

11. Baroclinic Instability and Cyclogenesis

11.1 Concept of Baroclinic Instability

Two major problems in extratropical large-scale dynamics are: (A) frontogenesis, (B) cyclogenesis.

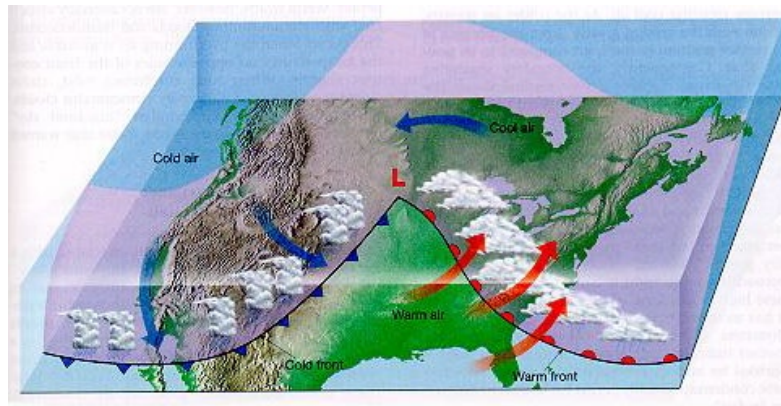
(A) Frontogenesis

- *Bjerknes polar front model*

(http://apollo.lsc.vsc.edu/classes/met130/notes/chapter12/polar_front_schema.html)

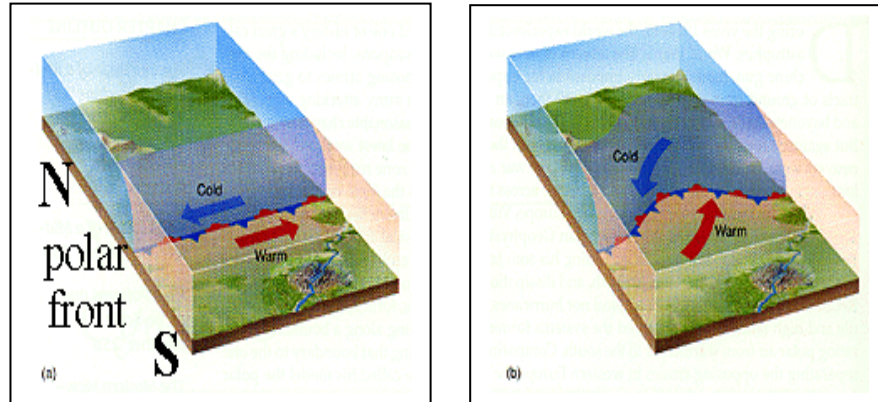
Fronts are boundaries between contrasting air masses.

- If an air mass is warmer than the other, it is more buoyant.
- When two air masses meet the warmer, the more buoyant (warmer) air mass will be uplifted relative to the colder, denser air mass.
- If the cold (warm) air mass is advancing against warm (cold) air mass, it is called **cold (warm) front**.



***Polar Front Theory* - Development and Evolution of a Wave Cyclone**

- (a) A **frontal wave** develops along a **polar front**. When a large temperature gradient exists across the polar front - the atmosphere contains a large amount of **Available Potential Energy**.

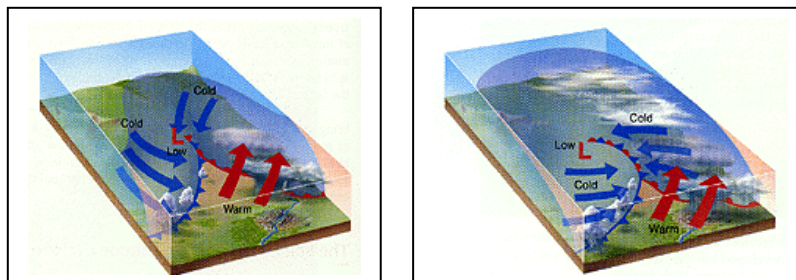


(From Aguado and Burt, 1999, Understanding Weather and Climate, Prentice-Hall, Inc)

- (b) The polar front develops when an instability occurs, **which converts available potential energy to kinetic energy**. This polar front is an incipient cyclone.

- (c) A fully-developed "**wave cyclone**" is seen 12-24 hours from its inception. It consists of:

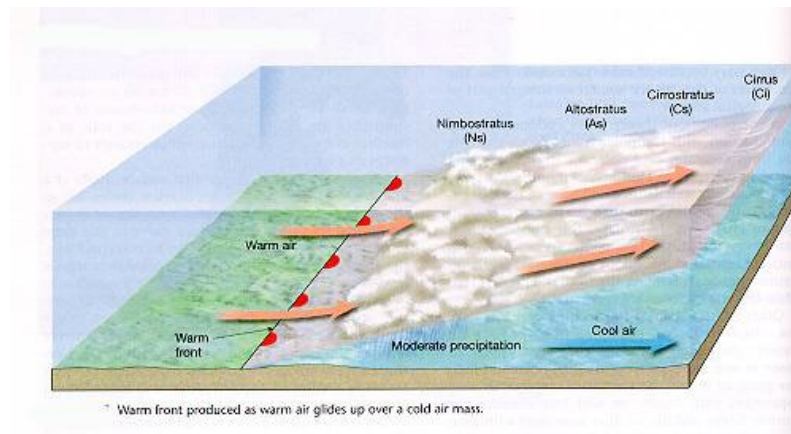
- A warm front moving to the northeast & a cold front moving to the southeast. There is a **warm sector** formed between warm and cold fronts.
- The low is deepening with time, while the cold air surges southward behind the cold front and the warm air overruns over the warm front.
- There is wide-spread precipitation ahead of the warm front and narrow band of precipitation along the cold front.
- Wind speeds continue to get stronger as the low deepens - **the KE is converted from the Available Potential Energy (APE), i.e. baroclinic instability occurs**.
- The production of clouds and precipitation are also being strengthened by the latent heat released.



(d) As the cold front moves swiftly eastward, the system starts to occlude.

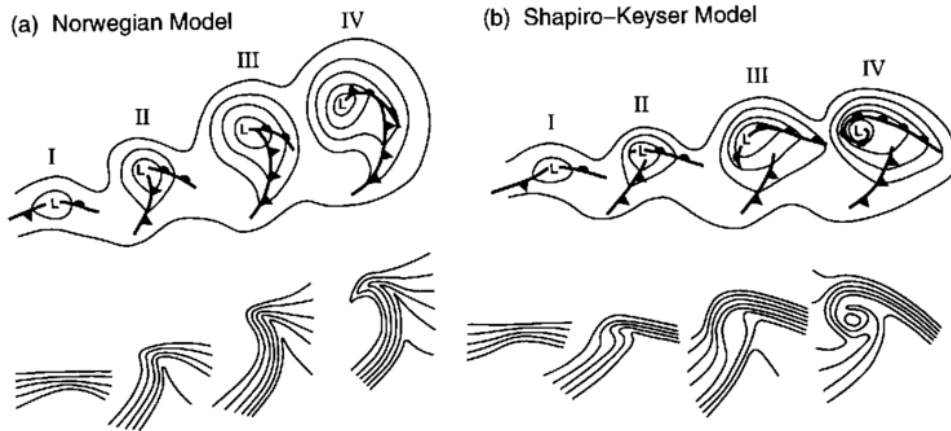
- Storm is most intense at this stage, which has an occluded front trailing out from the surface low.
- An occlusion, where the cold, warm and occluded fronts all intersect, often occurs.

Warm Fronts have broader, less steep slopes



(B) Cyclogenesis

- [Norwegian Cyclone Model](http://en.wikipedia.org/wiki/Norwegian_cyclone_model) (Bjerknes 1951)
(http://en.wikipedia.org/wiki/Norwegian_cyclone_model)

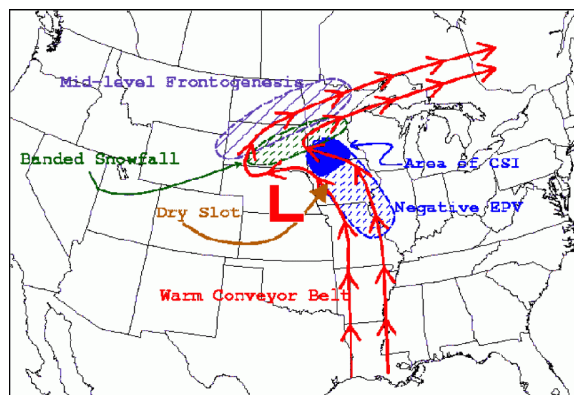


The older of the models of [extratropical cyclone](#) development is known as the [Norwegian Cyclone Model](#), developed during and shortly after World War I within the [Bergen School of Meteorology](#).

In this theory, [cyclones develop](#) as they move up and along a frontal boundary, eventually [occluding](#) and reaching a [barotropically cold environment](#).^[1]

It was [developed completely](#) from [surface-based weather observations](#), including descriptions of clouds found near frontal boundaries.

Developed from this (Norwegian) model was the concept of the [warm conveyor belt](#), which [transports warm and moist air](#) just ahead of the [cold front](#) above the surface warm front.



- Progresses in the development of theories

- Sutcliffe development theory (Q. J. 1947)

Describe development in terms of vertical distribution of divergence.

Cyclogenesis has to be accompanied by low-level convergence and upper-level divergence (see Carlson, p. 182). This also has established the foundation of NWP.

- Baroclinic instability theories

- Eady model (1949): on f -plane, vertically confined by surface and a rigid tropopause

- Charney model (JAS 1947): on β -plane, semi-infinite atmosphere.

- Hoskins and Bretherton's semi-geostrophic model (1975 JAS)

- Development of a Baroclinic Cyclone

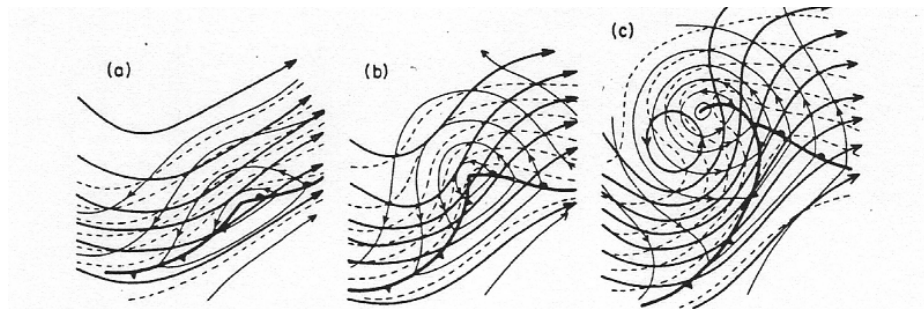
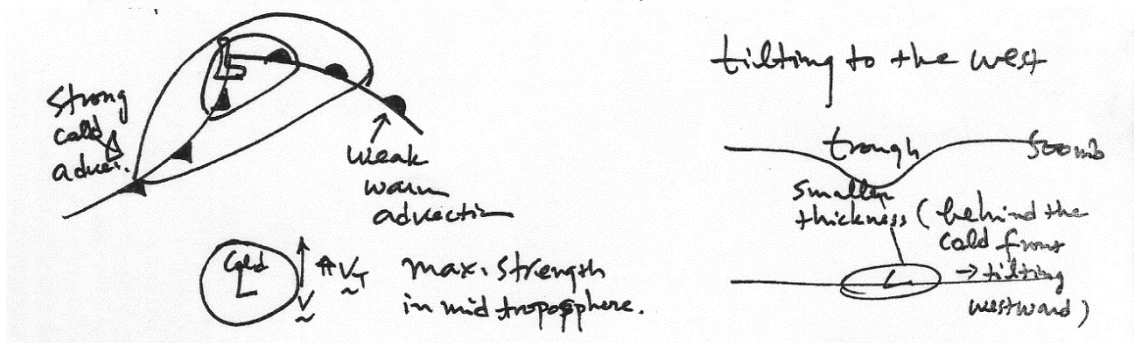
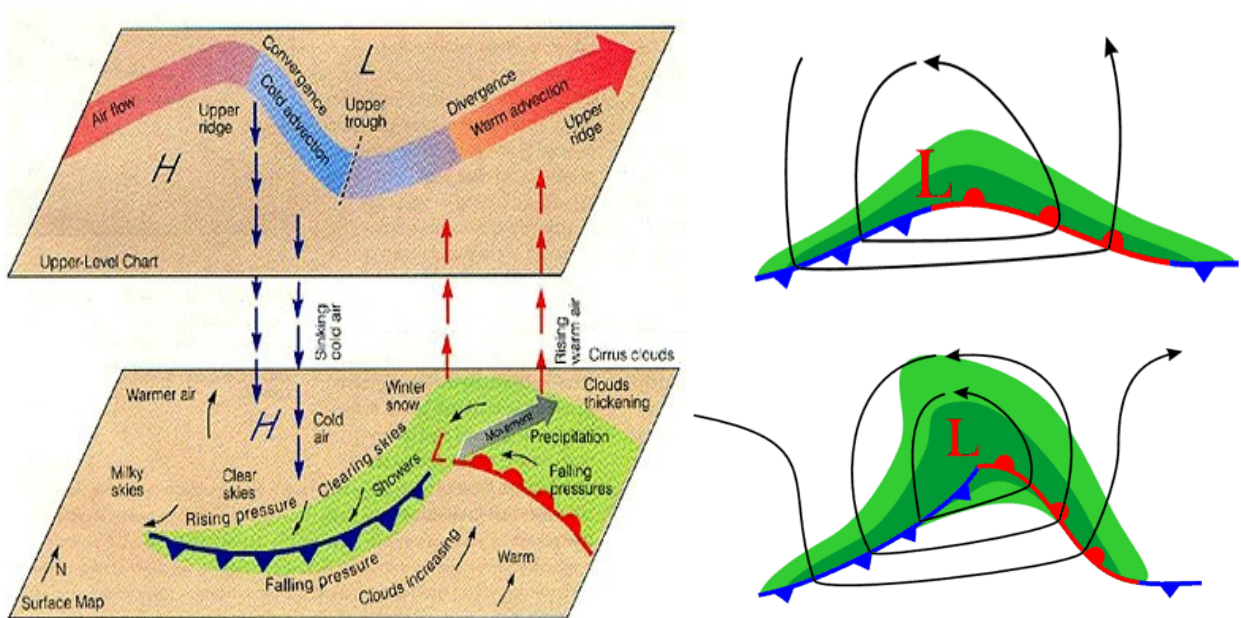
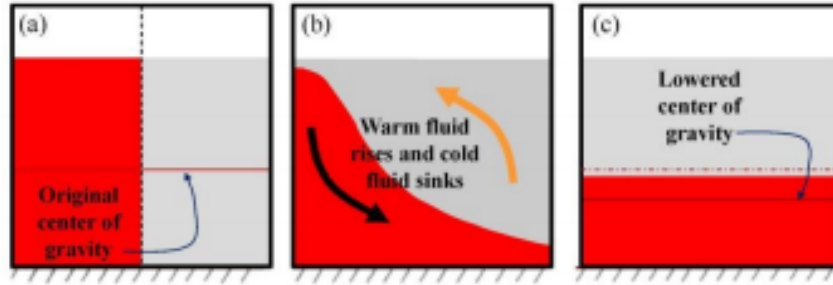


Fig. 6.5 Schematic 500-mb contours (heavy solid lines), 1000-mb contours (thin lines), and 1000-500-mb thickness (dashed) for a developing baroclinic wave at three stages of development. (After Palmén and Newton, 1969.)

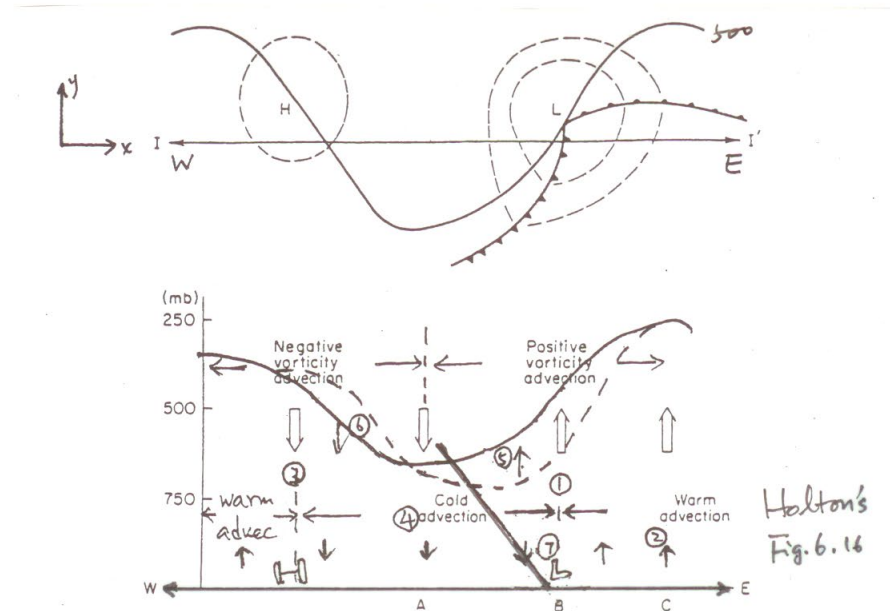


- Baroclinic Instability and Cyclogenesis

Available Potential Energy (APE) => Kinetic Energy (KE)



11.2 Idealized Model of Cyclogenesis



A. Based on ω equation [simple form: $w \propto \frac{\partial}{\partial z} (-V_g \cdot \nabla \zeta_g) - V_g \cdot \nabla T$]

- (1) & (5): PVA at 500mb \rightarrow Positive differential VA $\rightarrow w > 0$.
- (2): Warm advection $\rightarrow w > 0$.
- (3) & (6): NVA at 500mb \rightarrow Negative differential VA $\rightarrow w < 0$.
- (4): Cold advection $\rightarrow w < 0$.

B. Based on χ equation [simple form: $-\chi \propto -V_g \cdot \nabla \zeta_g + \frac{\partial}{\partial z} (-V_g \cdot \nabla T)$]

- (5): Ahead of 500 mb trough \rightarrow PVA $\rightarrow \phi \downarrow$ and
cold advection near surface $\rightarrow \frac{\partial}{\partial z} (-V_g \cdot \nabla T) > 0 \rightarrow \phi \downarrow$.
- (6): Ahead of 500mb ridge \rightarrow NVA $\rightarrow \phi \uparrow$ and
cold advection near surface $\rightarrow \frac{\partial}{\partial z} (-V_g \cdot \nabla T) > 0 \rightarrow \phi \downarrow$. $\phi?$

C. Development of the surface low

- (7): (i) Overall $w > 0$ creates surface convergence \rightarrow spin up surface positive vorticity \rightarrow low deepens.
(ii) 500 mb vorticity strengthens due to PVA \rightarrow coupled with surface low.