

Comments on Wave Cyclone Model

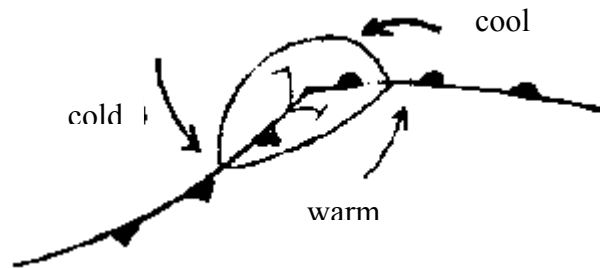
Assigned reading: Wallace and Hobbs, p. 126-128; 254-261

General reference: Palmen and Newton, Atmospheric Circulation Systems, 1969, Academic Press, 603 pp.

Atmospheric cyclogenesis can be described in many ways, from purely descriptive, “1004” treatments to sophisticated mathematical theories involving instabilities and non-linear wave interactions. The following discussion will be primarily descriptive but will refer to concepts in quasi-geostrophic theory. This handout is an attempt to modify the classical wave cyclone model to fit more recent ideas and observations.

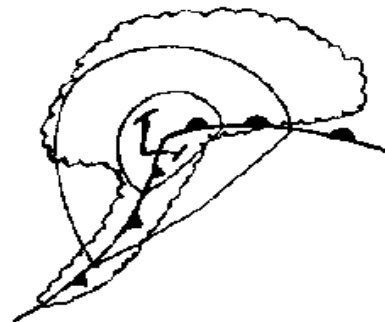
1. Initial development along a pre-existing baroclinic zone

The classical model has the low developing on a pre-existing front but this is not always true. At any rate, upper-level processes are responsible for the initial (and subsequent) surface pressure falls. There is usually an upper-level trough (positively vorticity center) upstream from the location of the incipient cyclone. Pressure falls are caused by “upper-level divergence” downstream from the trough line. This upper divergence is most likely associated with low-tropospheric warm advection and/or mid-to-upper tropospheric cyclonic vorticity advection. As surface pressures fall, the winds respond geostrophically, and a cyclonic circulation begins. This circulation acts to move the fronts and a “wave” appears.



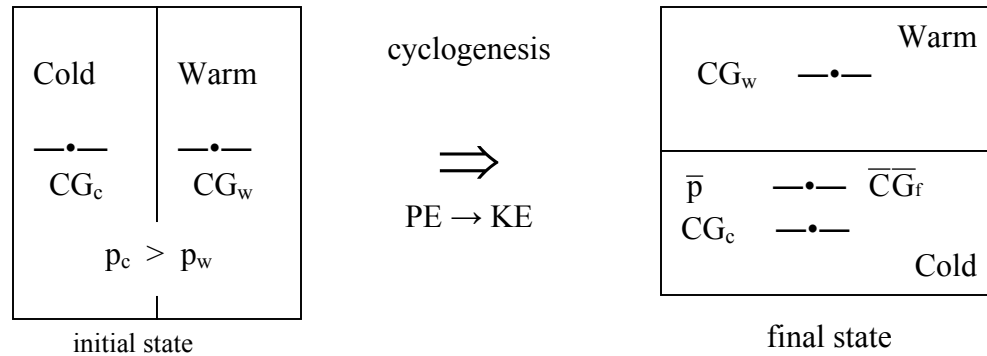
2. Young wave cyclone

As cold air moves equatorward and warm air poleward, air ascends along the frontal surfaces and clouds and precipitation occur. The beginning of the “comma-cloud” pattern appears on satellite imagery.



We shall briefly mention here the energy

source for extratropical cyclones. Consider two columns of air, one cold (with density ρ_c) and one warm (ρ_w). If the columns are the same depth, their center of gravities are at the same level (but surface pressure is much higher under the cold air).



Now if a cyclone initiates an adiabatic re-distribution of these air masses, the cold air flows towards the surface behind the cold front and the warm air ascends over the warm front. The idealized final state, which is shown in the diagram above, will have the warm air overlying the cold air and a new center of gravity lower than the original one. Thus we say that potential energy (PE) has been converted to the kinetic energy (KE) of the cyclone. Therefore it is the warm air rising and cold air sinking which is the energy source for wave cyclones. Latent heat release may contribute additional energy to wave cyclones, especially for explosively developing storms over oceans.

3. Occlusion process

An occlusion is said to occur because the cold air behind the cold front advances faster than the cool air recedes ahead of the warm front; hence the cold front “catches up” to the warm front and lifts the warm sector air aloft. It is probably more correct to say that as the upstream, upper-level vorticity center develops, the forcing for surface pressure falls becomes larger in the cold air away from the warm sector. This is associated with the increased vertical development of the low and the decrease in vertical tilt or slope of the system. The cyclone is experiencing its most rapid deepening during the occlusion stage and reaches maximum intensity shortly afterwards.

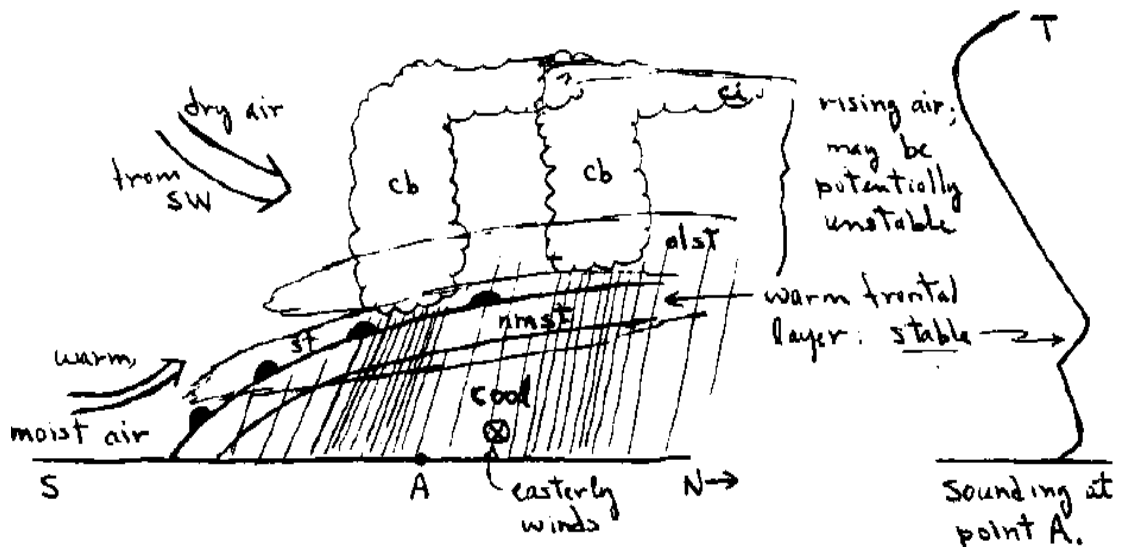
4. Dying or filling stage

The intensification of a cyclone is often called a self-development process because as the surface low responds to upper-level forcing, the low deepens, the circulation increases, cold and warm advection increase, vertical motions increase, upper-level divergence increases and so on. But self-limiting processes are at work also. As the low occludes and becomes more circular and vertical, the amount of cyclonic vorticity advection decreases. In addition, the cyclone

becomes surrounded by cold air which is harder to lift; i.e., - the low becomes more stably stratified. (Also, lifting of cold air converts K.E. to P.E.). Deprived of its energy source, the low is ultimately destroyed by surface friction (“spin-down”). A more complete and consistent treatment of cyclogenesis in terms of quasi-geostrophic theory will be presented later.

There are two final important points to make. One is that no two storms are alike and none follow the idealized scenario exactly. Thus while an understanding of their general structure and dynamics is important, each storm has to be dealt with individually. Second, the primary reason for point one is the different mesoscale structure within each cyclone. Since it is this structure which is partially responsible for the precipitation distribution around the storm, the idealized models have to be modified by what the radar, satellite and other mesoscale data sets are showing.

As an example, consider the precipitation structure north of the warm front. Although this is where steady precipitation classically occurs, observations show that it is quite intermittent in nature. The diagram below, though, suggests that this is quite logical in view of the air streams that interact here. The air below the warm front is cool and stable. The lapse rate above the warm front where the air is rising is much steeper and near moist-adiabatic.



The dry tongue from the southwest may bring in mid-tropospheric dry air, creating potential instability and the likelihood of embedded convection. Even in potentially stable air, mesoscale bands may form due to moist symmetric instability (slantwise convection) if the vertical shear is favorably aligned. These and other possible mechanisms reinforce the point that we cannot ignore the mesoscale structure in wave cyclones.

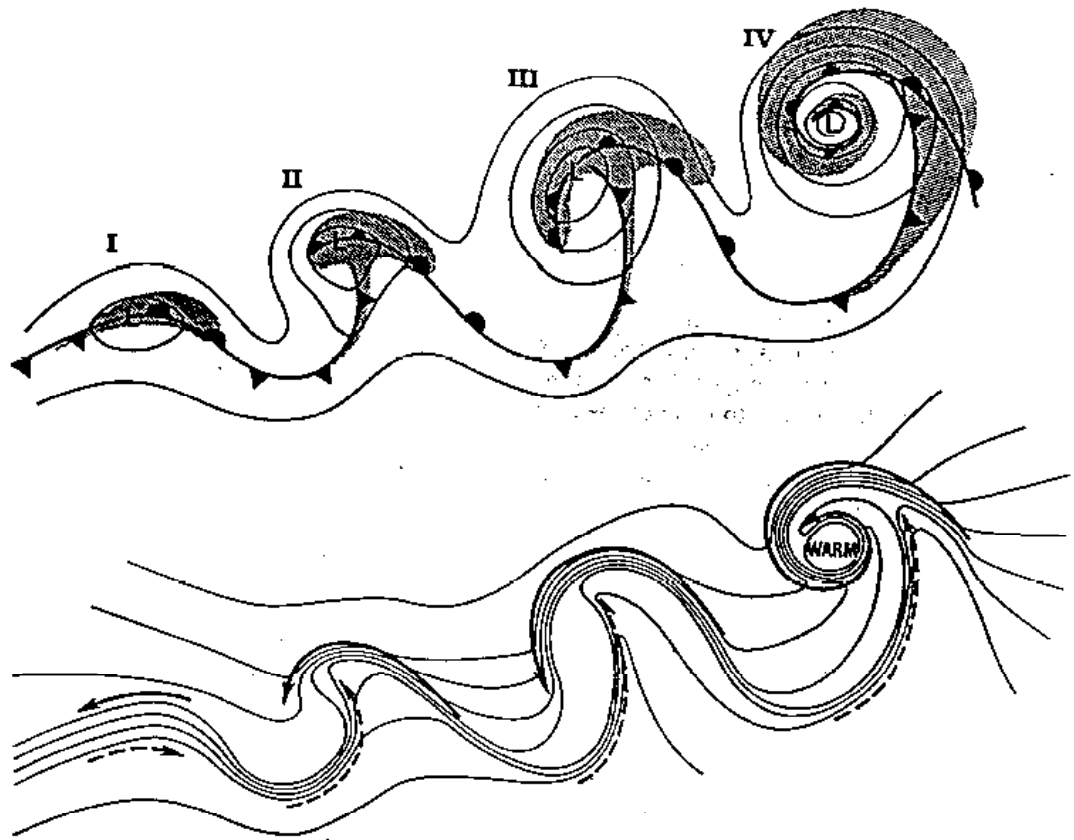


Fig. 21. An alternative model of frontal-cyclone evolution (Shapiro and Keyser 1990): incipient broadbaroclinic phase (I), frontal fracture (II), bent-back front and frontal T-bone (III), and warm-core frontal seclusion (IV). Upper: sea level pressure (solid), fronts (bold), and cloud signature (shaded). Lower: temperature (solid), and cold and warm air currents (solid and dashed arrows, respectively).