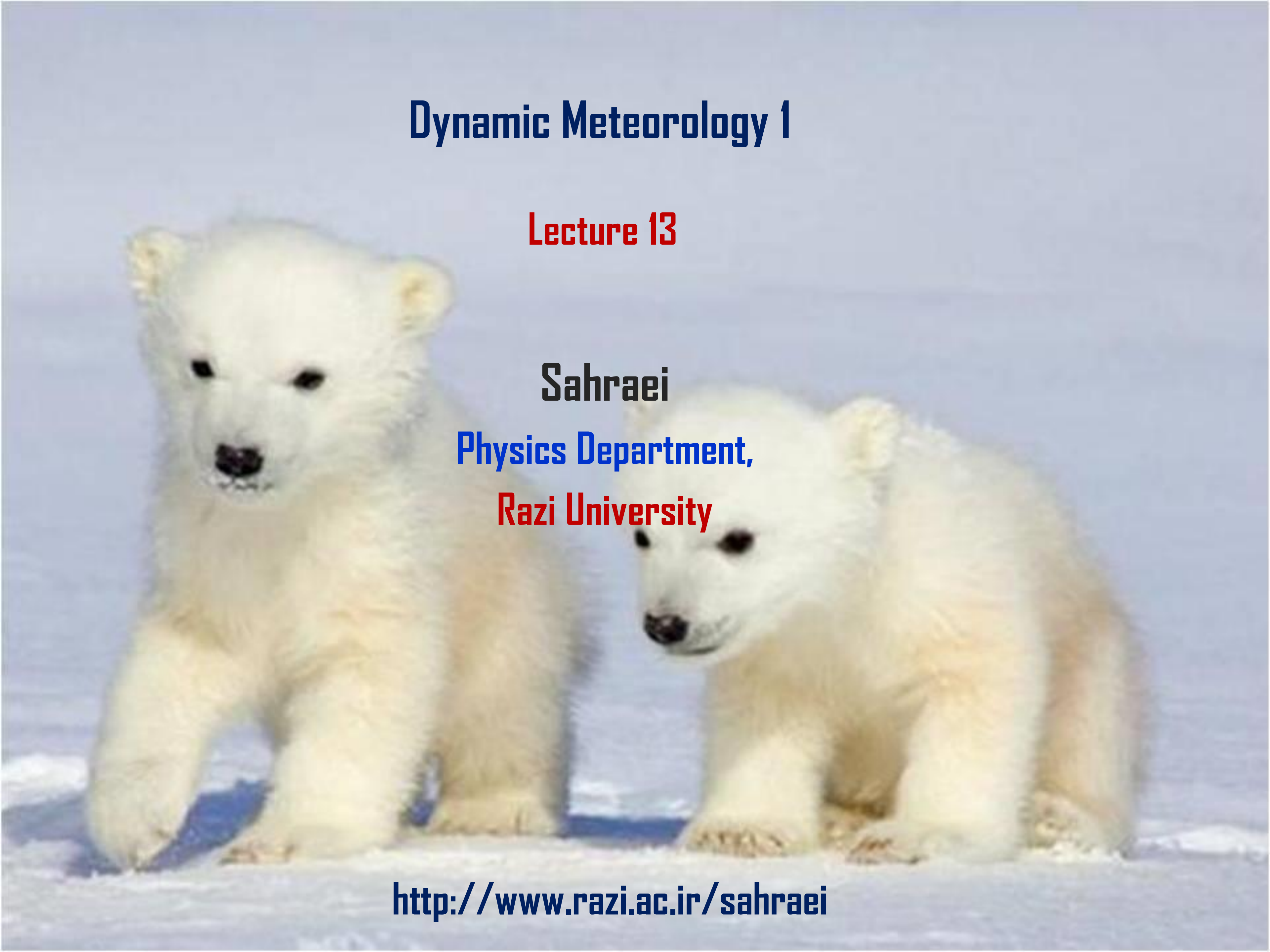

Dynamic Meteorology 1

Lecture 13

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Cyclostrophic Flow شارش چرخگرد

If the horizontal scale of a disturbance is small enough, the coriolis force may be neglected;

$$\frac{V^2}{R} + \cancel{fV} = -\frac{\partial \Phi}{\partial n}$$

This balance is between to the pressure gradient force and the centrifugal force.

If this equation is solved for V, we obtain the speed of the cyclostrophic wind:

$$V = \left(-R\frac{\partial \Phi}{\partial n} \right)^{1/2}$$

With the balance between the pressure gradient force in the n equation of motion and the centrifugal force, this constricts the possible types of flow to two types.

The flow can be either cyclonic or anti-cyclonic with a circular motion as a result of the centrifugal force.

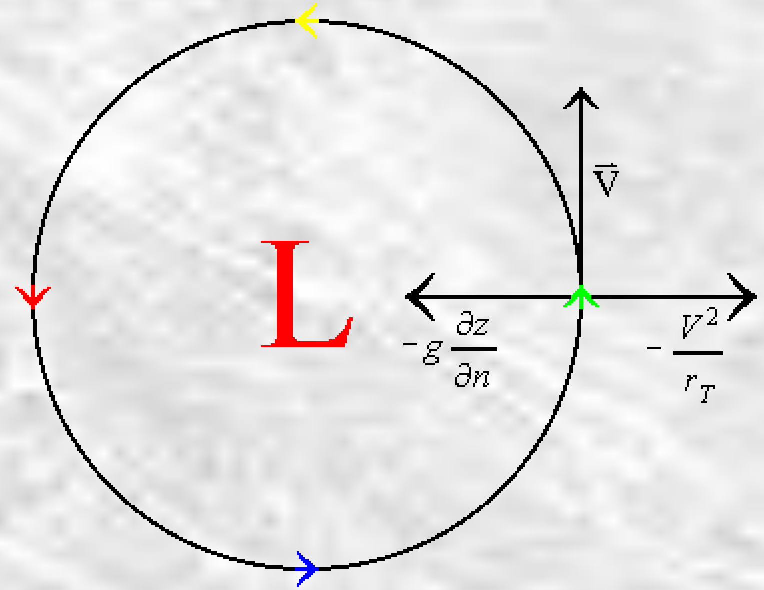
However, the pressure gradient force always points inward, making the center of circulation an area of low pressure.
Since only two forces are considered, there are certain assumptions the also have to be made.

The flow must be frictionless, always parallel to the height contours, and the scale of the flow is either small in scale or near the equator, where the coriolis force is essentially zero.
The following picture illustrates cyclostrophic flow:

Cyclonic Flow **شارش چرخندی**

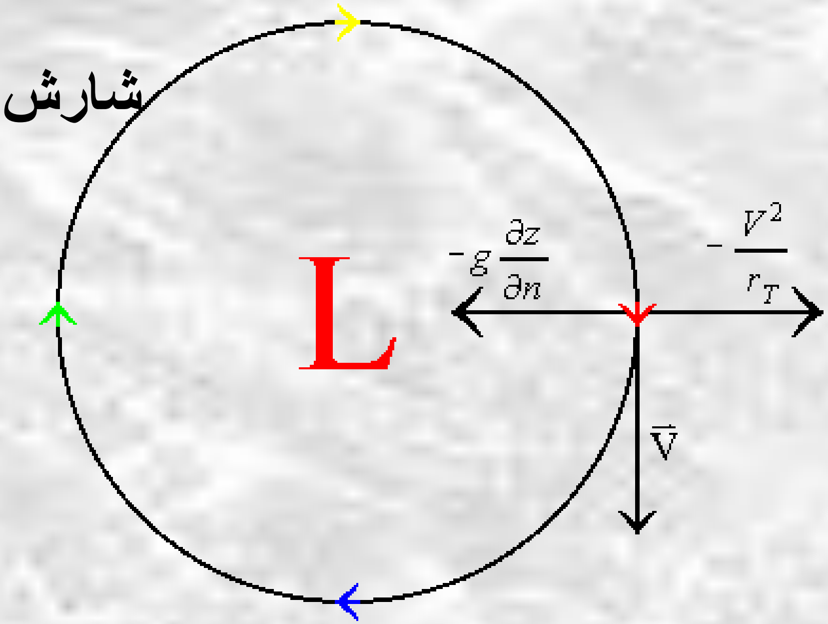
$$R > 0 \quad \frac{\partial \Phi}{\partial n} < 0 \rightarrow$$

$$\rightarrow R\frac{\partial \Phi}{\partial n} < 0 \Rightarrow V > 0$$



Anticyclonic Flow **شارش واچرخندی**

$$R < 0 \quad \frac{\partial \Phi}{\partial n} > 0$$



When we assume that a flow is cyclostrophic in nature, the coriolis force is defined as being zero.

Therefore, a method must exist to determine if the coriolis force can be neglected.

If the ratio of the centrifugal force to the coriolis force is large, then the cyclostrophic assumption can be made.

This ratio, called the *Rossby* number is defined below:

$$R_0 = \frac{V^2 / R}{fV} = \frac{V}{fR}$$

There are some real world applications to cyclostrophic flow.

Small scale circulations, such as tornados, waterspouts, and dust devils are small enough so that the coriolis force can be neglected.

For large-scale motion the pressure gradient force and the Coriolis force are an order of magnitude larger than the other terms, hence the geostrophic balance.
Other balances are conceivable though (**Table**).

All of them yield a *steady flow*, i.e. locally the wind speed nor the wind direction change.

In other words, the local acceleration is zero. The advection of horizontal momentum can be thought of, in coordinates following the flow, as a centrifugal force.

balance	friction	Coriolis force	pressure gradient force	centrifugal force
geostrophic		√	√	
cyclostrophic			√	√
inertial		√		√
antitriptic	√		√	

Antitriptic balance

A coastal sea breeze reaches its typical strength around noon and continues to blow at about the same speed for several hours.

Under a steady onshore pressure gradient force which is due to the temperature gradient, the sea breeze should continue to gain strength.

The main force opposing this pressure gradient force is surface friction. This balance is known as 'antitriptic'. Density currents, such as shallow outflows of cooler air from a mature thunderstorm, are largely antitriptically balanced.

The Gradient Wind Approximation
تقریب باد گرادیان

شرایط باد زمینگرد:

الف) فقط افقی باشد – ب) شتاب افقی صفر باشد- ج) اصطکاک صفر باشد.

شرایط باد گرادیان:

الف) فقط افقی باشد – ب) شتاب مماسی صفر باشد- ج) شتاب شعاعی صفر نیست د) اصطکاک صفر باشد.

$$\frac{V^2}{R} + fV = -\frac{\partial \Phi}{\partial n}$$

معادله باد گرادیان

$$V = -\frac{fR}{2} \pm \left(\frac{f^2 R^2}{4} - R\frac{\partial \Phi}{\partial n} \right)^{1/2}$$

In order to understand the possibilities, it is necessary to study the gradient wind equation more in depth.

In the denominator of the gradient wind equation, there is a positive root and a negative root.

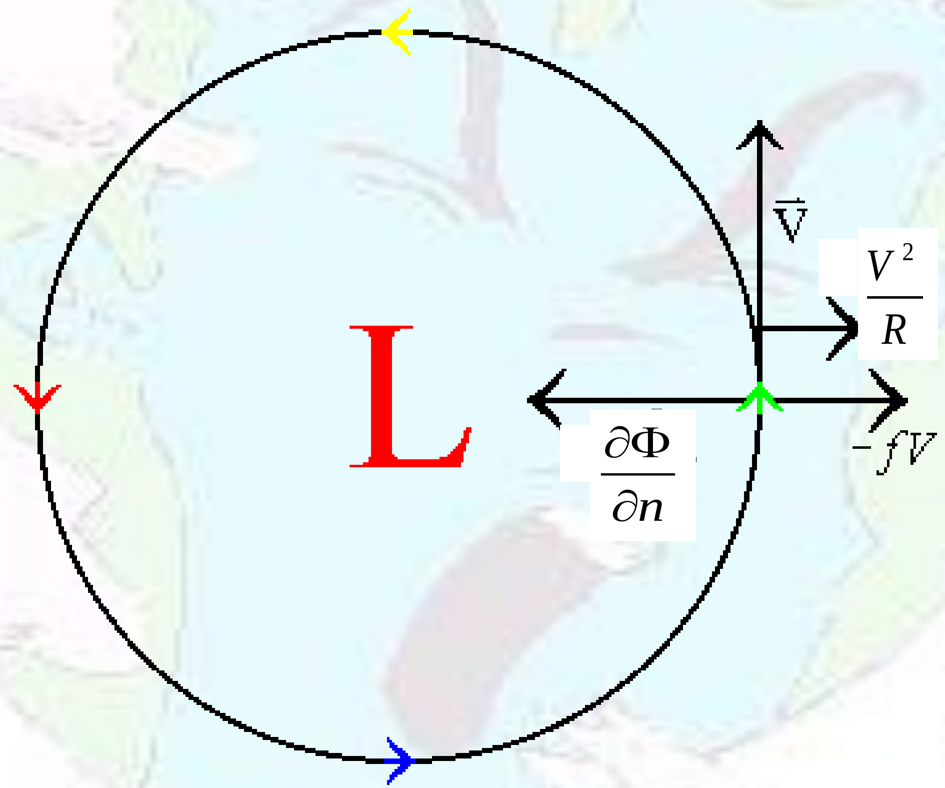
Mathematically, there are only four possible solutions that can be computed.

The table below illustrates these four possibilites:

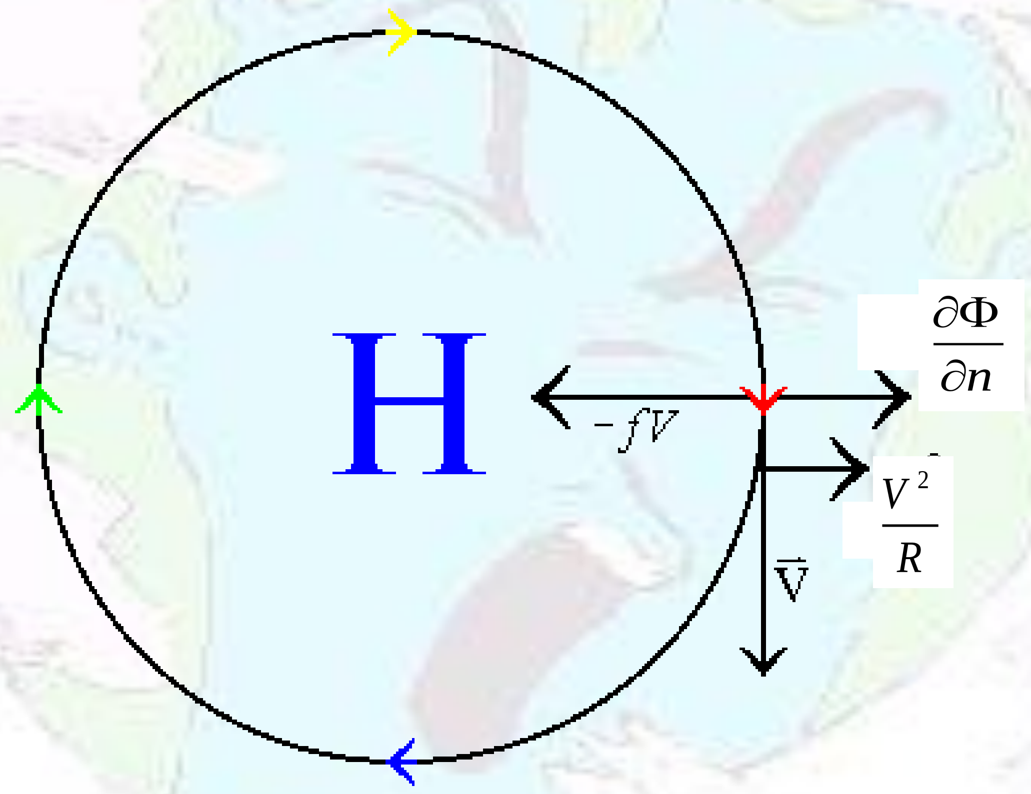
Classification of Roots of the Gradient Wind Equation in the Northern Hemisphere

Sign $\partial\Phi / \partial n$	R>0	R<0
Positive	Δ + $\rightarrow$ V < 0 unphysical	Δ + $\rightarrow$ V > 0: antibaric flow (anomalous low)
	Δ - $\rightarrow$ V < 0 unphysical	Δ - $\rightarrow$ V < 0 unphysical
Negative	Δ + $\rightarrow$ V > 0 (regular low)	Δ + $\rightarrow$ V > 0 ($V > -fR/2$); anticyclonic flow (anomalous high)
	Δ - $\rightarrow$ V < 0 unphysical	Δ - $\rightarrow$ V > 0 ($V < -fR/2$): Anticyclonic flow (regular high)

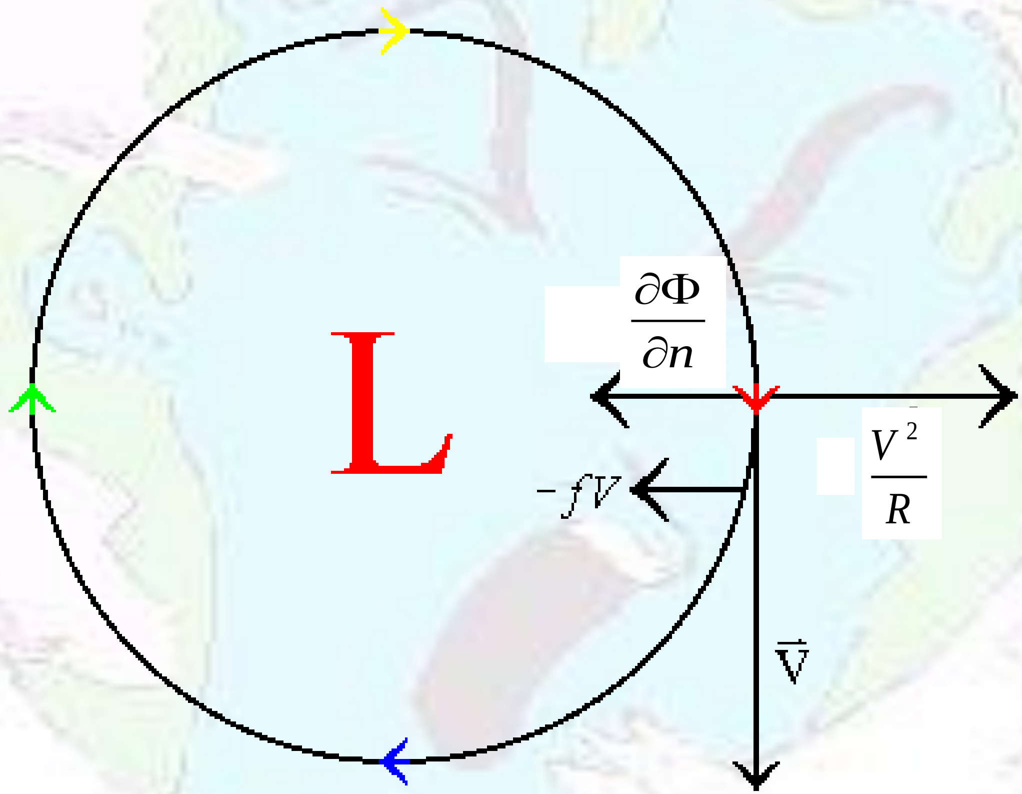
Normal Low Pressure System



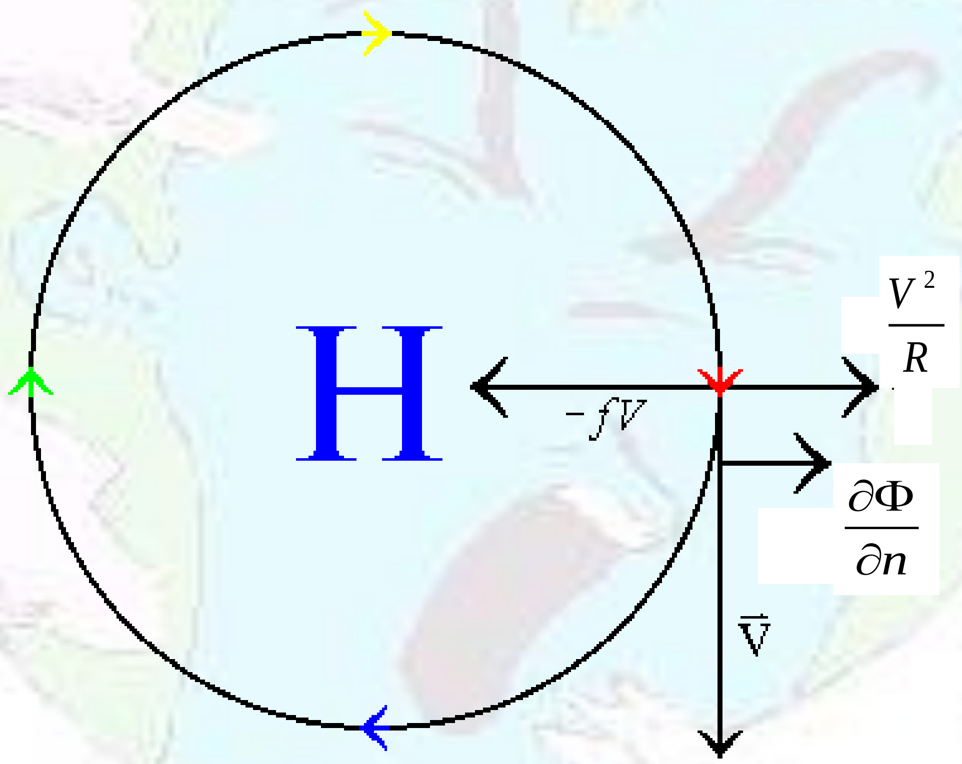
Normal High Pressure System



Anomalous Low Pressure System



Anomalous High Pressure System



In the cases of the normal high and normal low, the flow is ***baric***, meaning that the coriolis force and the pressure gradient force are in opposite directions of one another.

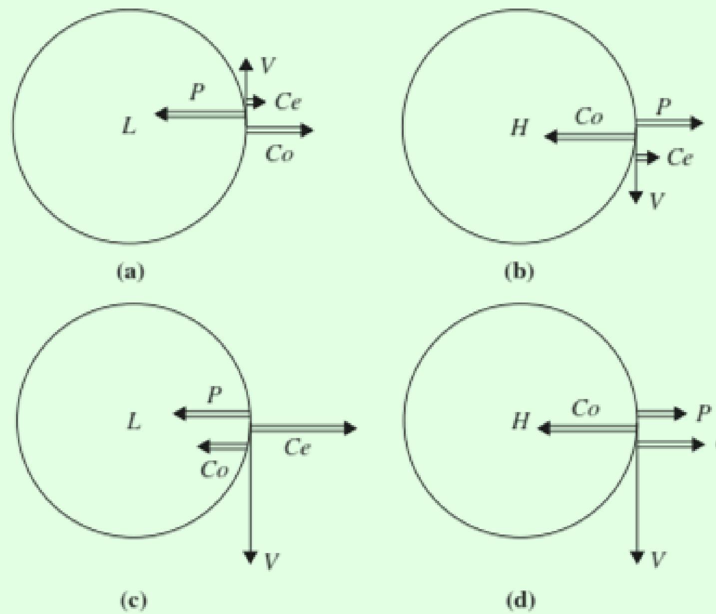


FIGURE 3.5 Force balances in the Northern Hemisphere for the four types of gradient flow: (a) regular low, (b) regular high, (c) anomalous low, and (d) anomalous high.