Synoptic Meteorology 1

Lecture 13

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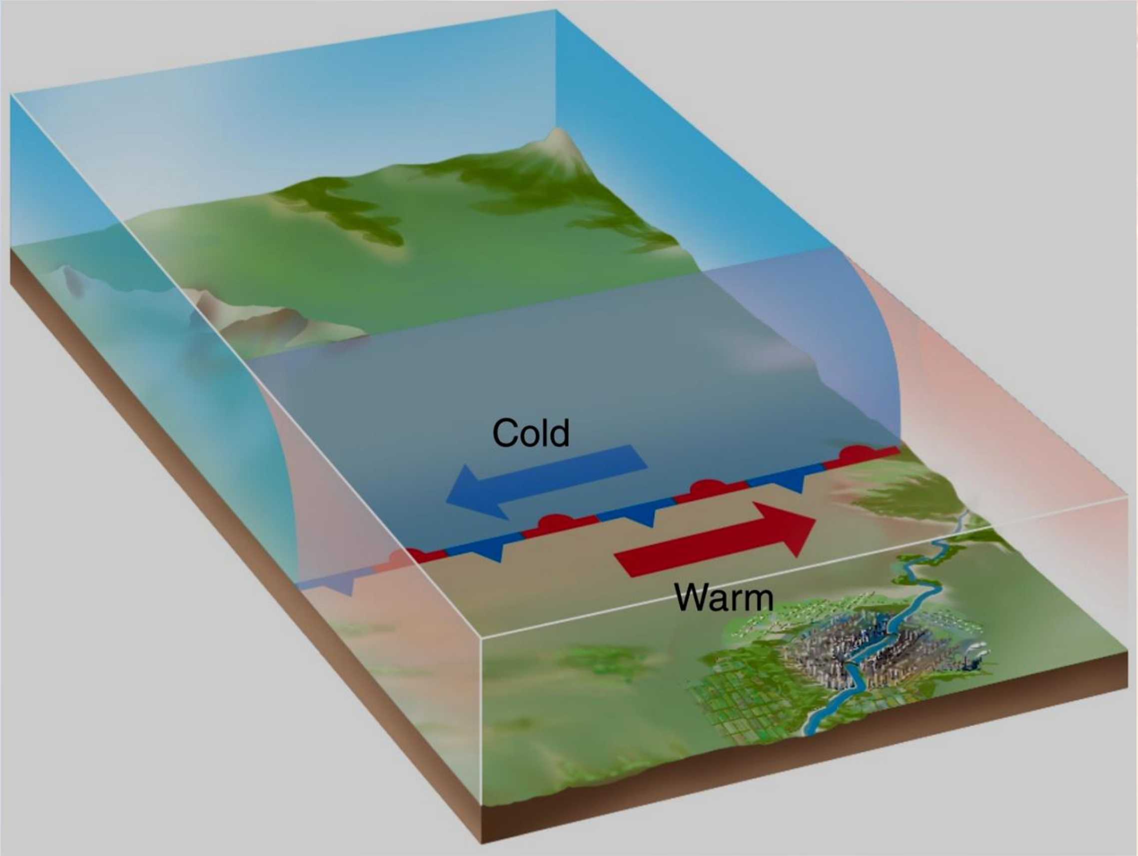
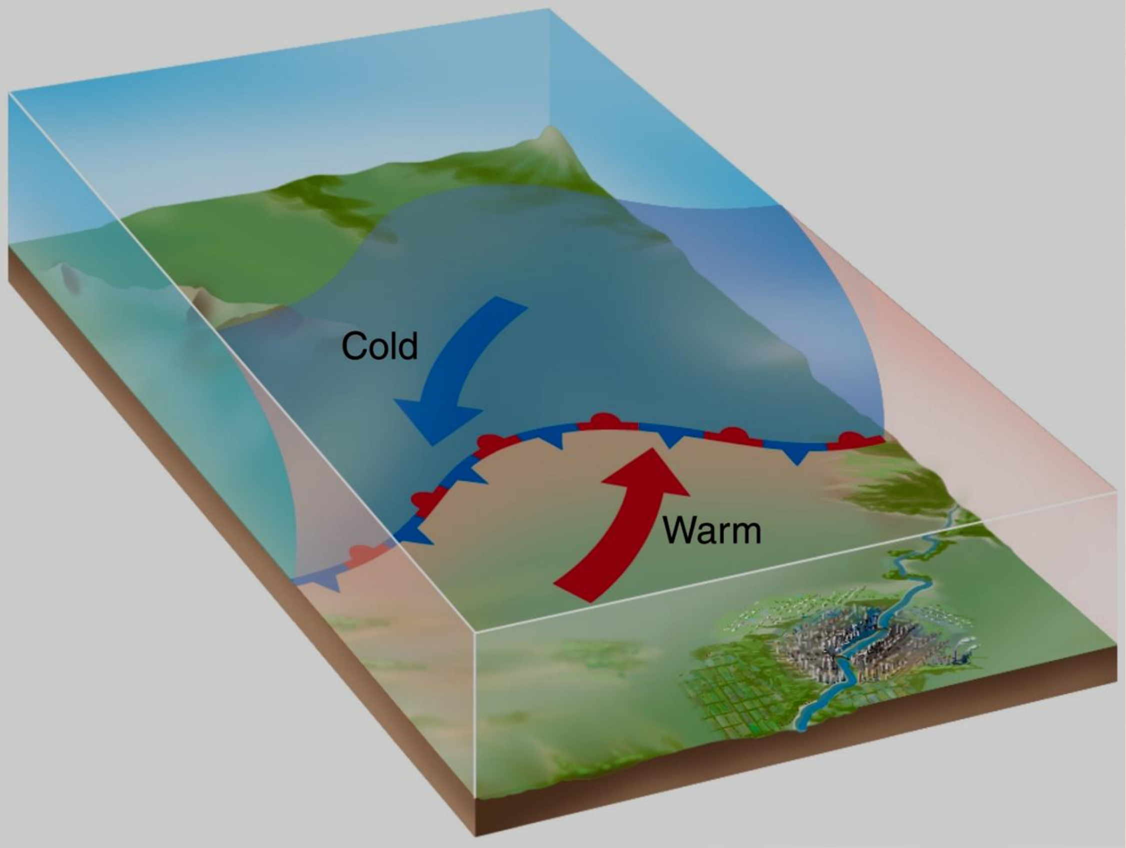
The Life Cycle of Midlatitude Cyclones

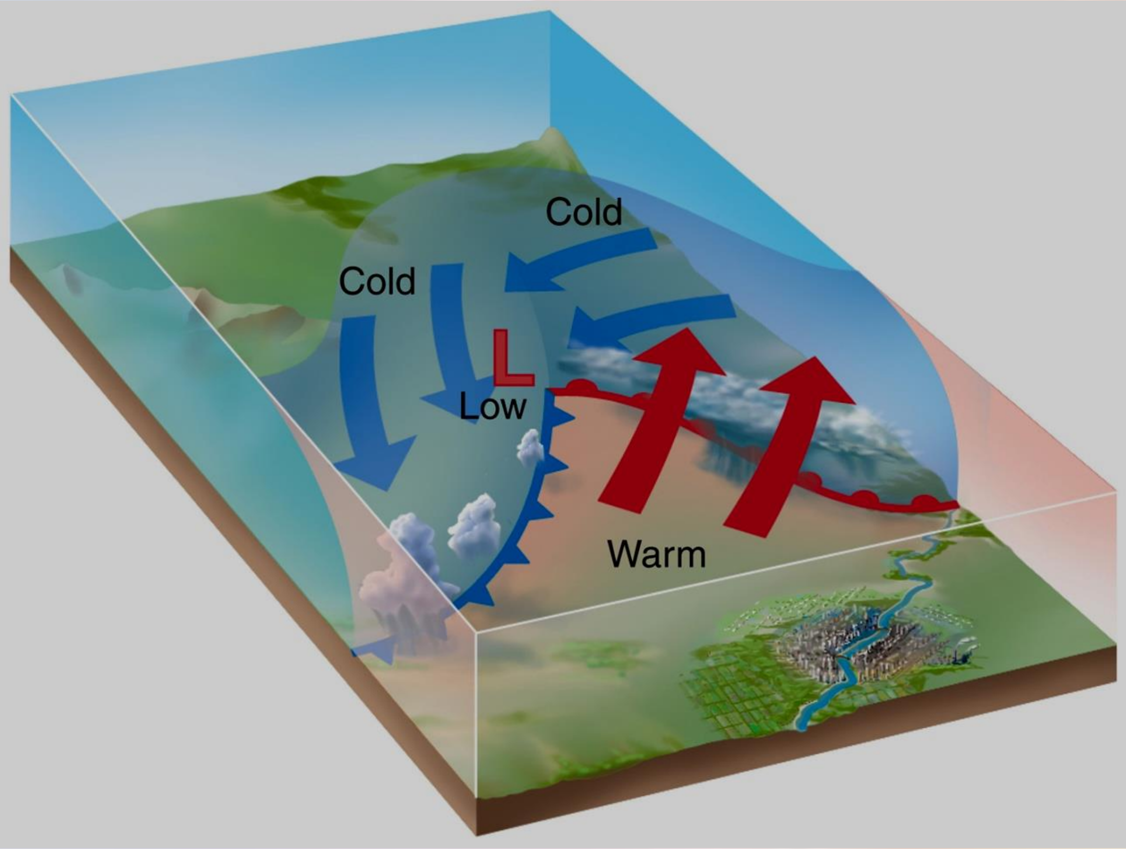
Cyclogenesis – the formation of a midlatitude cyclone

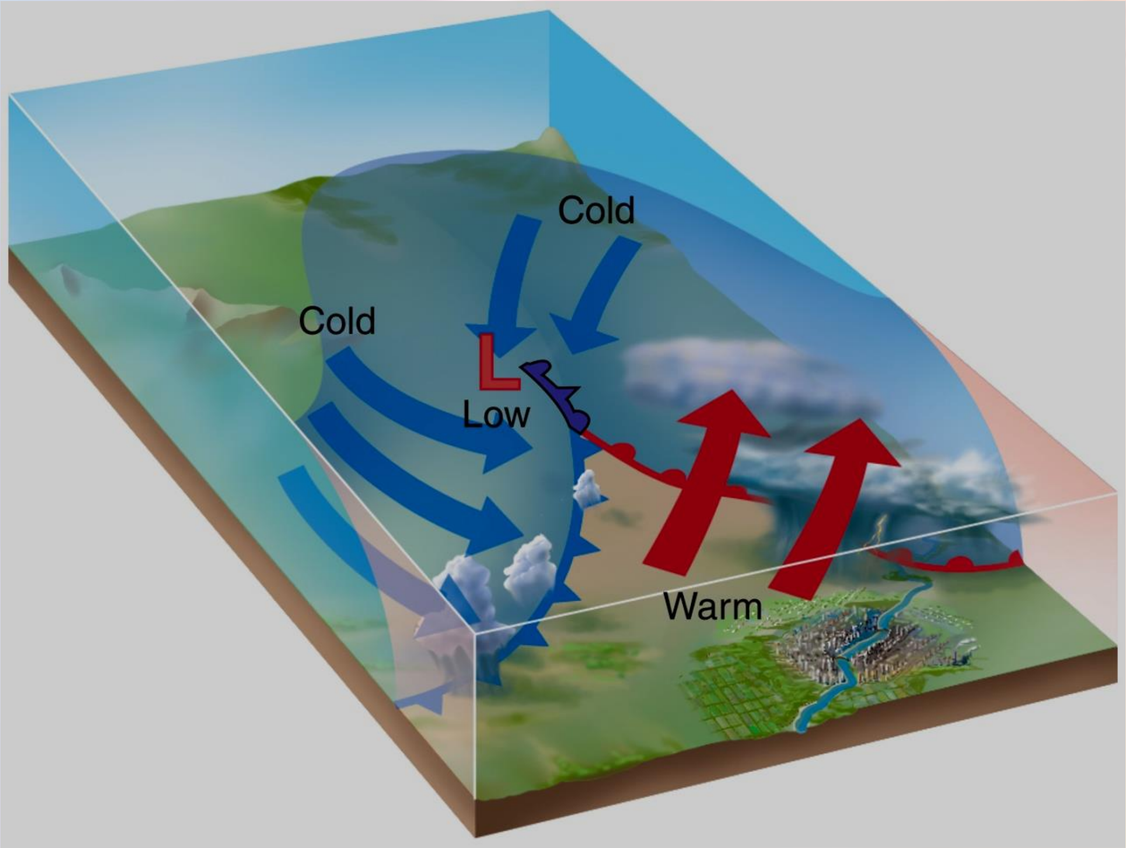
Cyclones often form at fronts (just like the Norwegian cyclone model states)

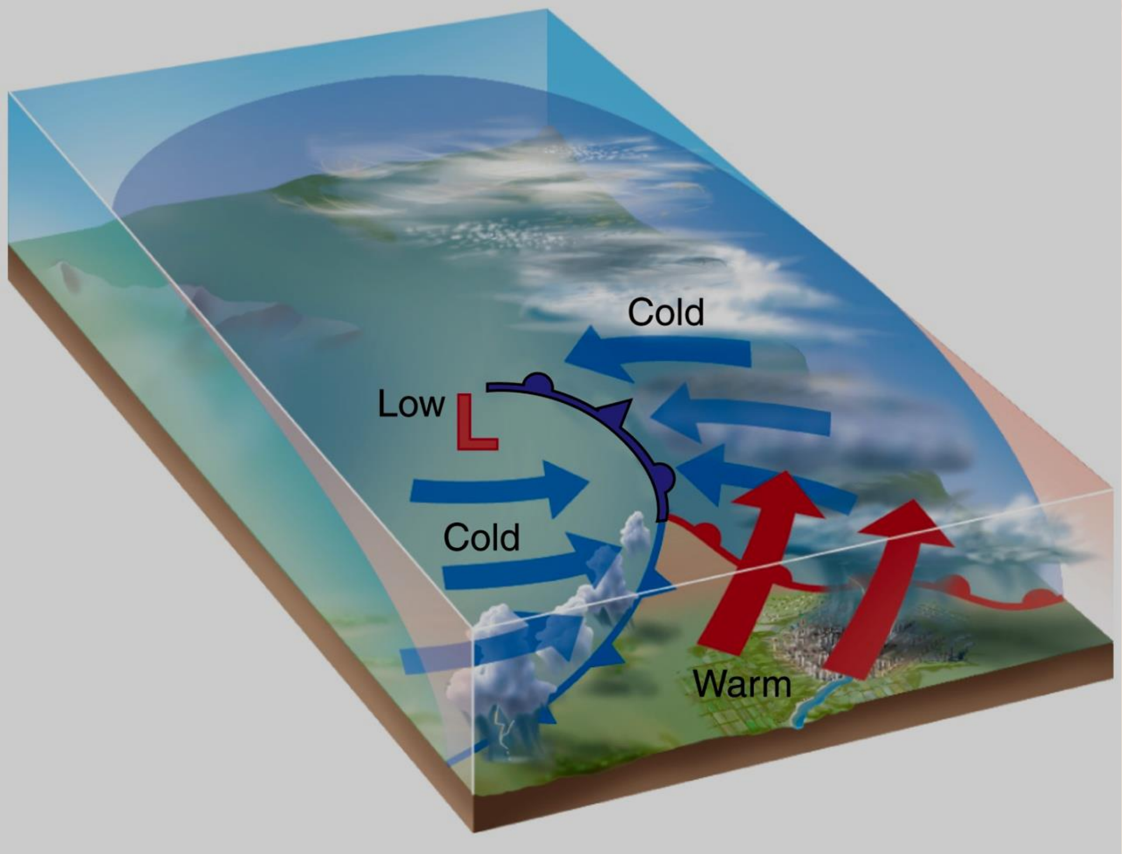

Cold
Warm


Cold
Warm

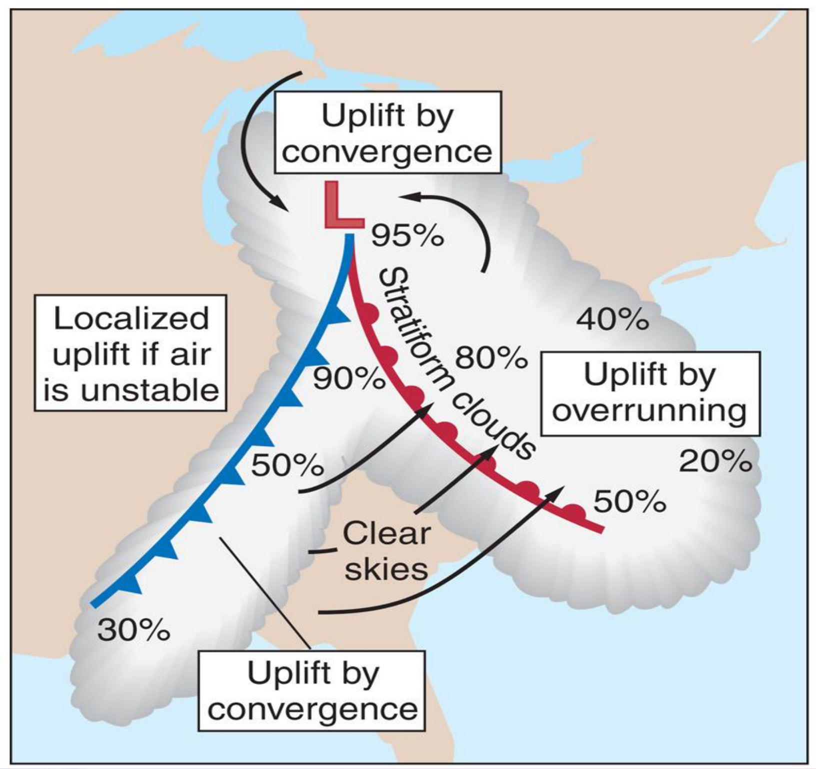
Mature cyclone – cyclone with active cold and warm fronts prior to occlusion

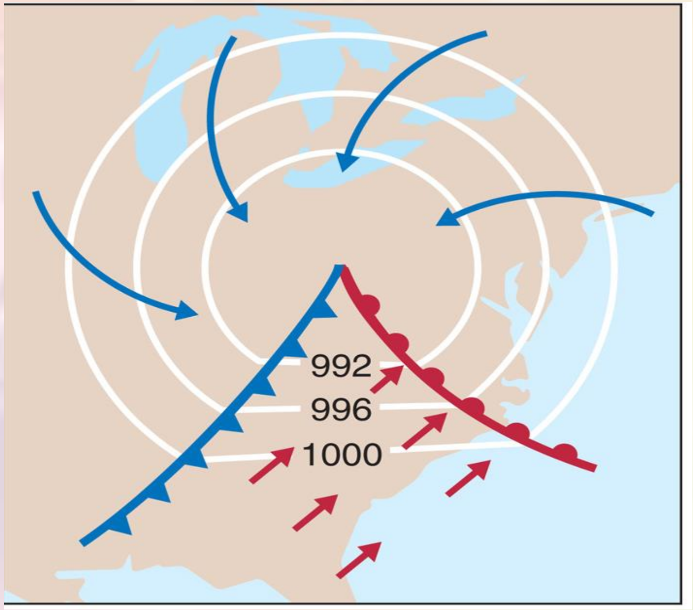



Cold
Cold
L
Low
Warm

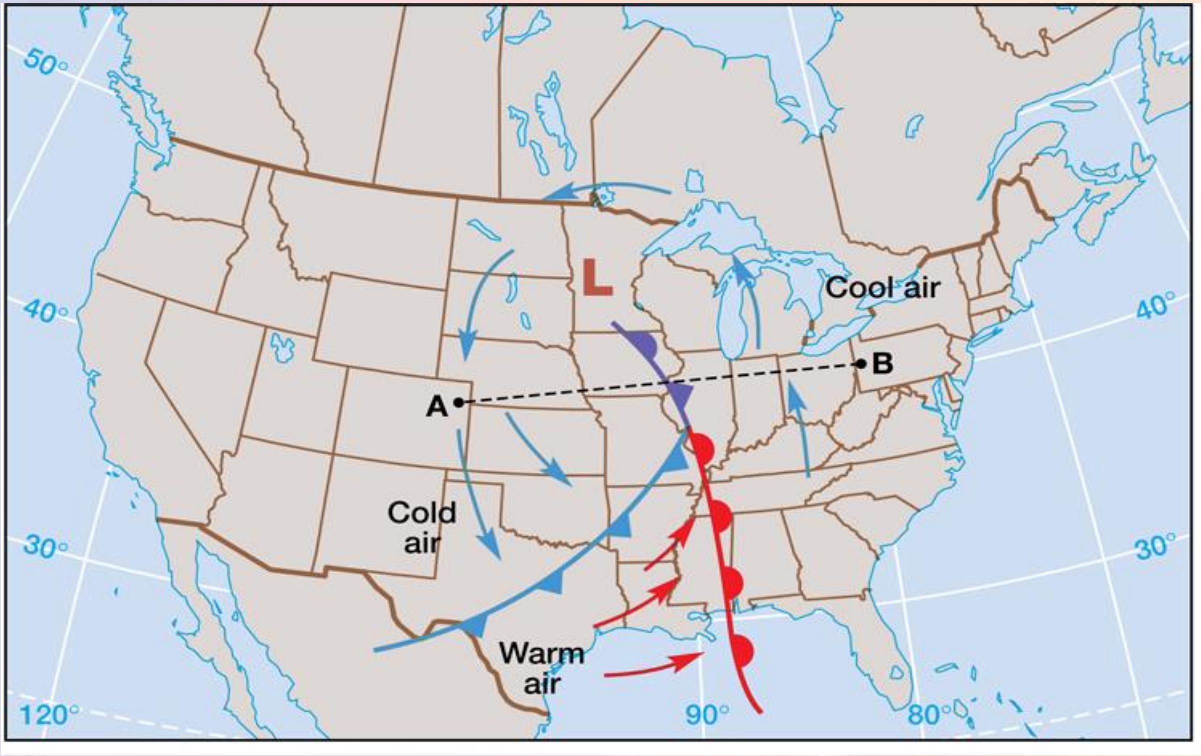

Cold
Low
L
Cold
Warm

Mature cyclone – cyclone with active cold and warm fronts prior to occlusion

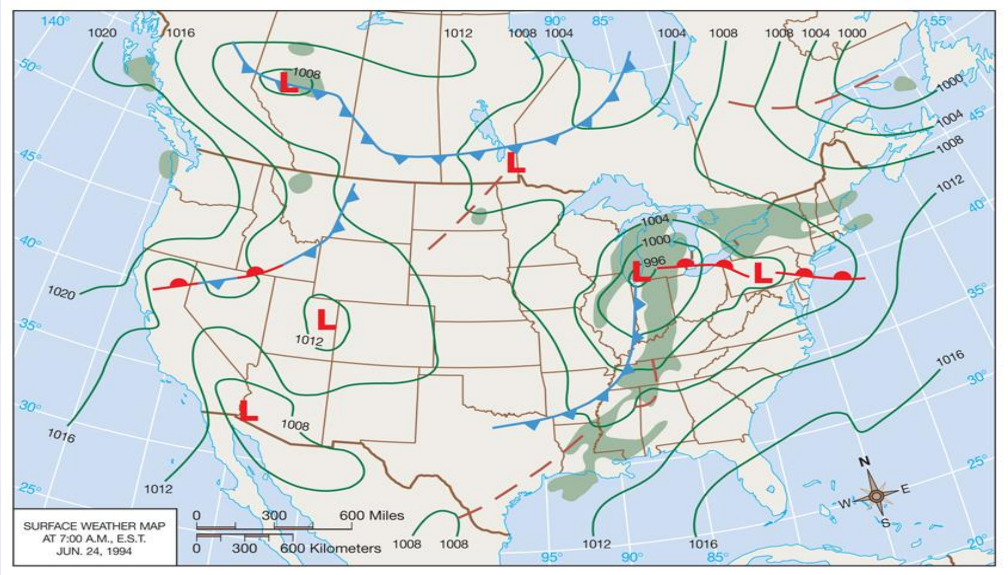


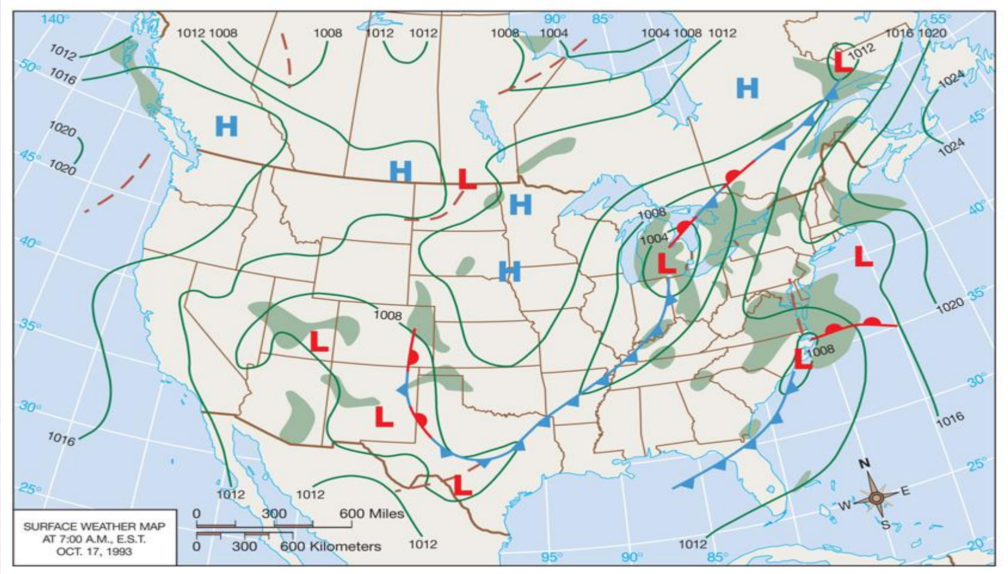


Occlusion – the end of the cyclone life cycle, associated with formation of occluded front



All Cyclones don't Look Alike…

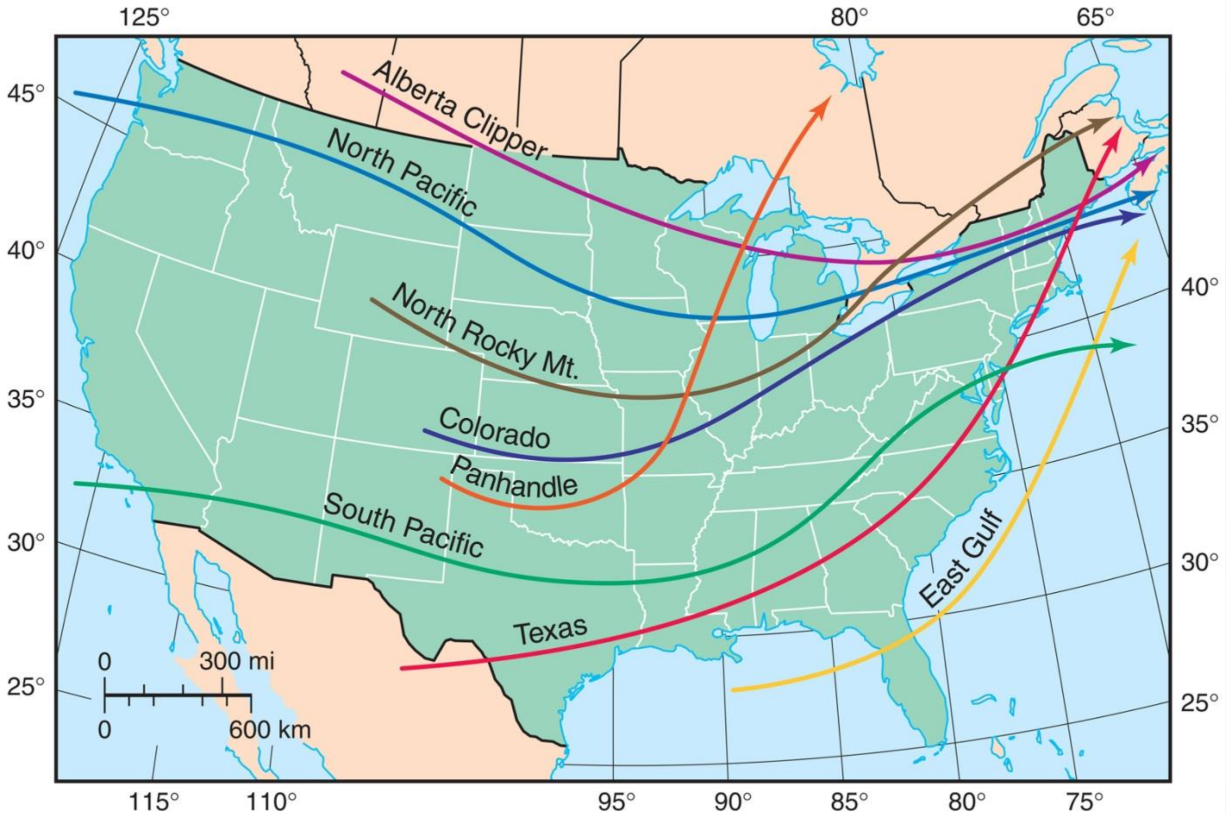




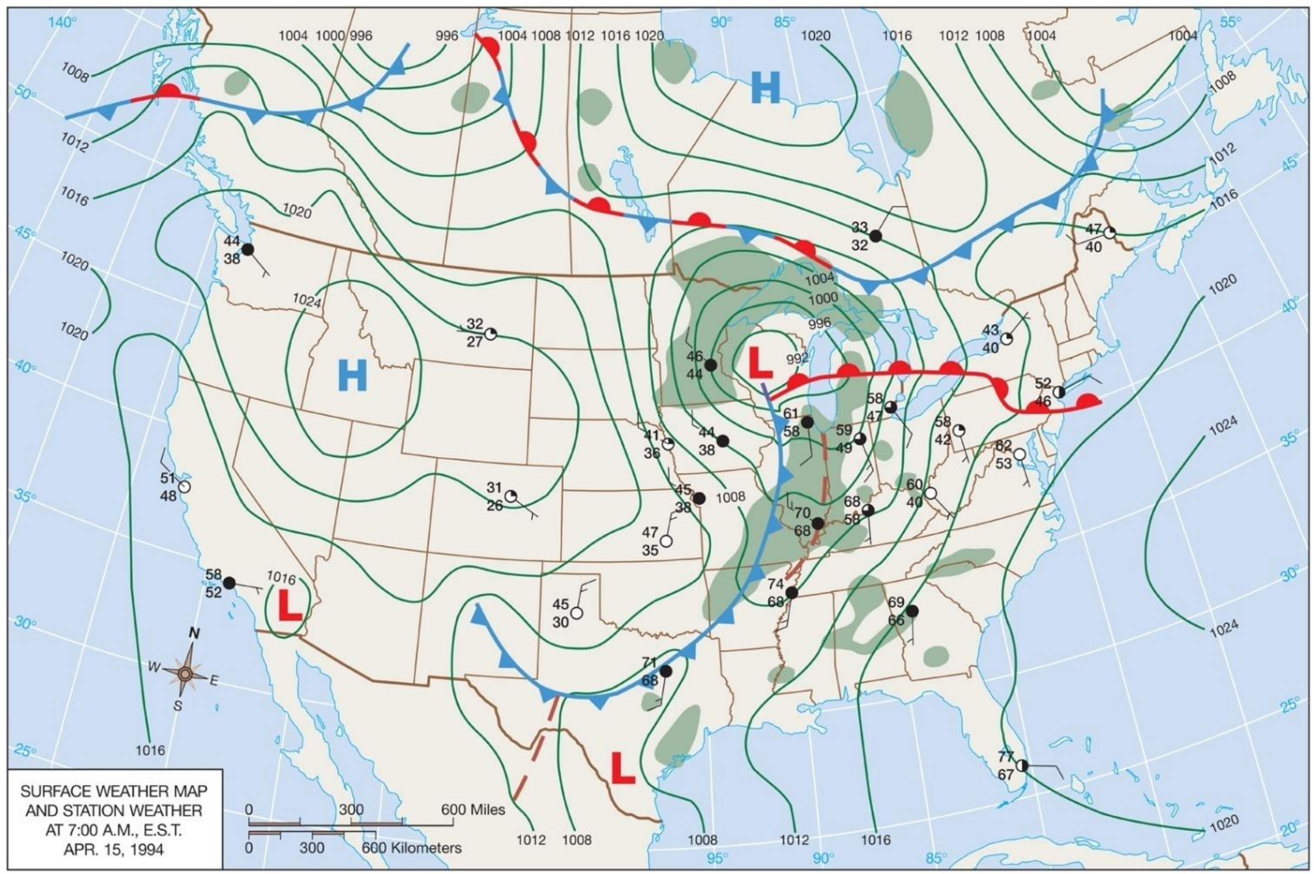
Cyclones

There are roughly 600 cyclones per year in the northern hemisphere

Cyclones generally travel from 0-160 kmh^{-1}

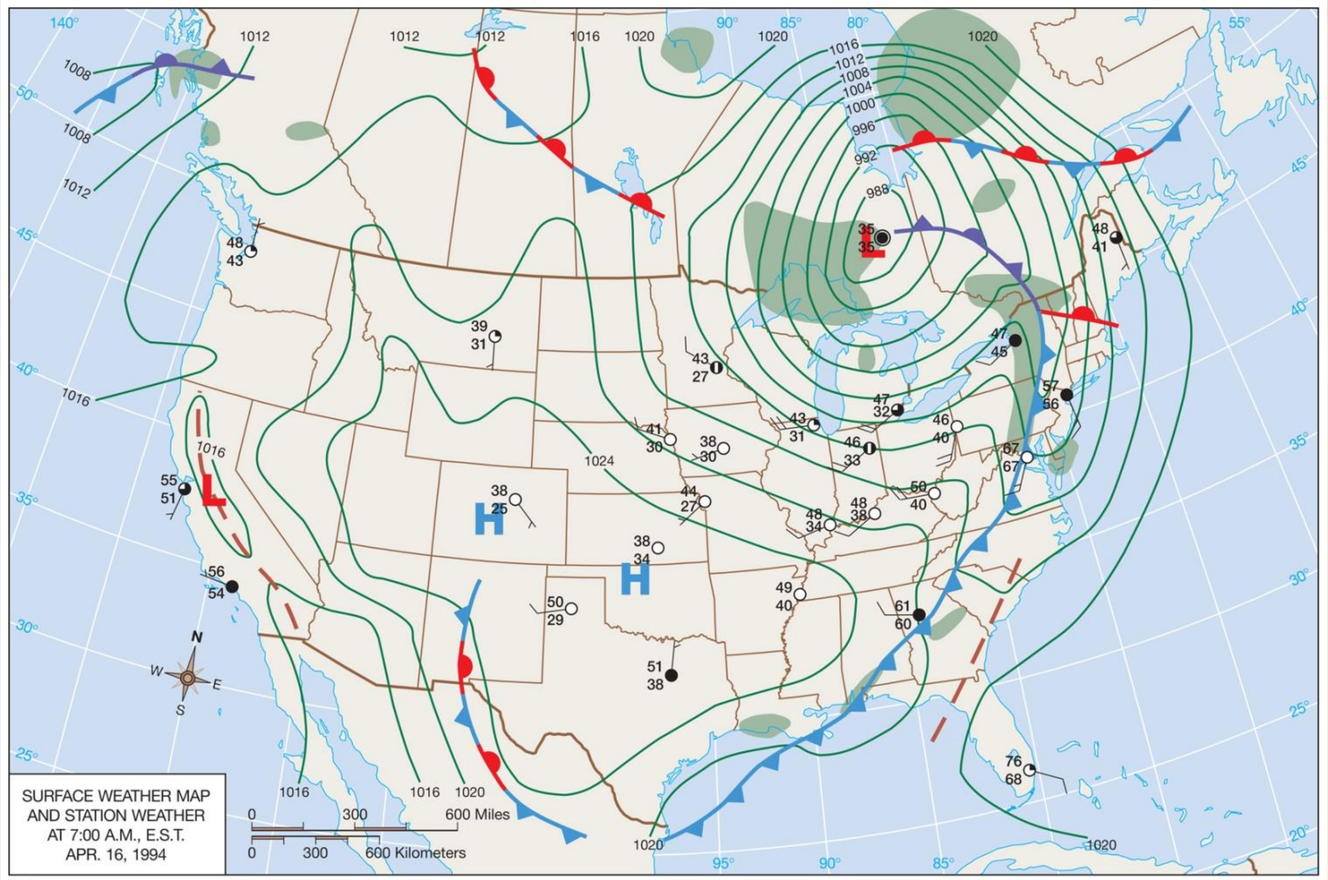


Cyclones: An Example

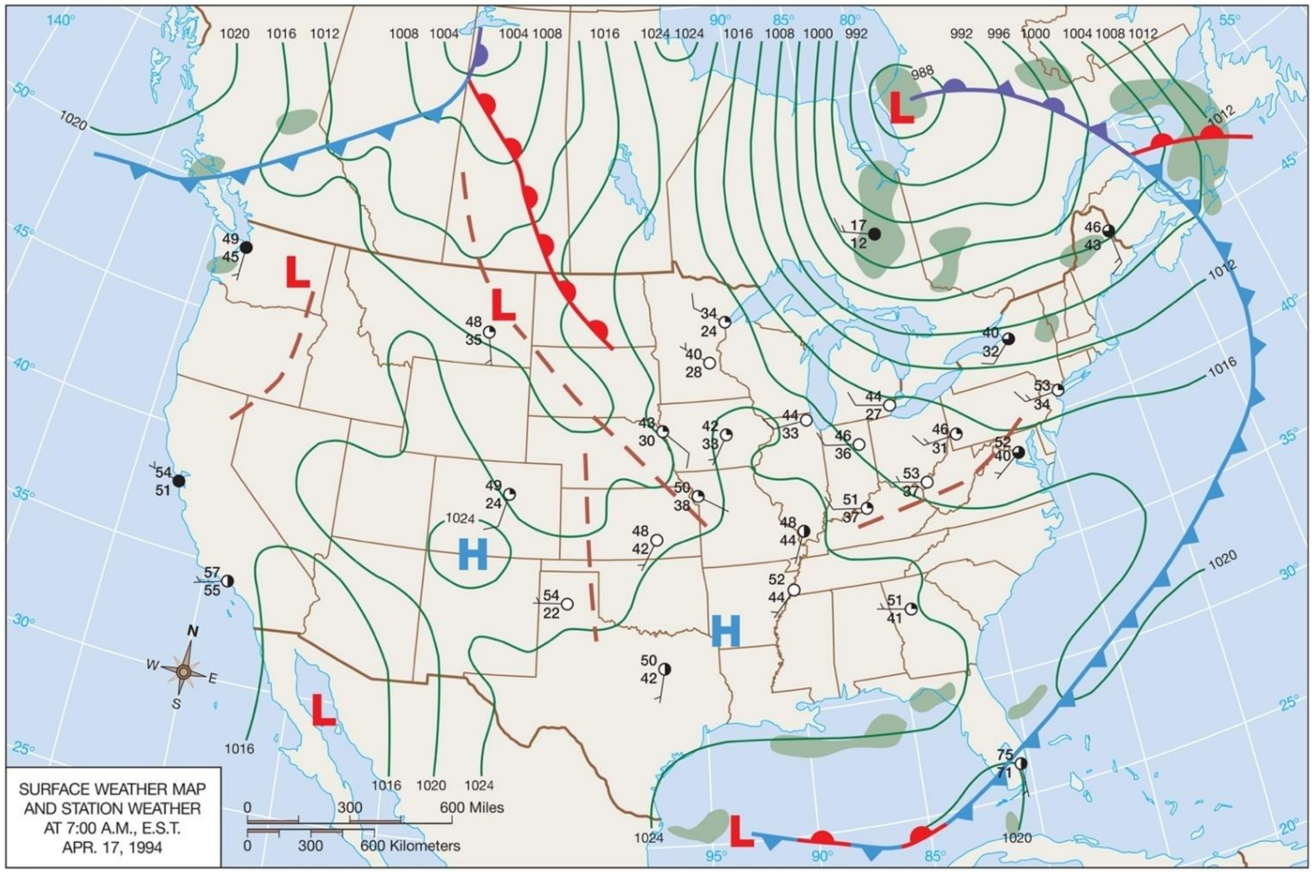


(a)

Surface Weather – Day 1



Surface Weather – Day 2



(a)

Surface Weather – Day 3

Potential Temperature

$$T = cons. \times P^k$$

$$k = R / c_p$$

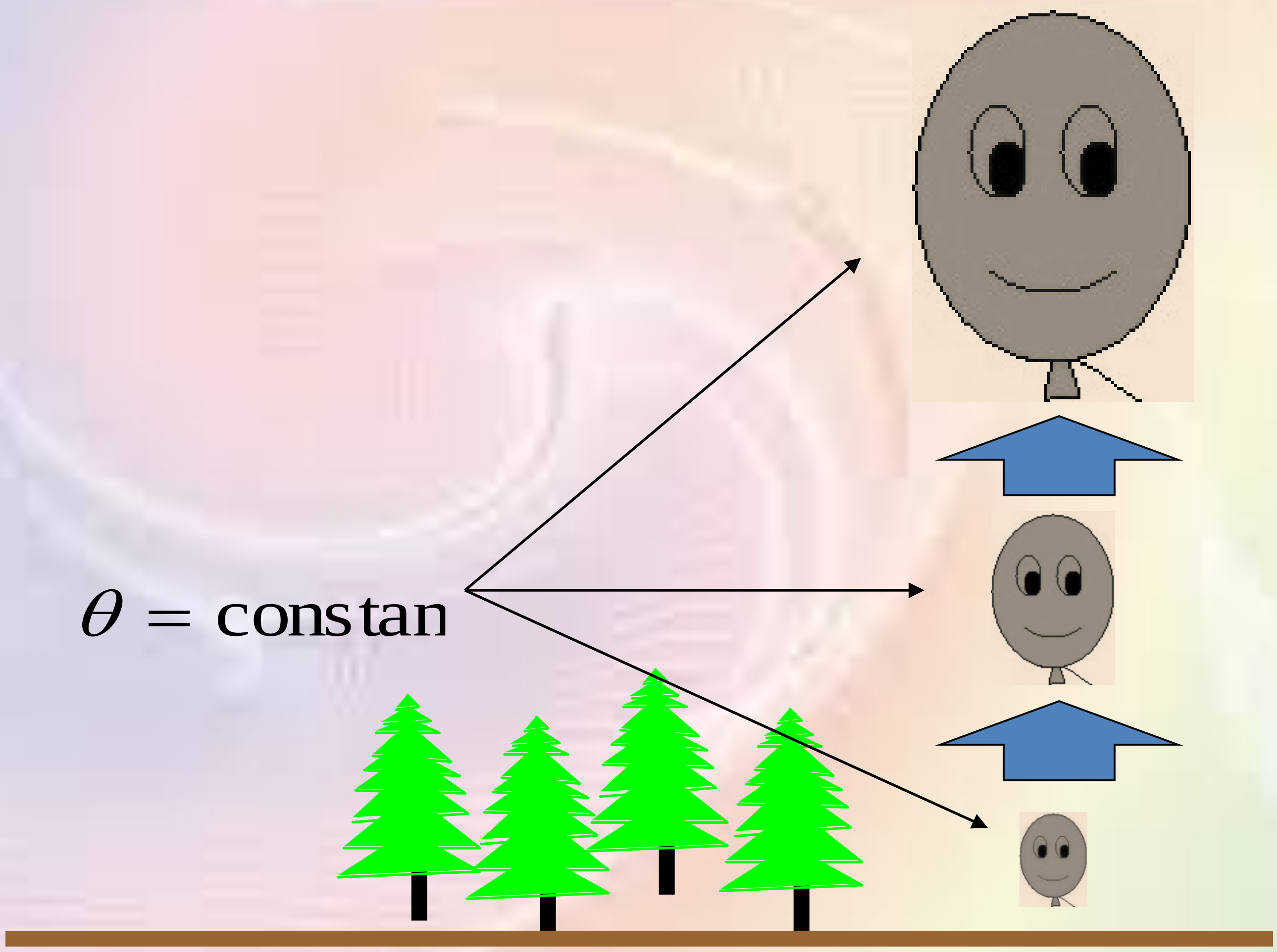
$$\frac{\theta}{1000^k} = \frac{T}{p^k} = cons.$$

$$\theta = T\left(\frac{1000}{p}\right)^k$$

Potential temperature, θ, is a conserved quantity in an adiabatic process.

The temperature a parcel would have if moved to the 1000 hPa level in a dry adiabatic process.

Potential temperature can act as a tag or air tracer



Kinematic Frontogenesis

Definition of Frontogenesi:s:

Frontogenesis refers to the change in the magnitude and orientation of the temperature gradient at a level or layer (e.g. 850 – 700 mb) due to the directional and speed changes in the wind field (e.g. convergence and divergence).

Increase in the horizontal thermal gradient with time

Frontolysis – simply defined as a decrease in the horizontal thermal gradient with time.

The kinematic processes that influence the strength of the potential temperature (θ) gradient as a function of time, called the Frontogenetic Function (F).

$$F = \frac{d}{dt}\left|\nabla \theta\right|$$

$$\mathcal{F} > 0 \longrightarrow \textit{Frontogenesis}$$

$$\mathcal{F} < 0 \longrightarrow \textit{Frontolysis}$$

Frontogenesis is a meteorological process of tightening of horizontal temperature gradients to produce fronts.

In the end, two types of fronts form: cold fronts and warm fronts.

A cold front is a narrow line where temperature decreases rapidly.

A warm front is a narrow line of warmer temperatures and essentially where much of the precipitation occurs.

$$F = \frac{d}{dt}\left|\nabla\theta\right|$$

the total derivative $\frac{d}{dt}$

Algebraically, this involves expanding the total derivative

$$\frac{d}{dt} = \frac{\partial}{\partial t} + u\frac{\partial}{\partial x} + v\frac{\partial}{\partial y} + w\frac{\partial}{\partial z} = \frac{\partial}{\partial t} + \vec{V}.\nabla$$

Where $\left|\nabla\theta\right|$ is the magnitude of the 3-D potential temperature gradient

expanding the term involving the magnitude of the gradient

$$\left|\nabla\theta\right| = \left[\left(\frac{\partial\theta}{\partial x}\right)^2 + \left(\frac{\partial\theta}{\partial y}\right)^2 + \left(\frac{\partial\theta}{\partial z}\right)^2\right]^{1/2}$$

$$F = \frac{d}{dt}\left|\nabla\theta\right|$$

implies that the change in the θ gradient is calculated following air-parcel motion

We shall first examine the kinematic effects whereby advection, shear, and local heating act to increase the density gradient.

Then, we will examine the dynamic effects whereby forces induced as a result of the kinematic changes produce circulations that can enhance the kinematic effects.

$$p\alpha = R_d T$$

$$P\frac{d\alpha}{dt} + \alpha\frac{dp}{dt} = R_d\,\frac{dT}{dt}$$

$$P\frac{d\alpha}{dt} + \alpha\frac{dP}{dt} = c_P\,\frac{dT}{dt} - c_V\,\frac{dT}{dt}$$

$$P\frac{d\alpha}{dt} + c_V\,\frac{dT}{dt} = c_p\,\frac{dT}{dt} - \alpha\frac{dp}{dt}$$

Since heating is manifest as a combination of expansion at constant temperature and increase of temperature at constant volume,

$$\frac{dQ}{dt} = c_p\,\frac{dT}{dt} - \alpha\frac{dp}{dt}$$

This is the first law of thermodynamics as applied to a parcel of air.

The processes by which a front forms or decays can be understood more directly by expanding the frontogenetical function

$$F = \frac{d}{dt}\left|\nabla \theta\right|$$

then using the thermodynamic equation

$$C_p \frac{dT}{dt} - \alpha \frac{dp}{dt} = \frac{dQ}{dt} \qquad \frac{C_p}{T}\frac{dT}{dt} - \frac{R}{P}\frac{dp}{dt} = \frac{1}{T}\frac{dQ}{dt}$$

$$C_p \frac{d\ln T}{dt} - R\frac{d\ln p}{dt} = \frac{1}{T}\frac{dQ}{dt} \qquad \frac{d\ln\theta}{dt} = \frac{d\ln T}{dt} - \frac{R}{c_P}\frac{d\ln P}{dt}$$

$$\frac{d\ln\theta}{dt} = \frac{1}{c_P T}\frac{dQ}{dt} \qquad \theta = T\left(\frac{P_0}{p}\right)^{R/C_P} \qquad \frac{d\theta}{dt} = \left(\frac{p_0}{p}\right)^k \frac{1}{c_p}\frac{dQ}{dt}$$

to replace the term $\frac{d\theta}{dt}$ in the resulting equation

There are eight mechanisms that influence temperature gradients

1- horizontal deformation,

2- horizontal shearing,

3- vertical deformation,

4- differential vertical motion,

5- latent heat release,

6- surface friction,

7- turbulence

8- radiation

Deformation is the rate of change of shape of fluid bodies

Semigeostrophic frontogenesis theory focuses on the role of horizontal deformation and shear.

Horizontal deformation in mid-latitude cyclones concentrates temperature gradients, cold air from the north and warm air from the south.

Horizontal shear has two effects on an air parcel; it tends to rotate the parcel (think of placing a wheel at a point in space and as the wind blows, the wheel rotates) and deform the parcel through stretching and shrinking.

Within a mid-latitude cyclone, these two key features play an essential role in frontogenesis.

Four factors which can effect the horizontal thermal gradient resulting in frontogenesis or frontolysis. (Several flow patterns are characteristic of large deformation)

1-Shear

2-Confluence/Difluence

3-Tilting

4- Diabatic Heating

Confluence, also known as stretching, is the elongating of a fluid body along the flow (streamline convergence).

Diffluence, also known as shearing, is the elongating of a fluid body normal to the flow (streamline divergence).

Streamlines are lines that are everywhere parallel to the velocity vectors at a fixed time.

They consider the direction of the velocity but not the speed.

Streamlines generally change from one time to the next, giving us "snapshots" of the motion of air parcels.

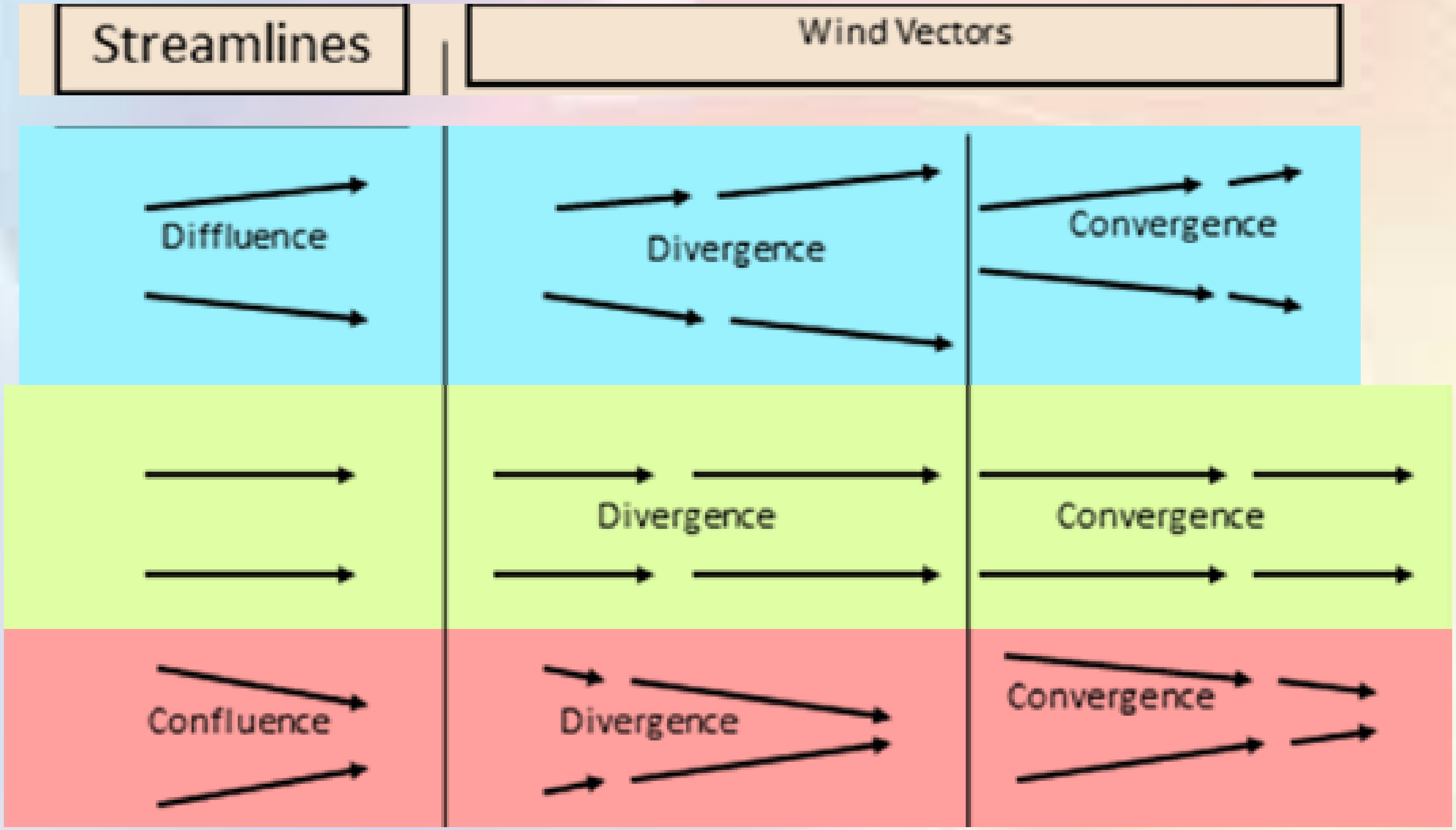
For maps of wind observations for a fixed time, we often look at streamlines.

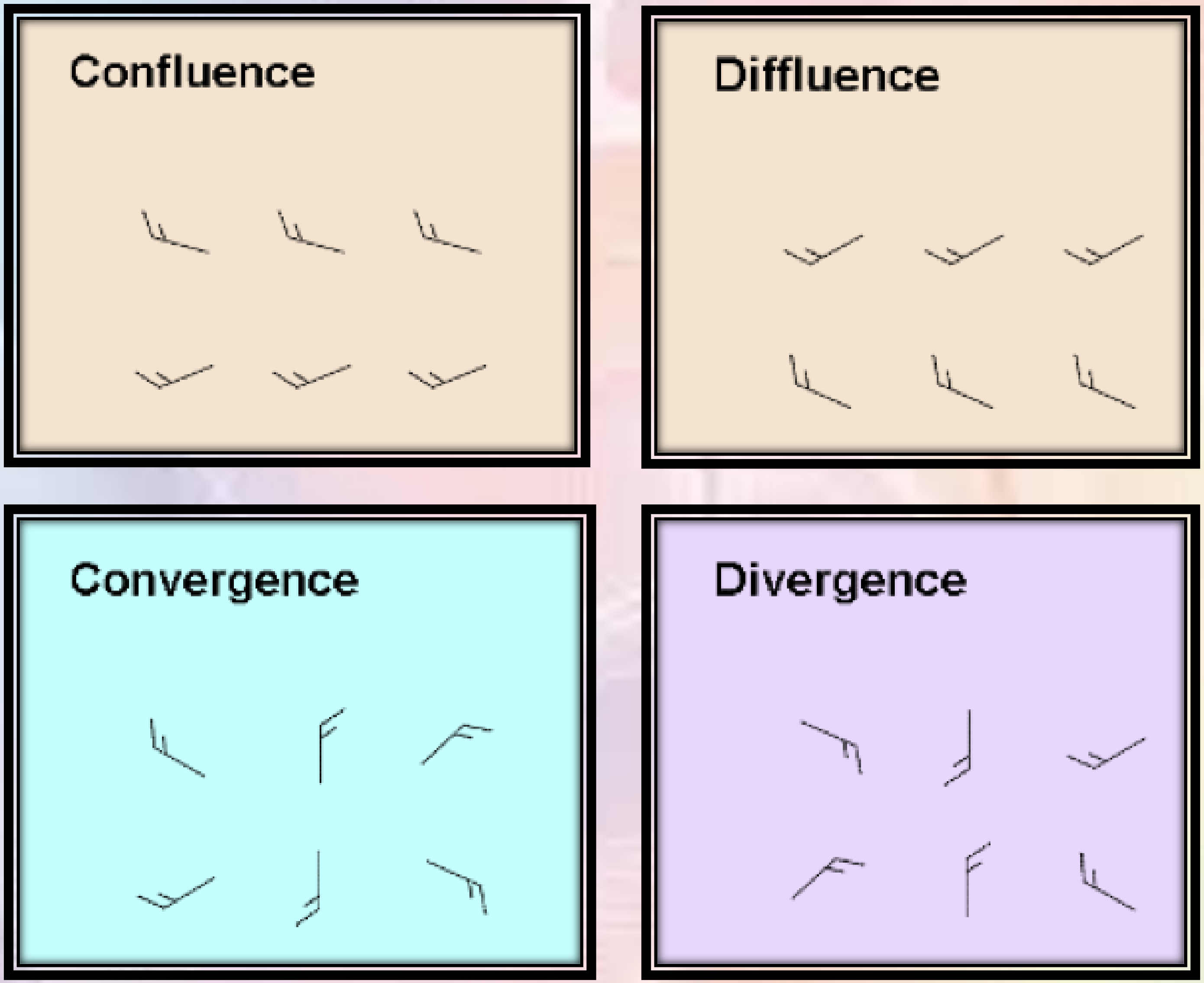
On a map of streamlines, you will see that the lines aren't always straight and don't always have the same spacing.

Confluence is when streamlines come together.

Diffluence is when they move apart.

Confluence/Diffluence and Convergence/Divergence




Confluence
Diffluence
Convergence
Divergence

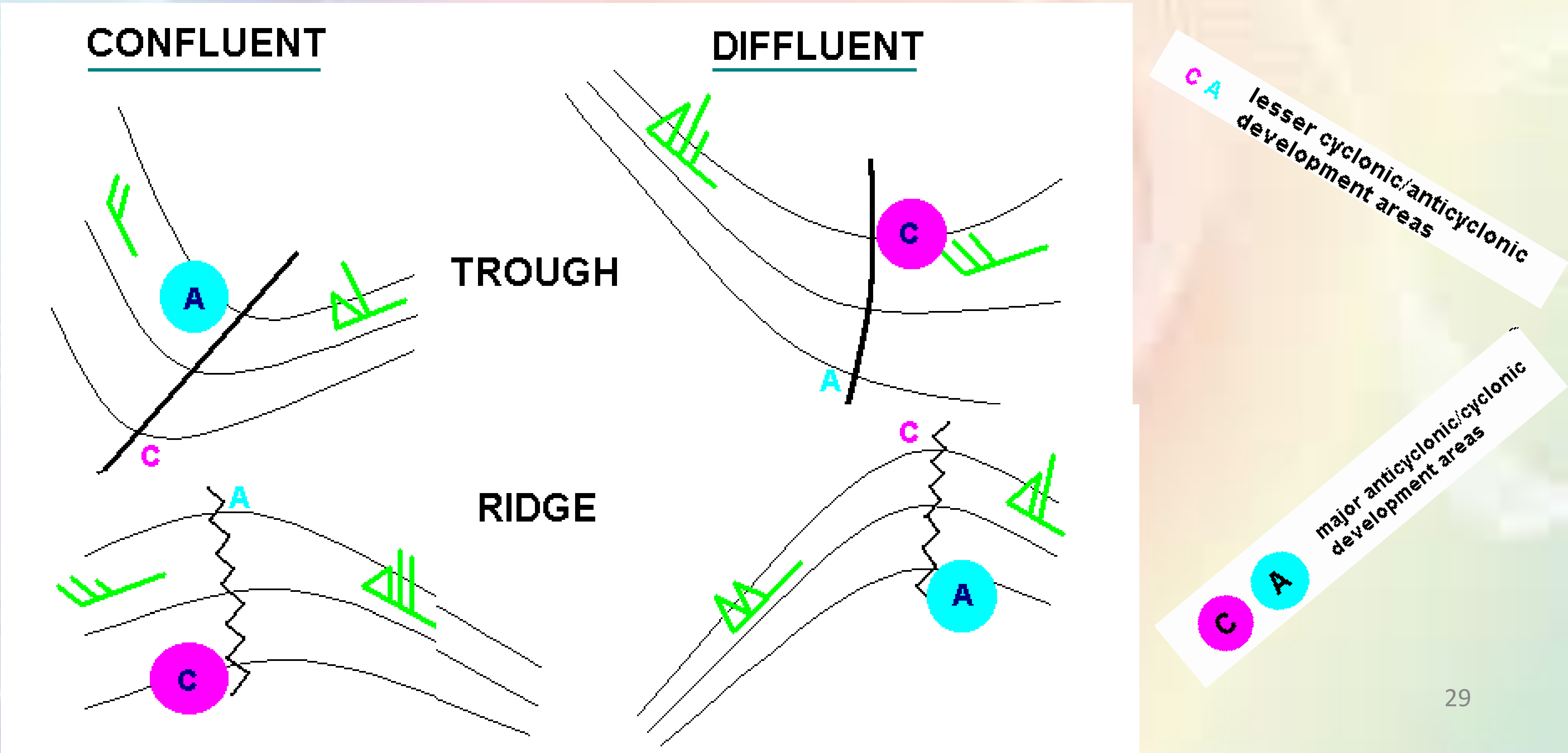
The shape of the trough/ridge is also important

diffluent: Air slows down on leaving the trough compared to entry.

confluent: Air speeds up on leaving the trough compared to entry.

diffluent: Air slows down on exit from the ridge compared to entry.

confluent: Air speeds up on exit from the ridge compared to entry.



Factors Causing Frontogenesis/Frontolysis

$$F = \frac{d}{dt}\left|\nabla\theta\right| = \text{Shear} + \text{Confluence/Difluence} + \text{Tilting} + \text{Diabatic Heating}$$

$$F = \frac{d}{dt}\left|\nabla\theta\right| = \frac{\partial}{\partial t}\left|\nabla\theta\right| + \vec{V}.\nabla\left(\left|\nabla\theta\right|\right)$$

$$\left|\nabla\theta\right| = \left[\left(\frac{\partial\theta}{\partial x}\right)^2 + \left(\frac{\partial\theta}{\partial y}\right)^2 + \left(\frac{\partial\theta}{\partial z}\right)^2\right]^{1/2}$$

$$\frac{d\theta}{dt} = \left(\frac{p_0}{p}\right)^k \frac{1}{c_p}\frac{dQ}{dt}$$