Module 7 – Mid-latitude Cyclones and Fronts

Lecture Outline

# Cold and Warm Fronts

## Air Masses

* + - The atmosphere is made up of large air masses, which have relatively uniform temperature and moisture characteristics based on their geographical location.
    - Air masses are described based on their general characteristics:
      * Continental (dry) vs. Maritime (moist)
      * Polar (cold) vs. Tropical (warm)

*[Show a map of air masses over North America]*

*[Show meteograms within the different air masses]*

* + - The type and location of air masses changes by season, which helps define the climate of a location.

*[Show temperature and moisture climate maps for different seasons]*

* + - Although air masses form over specific locations, the air can and does move due to large-scale atmospheric wind patterns. At the same time, air masses modify the pressure gradients and the associated winds.

*[Show maps of temperature and pressure/wind]*

* + - Fronts occur along the boundaries of air masses, and are named based on the temperature of the air mass that is moving.
      * Warm front or cold front.

*[Show map of mid-latitude cyclone with warm and cold fronts labeled]*

## Structure of a Warm Front

* + - A warm front occurs when a warm air mass moves into a cold air mass.
    - Warm fronts have a larger horizontal extent than a vertical extent as warm air rises over the cold air.
      * Warm air is less dense than cold air, which causes the air to rise.
    - Warm fronts are usually characterized by widespread cloud cover and steady precipitation.
      * Clouds are called “stratiform” due to their layered structure.
    - Warm fronts are often associated with widespread rainfall or snowfall, depending on the season.

## Structure of a Cold Front

* + - A cold front occurs when a cold air mass moves into a warm air mass.
    - Cold fronts have a steep vertical slope as cold air moves into warmer air, leading to strong vertical temperature gradients.
    - Cold fronts are usually characterized by convective clouds and precipitation.
      * Clouds are called “cumuliform” due to their large vertical extent.
    - Cold fronts are usually associated with severe thunderstorms and heavy rainfall.
    - When warm and cold fronts combine, they become an occluded front.
    - When one air mass stops moving into another air mass, the boundary is called a stationary front.
      * Often associated with flooding since the associated precipitation tends to stay over the same area.

# Life cycle of a Mid-latitude Cyclone

## What Is a Mid-latitude Cyclone?

* + - As a column of air increases in temperature, it will expand as volume increases. As a result, two columns of air with a different temperature will have a horizontal pressure difference between them.
      * Strongest difference in the winter because of the large temperature gradient between the Tropics and the Poles.
    - Air will flow from high to low pressure due to the pressure gradient force, following the same general process of water flowing downhill.
      * A low pressure would be the bottom of a bowl while a high pressure would be the top of the bowl.
      * Meteorologists often look at the change in height on a surface of constant pressure so that the concepts can be used together.
    - As air flows from one air mass to another, the Coriolis effect causes the winds to move (or more precisely deflect) in a curve.
      * The Coriolis effect occurs because the Earth is spinning underneath the atmosphere. It’s is called an “apparent” deflection since the air isn’t actually moving in a curve (it just appears to be since the Earth is curved and spinning).
    - Due to the horizontal pressure gradient and the Coriolis deflection, in the Northern Hemisphere air flows clockwise around a high pressure and counterclockwise around a low pressure.
      * The opposite is true in the Southern Hemisphere.
    - The low pressure area and the associated flow around it is called a mid-latitude cyclone.
      * “Mid-latitude” since the temperature boundary usually occurs between the Polar and Tropical air masses in the middle latitudes.
      * “Cyclone” since the air is moving around the center of low pressure.

## Stages of a Mid-latitude Cyclone

* + - Mid-latitude cyclones generally go through a distinct set of stages, each associated with recognizable features, processes, and weather patterns.

*[Show image of five-stage life cycle of a MLC]*

* + - Stage 1: Stationary
      * A boundary separates the cold and warm air masses.
    - Stage 2: Initial Wave
      * An atmospheric disturbance generates wind shear (difference in wind speed or direction) along the front, causing a wave to form.
    - Stage 3: Advanced Wave
      * As the cold air mass begins to move into the warm air mass, the fronts begin to rotate around the low pressure center.
    - Stage 4: Mature
      * The cold front moves faster than the warm front, causing the cyclonic circulation to become stronger.
    - Stage 5: Occlusion
      * The cold front catches up to the warm front, at which point the fronts become “occluded” as the cold air slides underneath the warm air.
      * The wave now becomes a closed circulation, or loop.
    - Stage 6: Dissipation (cutoff low)
      * The cold air has now wrapped around the low pressure, cutting off the flow of warm air.
      * The wave is now entirely replaced by a loop, and the low pressure system begins to “dissolve” as it mixes with the air around it.

*[Show a consistent set of images for each slide, ideally showing cloud and precipitation features and the structure of each stage]*

## Structure of a Mid-latitude Cyclone

* + - From above, a mature mid-latitude cyclone is generally shaped like a giant “comma”, formed by clouds along the warm and cold fronts and within the central low pressure.
    - Depending on the stage of the cyclone, precipitation and cloud patterns can vary; however, the type and distribution of both can be predicted by meteorologists.
    - Surface weather patterns within a mid-latitude cyclone can change quickly, depending on your location and the strength of the system.
    - Mid-latitude cyclones have distinct (and complicated) three-dimensional structures, but the following characteristics are the most important:
      * Initial waves usually form around the upper-level Jet Stream.
      * Different vertical temperature gradients lead to different cloud and precipitation patterns along warm and cold fronts.
      * Wind speeds generally increase with height due to stronger pressure gradients.
      * Wind direction changes rapidly along frontal boundaries.

# 3D Structure of Mid-latitude Cyclones

## Temperature Structure of a Mid-Latitude Cyclone

* Open IDV, then open file “MLC\_TemperatureStructure.xidv”.
  + This will import one 32-km North American Regional Reanalysis (NARR) file corresponding to 12Z on March 13, 1993.
    - This time period corresponds to the height of what is popularly known as the “1993 Super Storm”.
  + The following displays will be loaded:
    - Maps: Blue Marble (underlay), World country outlines.
    - Plan View: Color-shaded temperature maps at 300, 500, 850, and 1000 hPa.
    - Isosurface of temperature at 0°C.
* Features to note:
  + Note that although the magnitude of temperature changes with height, the general large-scale temperature pattern remain consistent.
    - Visualize the plan view color-shaded temperature surfaces sequentially to see how temperature changes horizontally and vertically.
    - Note that the color scales for each of the plan view images changes to highlight temperature patterns.
  + The 3D nature of the temperature patterns clearly indicates the location and strength of the cold and warm fronts associated with the cyclone.
    - Visualize the 0°C isothermal surface and note the temperature “walls” surrounding the Southeast US and north along the US East Coast.

## Wind and Pressure Patterns in a Mid-Latitude Cyclone

* Open IDV, then open file “MLC\_PressureStructure.xidv”.
  + This will import one 32-km North American Regional Reanalysis (NARR) file corresponding to 12Z on March 13, 1993.
    - This time period corresponds to the height of what is popularly known as the “1993 Super Storm”.
  + The following displays will be loaded:
    - Maps: Blue Marble (underlay), World country outlines.
    - Plan View: Color-shaded heights maps at 300, 500, 850, and 1000 hPa.
    - Plan View: Wind vectors at 300, 500, 850, and 1000 hPa.
* Features to note:
  + The central low pressure of the cyclone is more pronounced near the surface, while in the upper levels it is more clearly seen as a large-scale wave.
    - Visualize the height maps starting at 1000 hPa and then go up in altitude.
    - Note that each map has a different scale to better illustrate the patterns at each level.
  + Mid-latitude cyclones are generally tilted as they mature, such that the center of the cyclone shifts west with increasing height.
    - With all four height maps visible, rotate the display to see them all in profile. This is best done by looking at the maps from the south (centered west of South America while looking north).
  + As a cyclone matures, the cut-off low will generally form at the surface and then move up.
    - Overlaying the height maps with the corresponding wind vectors at 1000 hPa, one can see the cyclonic flow around the central low.
    - Doing the same visualization at each subsequent level shows that while “closed” cyclonic flow is visible at 850 hPa, at higher levels (500 and 300 hPa) the flow is not closed, but more wave-like in nature.

## Evolution of a Mid-latitude Cyclone

* Open IDV, then open file “MLC\_Evolution.xidv”.
  + This will import five 32-km North American Regional Reanalysis (NARR) files corresponding to 12Z on March 10, 1993 through 12Z on March 14, 1993.
    - This time period corresponds to the progression of what is popularly known as the “1993 Super Storm” from the wave stage through the mature stage.
  + The following displays will be loaded:
    - Maps: Blue Marble (underlay), World country outlines.
    - Plan View: Color-shaded height and temperature maps at 500 hPa.
    - Plan View: Wind vectors at 500 hPa.
    - Isosurfaces of wind magnitude at 45, 55, and 65 meters per second.
* Features to note:
  + The height pattern at 500 hPa is based on the temperature pattern.
    - Visualize 500 hPa temperature through the five-day loop, then visualize 500 hPa pressure and wind through the same loop.
    - Alternate making temperature and pressure/wind visible so that the patterns of each can be identified and compared.
  + The Jet Stream, seen as an area of high winds in the upper troposphere, largely drives the formation and propagation of cyclones.
    - Visualize the 45, 55, and 65 m/s surface of constant wind speed (a.k.a., isotachs), which are colored green, yellow, and red, respectively.
      * Transparency is set such that all three surfaces can be seen at once.
    - Note how the structure, shape, and extent of the Jet Stream change over the five day period.
    - Visualize the Jet Stream along with the 500 hPa pressure or wind map to see how the Jet Stream leads to patterns at lower atmospheric levels.

Knowledge Test Questions

* + - * What is the primary reason that mid-latitude cyclones form in the atmosphere?
      * Why do mid-latitude cyclones spin?
      * What are the primary stages of a mid-latitude cyclone?
      * During what season do mid-latitude cyclones usually form over the United States?
      * What is an atmospheric “front”?
      * Which type of atmospheric front is usually associated with thunderstorms?
      * Where are cold and warm fronts generally situated with respect to the center of a mid-latitude cyclone over the United States?
      * Why does wind speed and direction change so rapidly across a cold front?
      * Why is it usually so warm and humid ahead of a cold front in the Southeast US?