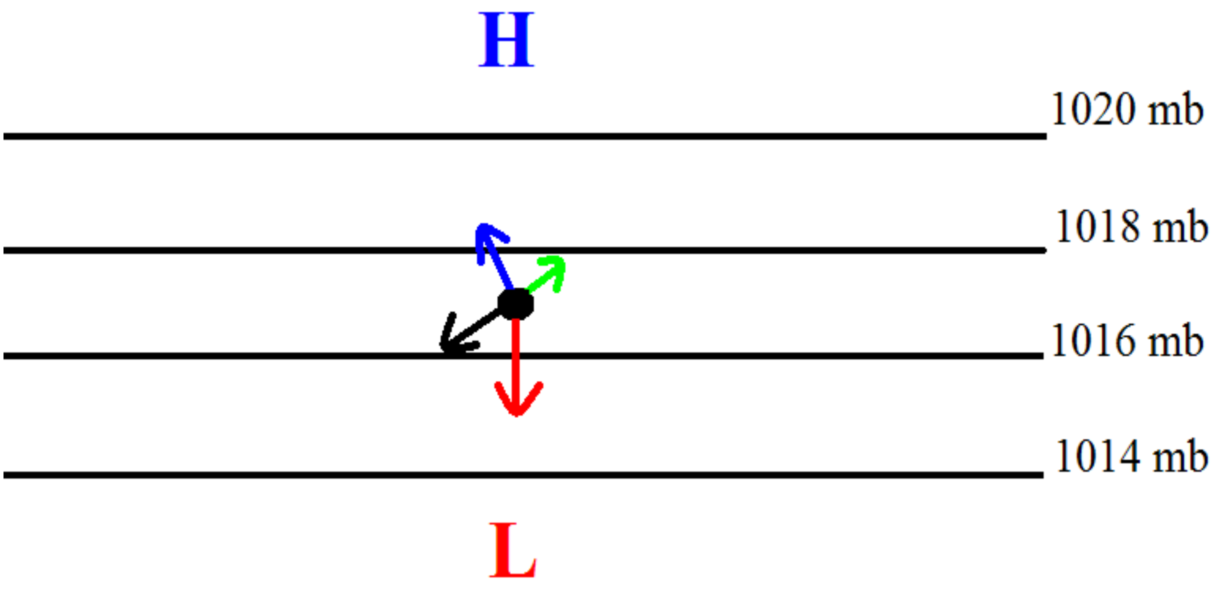
H

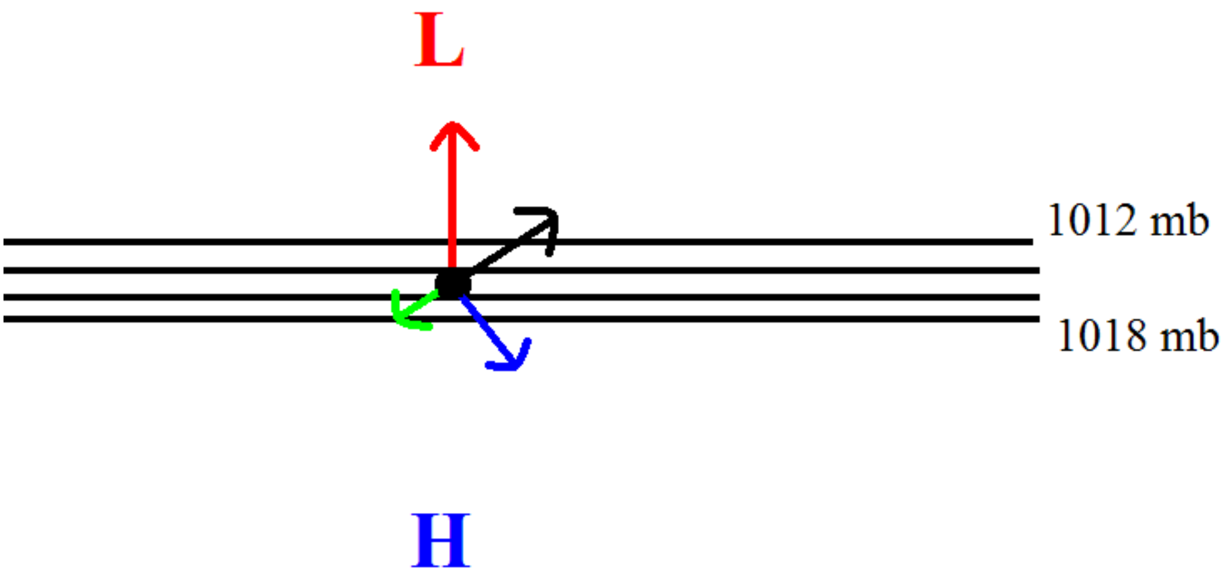
500 mb Heights



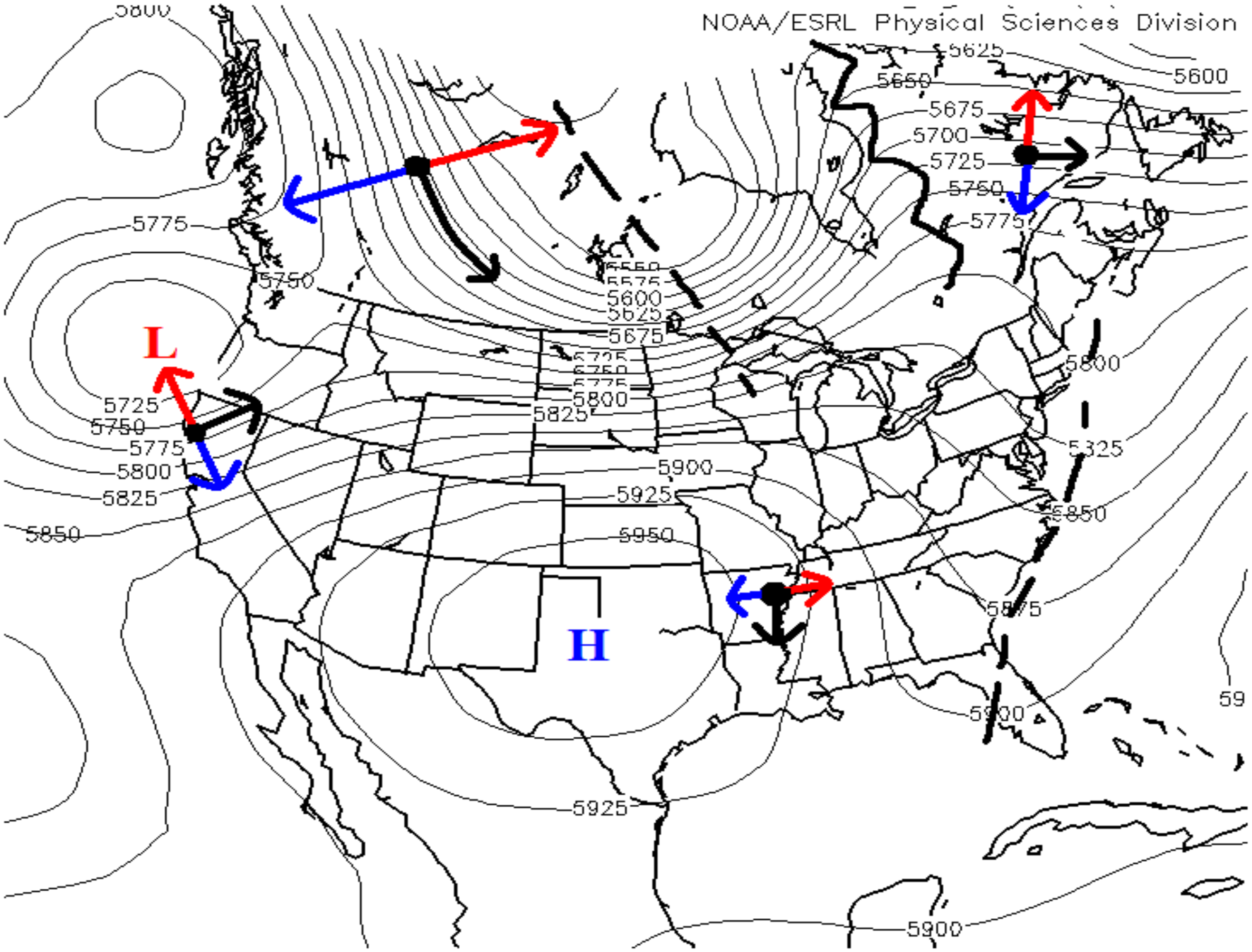


Sea Level Pressure



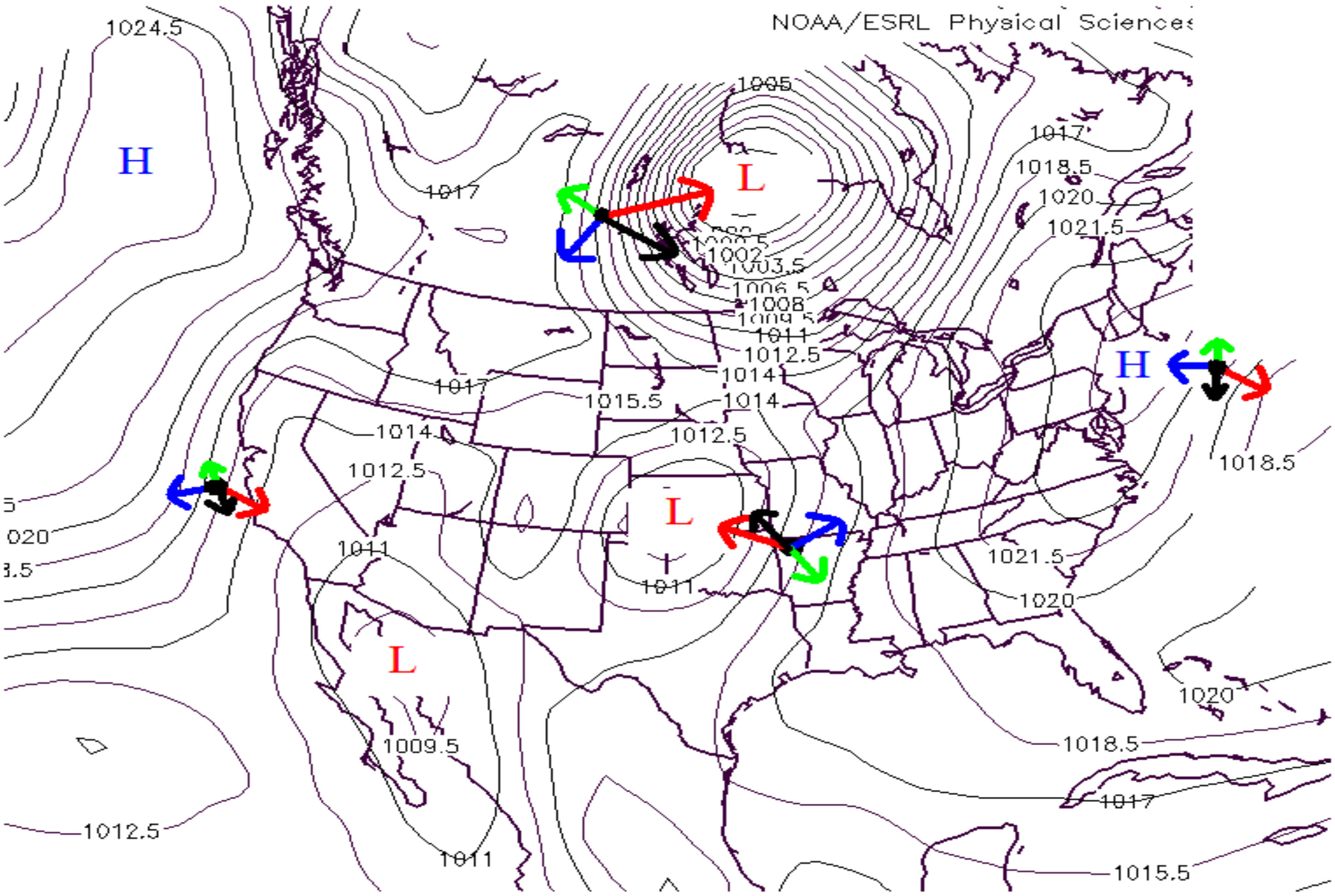


500mb Isobaric Surface Map



500mb Geopotential Height (m) Composite Mean
7/10/09 to 7/10/09
NCEP/NCAR Reanalysis

Sea Level Pressure Map



Sea Level Pressure (mb) Composite Mean
7/10/09 to 7/10/09

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