Chapter 12
Mid latitude Cyclones

Mid-latitude Cyclones
Definition
• A cyclone is an area of low pressure around which the winds flow counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

http://www2010.atmos.uiuc.edu/(Gh)/guides/mtr/cyc/def.rxml
Visible satellite image showing a mid-latitude cyclonic storm with its weather fronts over the Atlantic Ocean during March, 2005.

Mid-latitude Cyclones - Introduction

- Important for global heat transport
- They also redistribute/reduce energy in the atmosphere
- Often are significant weather producers
- First studied extensively by a group of scientists from Bergen, Norway (Vilhelm and Jakob Bjerknes, Halvor Solberg, and Tor Bergeron)
  - They developed the Polar Front Theory for the formation and evolution of mid-latitude cyclones shortly after WWI.
Polar Front Theory - Development and Evolution of a Wave Cyclone

(a) - The wave cyclone (often called a frontal wave) develops along the polar front
  - when a large temperature gradient exists across the polar front - the atmosphere contains a large amount of Available Potential Energy
(b) - An instability (kink) forms in the polar front. This instability is the 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
  - region between warm and cold fronts is the "warm sector"
  - the central low pressure (low, which is deepening with time)
  - overrunning of warm air over the warm front
  - cold air surging southward behind the cold front
  - wide-spread precip ahead of the warm front
  - narrow band of precip along the cold front
  - Wind speeds continue to get stronger as the low deepens - the Available Potential Energy (APE) is being converted to Kinetic Energy (KE)
  - The production of clouds and precip also generates energy for the storm as Latent Heat is released
(d) - As the cold front moves swiftly eastward, the systems starts to occlude.
   - Storm is most intense at this stage
   - have an occluded front trailing out from the surface low
   - triple point/occlusion - is where the cold, warm and occluded fronts all intersect

(e) - the warm sector diminishes in size as the systems further occludes.
   - The storm has used most all of its energy and dissipates
   - All of the APE has been utilized and the KE has dissipated into turbulence- cloud/precip production has diminished
   - The warm sector air has been lifted upward
   - The cold air is at the surface - stable situation.
Here is a movie loop of color enhanced infrared images

- http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/cyc/sat.rxml

Cyclone Families - Cyclogenesis Regions

- Many cyclones in different phases of their evolution are often observed along the polar front.

- Sometimes, cyclones deepen very rapidly - if deepening rate exceeds 24 mb in 24 hours, it is referred to as explosive cyclogenesis and the associated storm is often called a "bomb"

- Explosive cyclogenesis often occurs during the winter months just off the east coast of the US.
Where Do mid-latitude Cyclones Tend to Form?

• Any development or strengthening of a mid-latitude cyclone is called cyclogenesis.
• Cyclogenesis over the US tends to occur near:
  – Eastern Slope of the Rockies
  – The Great Basin Area
  – Gulf of Mexico
  – Atlantic Coast east of the Carolinas
As westerly winds blow over a mountain range, the airflow is deflected in such a way that a trough forms on the downwind (leeward) side of the mountain. Troughs that form in this manner are called *lee-side lows*.

**Colorado Low**: lee-side lows  
**Hatteras Low**: Warm Gulf Stream water can supply moisture and warmth to region south of stationary front – *northeraters*.  
**Gulf Low**: Warm air and water
The surface weather map for 7:00 A.M. (EST) December 11, 1992, shows an intense low-pressure area (central pressure 988 mb, or 29.18 in.), which is generating strong northeasterly winds and heavy precipitation (area shaded green) from the mid-Atlantic states into New England. This northeaster devastated a wide area of the eastern seaboard, causing damage in the hundreds of millions of dollars.

Temperature and pressure

- Any process that warms the air can contribute to a decrease in surface air pressure, whereas any process that cools the air can contribute to an increase in surface air pressure.
- Thermal lows: Shallow
- Frontal Lows: Deep
Convergence and Divergence

- Convergence and divergence of air may result from changes in wind direction and wind speed.
- Wind direction:
  - Contour lines move closer—convergence
  - Contour lines move apart -- divergence
- Wind speed
  - From fast to low—convergence
  - From low to fast divergence
- Wind speed at ridge—fast; wind speed at trough -- low
Vertical Structure of a Developing Wave Cyclone

• Mid-latitude cyclones are "deep" pressure systems extending from the surface to tropopause level
• recall that they are an example of a "cold core low"

• For the storm to develop and grow, it can not be vertically "stacked" as shown to the right -->>

• Why?

Tilted Vertical Structure of a Developing Wave Cyclone

• The upper-level low MUST be located north and west of the surface low - i.e., the area of low pressure must tilt to the northwest with height.
• An area of divergence MUST be directly above the surface low
• If divergence aloft -> convergence at surface, will the low will deepen, or decay?
  – Depending on which one is stronger
Anticyclone:

- The upper-level high MUST be located **south and west** of the surface high - i.e., the area of high pressure must tilt to the southwest with height
- An area of convergence MUST be directly above the surface high
- If convergence aloft > divergence at surface, pressure at surface will increase and the high will build (intensify)
- If convergence aloft < divergence at surface, pressure at surface will decrease and the high will decrease in intensity

Upper-level waves and surface storms

**Storm motion and speed**

- The direction and speed of the cyclone is closely approximated by the speed and direction of the flow at 500mb - referred to as the **steering level**
  - Cyclone moves in direction of 500 mb winds
  - Cyclone moves with speed = 1/2 500mb wind speed
- The flow aloft appears to be quite important for the development and propagation of cyclones and anticyclones - let's take a closer look......
Long and short waves in the upper-level flow

- **Long waves** - are a fundamental feature on an unevenly heated rotating spherical planet.
- Also referred to as Rossby waves
- Usually are 4-6 of them around the globe at a given time
- Wavelength varies between 4000-8000 km
- Are generally stationary - or move very slowly east or west

- **Short waves** (short wave troughs) - are embedded in the long waves
- Move quickly to the east
- Weaken when move to a long-wave ridge
- Strengthen when they move to a long-wave trough
- Short waves are readily observable at mid levels (e.g., 500 mb chart)
- Short waves are an important ingredient for the development and intensification of a mid-latitude cyclone - through baroclinic instability
Warm and Cold Advection Generated by Short Waves at Mid Levels

- Consider a long wave trough over a stationary front (a). Then, a short wave moves into the trough, intensifying the trough (b).
- Notice that initially (a), the streamlines and isotherms are parallel to each other - the atmosphere is barotropic.
- In (b), the short wave has acted to cause the streamlines to cross the isotherms both west and east of the trough. The atmosphere there is now "baroclinic".

- In the baroclinic region west of the trough, cold-air advection is occurring.
- In the baroclinic region east of the trough, warm-air advection is occurring.

Baroclinic instability

- Cold-air advection west of the trough will produce sinking motion as the cold air descends to the surface behind the cold front.
- Warm-air advection east of the trough will produce rising motion near the center of the low as the warm air ascends.
- This sinking and rising of cold and warm air due to cold and warm air advection is called baroclinic instability.
- Baroclinic instability is a necessary ingredient for the development and intensification of a mid-latitude cyclone.
Jet Stream– Convergence and Divergence

- Jet streaks (wind maximum in jet stream) tend to be found in base of trough
- Convergence at the entrance (1,2)
- Divergence at the Exit

The role of the jet stream/streaks in cyclone development

- Convergence of air occurs in the entrance region and is maximized on the left side (point C)
- Divergence of air occurs in the exit region and is maximized on the left side (point D)
- So, you want point D directly over the surface low removing air from the surface low
- Point C should be directly over the surface high supplying air to the surface high
Summary of key features associated with a developing wave cyclone

- Usually need to have a disturbance at the surface (area of lower pressure) normally along the polar front
- Also need upper-level support - a short wave with associated upper-level low/trough must be situated such that the upper-level low is to the northwest of the surface low.
- The shortwave generates warm and cold-air advection at mid-upper levels (referred to differential temperature advection)
- The differential temperature advection generates sinking and rising motion
- At jet-stream level, jet streaks in the base of a trough generate areas of convergence west of the trough, and divergence east of the trough.
- Without upperlevel support, surface disturbances can not readily intensify.

Summary of clouds, weather, and vertical motions and upper-air support associated with a developing mid-latitude cyclone.
Warm and Cold Conveyor Belts

- The sinking and rising of warm air produced by baroclinic instability can also be visualized by the warm- and cold-conveyor belt model.
- **Warm conveyor belt** -
  - Originates at low levels in the warm sector.
- **Cold, dry conveyor Belt** -
  - Originates at upper levels and descends to the surface.
- Often produces a region of clearing skies behind the cold front.
The March Storm of 1993

A color-enhanced infrared satellite image that shows a developing mid-latitude cyclone at 2 A.M. (EST) on March 13, 1993. The darkest shades represent clouds with the coldest and highest tops. The dark cloud band moving through Florida represents a line of severe thunderstorms. Notice that the cloud pattern is in the shape of a comma.

Surface weather map for 4 A.M. (EST) on March 13, 1993. Lines on the map are isobars. A reading of 96 is 996 mb and a reading of 00 is 1000 mb. (To obtain the proper pressure in millibars, place a 9 before those readings between 80 and 96, and place a 10 before those readings of 00 or higher.) Green shaded areas are receiving precipitation. Heavy arrows represent surface winds. The orange arrow represents warm, humid air; the light blue arrow, cold, moist air; and the dark blue arrow, cold, arctic air.
**The 500-mb chart** for 7 A.M. (EST) March 13, 1993. Solid lines are contours where 564 equals 5640 meters. Dashed lines are isotherms in °C. Wind entries in red show warm advection. Those in blue show cold advection. Those in gray indicate no appreciable temperature advection is occurring.

The development of the ferocious mid-latitude cyclonic storm of March, 1993. A small wave in the western Gulf of Mexico intensifies into a deep open-wave cyclone over Florida. It moves northeastward and becomes occluded over Virginia where its central pressure drops to 960 mb (28.35 in.). As the occluded storm continues its northeastward movement, it gradually fills and dissipates. The number next to the storm is its central pressure in millibars. Arrows show direction of movement. Time is Eastern Standard Time (EST).
Polar Lows

- The storms developed over water behind (or poleward of) the main polar front – Polar low

- Arctic front
  - Cold air over snow-ice covered surface
  - Warm air over relatively warm ocean current

Short Waves and Vorticity

- Importance of upper air convergence and divergence – How to measure them?
  - **Vorticity**

  - Vorticity is a measure of a parcel's "spin".
    - If a parcel spins counterclockwise, it has positive vorticity
    - If a parcel spins clockwise, it has negative vorticity

  - Vorticity around the vertical axis is called "**vertical vorticity**"
Planetary Vorticity

- There are two primary sources of "vertical vorticity"
  - planetary vorticity
  - relative vorticity
- Any object on earth will acquire planetary vorticity generated by the rotating earth
  - is zero at equator
  - is maximum at pole (one revolution per day)
  - is always positive (cycloonic)
- So, an air parcel that is stationary relative to the earth's surface will have planetary vorticity.

Relative Vorticity

- Moving air will generally have additional vorticity relative to the earth's surface—Relative Vorticity
- Produced by two effects:
  - curvature
  - shear
The sum of a parcel's planetary vorticity and its relative vorticity is called **absolute vorticity**.

In middle and high latitudes, the earth’s vorticity is great enough to make the parcel’s spin cyclonic everywhere on the earth.

A parcel of air moves with the upper-level flow:
- an increase in its absolute vorticity is related to upper-level convergence
- a decrease in its absolute vorticity is related to upper-level divergence

**Absolute Vorticity and Vertical Velocity**

The wavy path of air aloft due to the conservation of absolute vorticity.
Relationship between Absolute Vorticity Maxima and vertical motion

- East of vorticity max will be divergence, upward motion
- West of vorticity max will be convergence, downward motion
- When a vorticity max move toward the polar front, it is possible that it will help generate a wave cyclone
- Even in the absence of surface fronts, a short wave can produce an area of cloudiness and sometimes Precipitation.

This infrared water vapor image shows regions of maximum vorticity as cyclonic swirls of moisture off the coast of Oregon and Washington and out over the Pacific.
The blizzard of 83
Feb. 11, 1983

• Short waves are identified in the upper-level flow as maxima of absolute vertical vorticity.