Winds, Fronts, and Cyclogenesis

Outline

- Atmospheric pressure
- Forces that affect the wind
  - PGF, Coriolis, Centripetal, Friction
- Vertical Motion
- Fronts
- Mid-Latitude Cyclogenesis

Atmospheric Pressure

- Ideal Gas Law
  - \( p = \rho RT \)
    - \( p \): pressure; \( \rho \): density; \( R \): constant (287 J/kg/K); \( T \): temperature
  - It takes a shorter column of dense, cold air to exert the same pressure as a taller column of less dense, warm air
  - Warm air aloft is normally associated with high atmospheric pressure and cold air aloft with low atmospheric pressure
  - At a given level, more molecules exist above warm air than cold air = higher pressure
Surface and Upper-Level Charts

- Sea-level pressure chart: constant height
- Upper level or isobaric chart: constant pressure surface (i.e. 500mb)
  - High heights correspond to higher than normal pressures at any given latitude and vice versa

Cold air aloft: low heights or low pressure
Warm air aloft: high heights or high pressures

Ridge: where isobars bulge northward
Trough: where isobars bulge southward

In Northern Hemisphere:
- High pressure: anticyclone (winds blow clockwise and outward from center)
- Low pressure: mid-latitude cyclone (winds blow counter clockwise and inward towards center)
Newton’s 2nd Law of Motion

- 2nd Law:
  - \( F = ma \)
  - \( F \): net force; \( m \): mass of object; \( a \): acceleration
- At a constant mass, the force acting on the object is directly related to the acceleration that is produced.
- The object accelerates in the direction of the net force acting on it.
- Therefore, to identify which way the wind will blow, we must identify all the forces that affect the movement of air.

Forces that Affect Wind

- Pressure gradient force (PGF)
- Coriolis force
- Centripetal force
- Friction

Pressure Gradient Force

- Pressure gradient = \( \Delta p/d \)
  - \( \Delta p \): difference in pressure
  - \( d \): distance
- PGF has direction & magnitude
  - Direction: directed from high to low pressure at right angles to isobars
  - Magnitude: directly related to pressure gradient
    - Tight lines (strong PGF) \( \Rightarrow \) stronger wind
- PGF is the force that causes the wind to blow
Coriolis Force

- Apparent deflection due to rotation of the Earth
- Right in northern hemisphere and left in southern hemisphere
- Stronger wind = greater deflection
- No Coriolis effect at the equator greatest at poles.
- Only influence direction, not speed
- Only has significant impact over long distances
- Coriolis = 2Ωsinφ
**Geostrophic Winds**

- When the force of PGF and Coriolis are balanced
- Travel parallel to isobars at a constant speed
- An approximation since isobars are rarely straight in the real atmosphere but close enough to understand winds *aloft*
- Spacing of isobars indicates speed
  - Close = fast, spread out = slow

**Gradient Winds & Centripetal Force**

- Gradient wind parallel to curved isobars above the level of frictional influence (winds *aloft*)
- An object accelerates when it is changing speed and/or direction.
  - Therefore, gradient wind blowing around a low pressure center is constantly accelerating
- Centripetal acceleration: directed at right angles to the wind, inward toward center of low
- Centripetal force: inward-directed force
  - Results from an imbalance between the Coriolis force and the PGF

- Cyclonic flow: PGF > CF
- Anticyclonic flow: PGF < CF
Zonal & Meridional Winds

- Zonal winds: oriented in the W-E direction (parallel to latitude)
  - Moves clouds, storms, surface anticyclones rapidly from west to east
- Meridional winds: oriented in a N-S trajectory
  - Surface storms move slowly and often intensify major storm systems

Surface and Upper-Level Winds

- Winds on Upper-level Charts
  - Winds parallel to contour lines and flow west to east
  - Heights decrease from north to south
- Surface Winds
  - Winds normally cross isobars and blow more slowly than winds aloft
    - Friction reduces the wind speed which in turn decreases the Coriolis effect
  - Friction layer: surface to about 1000m (3300ft)
  - Winds cross the isobars at about 30° into low pressure and out of high pressure

- PGF at surface is balanced by the sum of friction and Coriolis force
- Surface winds into low and outward from high
Winds & Vertical Motions

- Since surface winds blow into the center of a low, they are converging and that air has to go somewhere ⇒ slowly rises
  - Vice versa for winds blowing outward from H
- Therefore, a surface low has convergence at surface and divergence aloft and a surface high has the opposite.

Hydrostatic Balance

- There is always a strong PGF directed upward
- Gravity balances the upward PGF
  - When they are equal, hydrostatic equilibrium exists
- Good approximation for atmosphere with slow vertical movements
- Is not valid for violent thunderstorms and tornadoes.
Air Masses of North America

- Continental Polar (cP) & Arctic (cA)
  - Cold, dry, stable air in winter
  - In summer, cP air mass usually brings relief from oppressive heat in central and eastern US

- Maritime Polar (mP)
  - In winter, cP/cA air mass is carried over Pacific Ocean where moisture and warmth is added
  - mP at Pacific Coast is cool, moist, and conditionally unstable
  - East of Rockies - brings fair weather and cooler temperatures (moisture has been removed by mountains)
  - East coast mP air mass: originates in N. Atlantic
    - Storms may develop (heavy rain or snow, coastal flooding)
    - Late winter, early spring

Air Masses and Fronts

- A front is a transition zone between two air masses of different densities
- Fronts extend both horizontally and vertically

Cold Front

- Cold, dry stable polar air (cP) is replacing warm, moist, conditionally unstable subtropical air (mT)
- Slope vertical boundary due to surface friction slowing down the surface front
- Has strong vertical ascent along the surface front
- Strong upper level westerlies push ice crystals far ahead of the front, creating Cs and Cb in advance of the front
  - Cold, dense air wedges under warm air, forcing the warm air upward, producing cumuliform clouds
  - Can cause strong convection, severe weather, and squall lines.
  - Air cools quickly behind the front
Cold Front

- Rising motion causes decreased surface pressure ahead of the front.
  - On a surface pressure map, frontal location can be seen by “kinks” in the isobars, changes in wind direction from a southwesterly to a northwesterly wind, and decreases in temperature.
  - Pressure is lowest at the surface front.
- On weather maps, cold fronts are indicated by blue lines with triangles pointing in the direction of frontal motion (towards warmer air).

<table>
<thead>
<tr>
<th>Cold Front Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colder Temperatures</td>
</tr>
<tr>
<td>28°</td>
</tr>
<tr>
<td>31°</td>
</tr>
<tr>
<td>Warmer Temperatures</td>
</tr>
<tr>
<td>35°</td>
</tr>
<tr>
<td>62°</td>
</tr>
<tr>
<td>Cold Front</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cold Front</th>
<th>Before</th>
<th>While</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winds</td>
<td>S-SW</td>
<td>Gusty, shifting</td>
<td>W-NW</td>
</tr>
<tr>
<td>Temperature</td>
<td>Warm</td>
<td>Sudden drop</td>
<td>Steady drop</td>
</tr>
<tr>
<td>Pressure</td>
<td>Steady fall</td>
<td>Min, then sharp rise</td>
<td>Steady rise</td>
</tr>
<tr>
<td>Clouds</td>
<td>Increasing, CI, Cs, Cb</td>
<td>Cb</td>
<td>Cu</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Brief showers</td>
<td>Heavy rains, severe weather</td>
<td>Showers, then clearing</td>
</tr>
<tr>
<td>Visibility</td>
<td>Fair to poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Dew Point</td>
<td>High, remains steady</td>
<td>Sharp drop</td>
<td>Lowering</td>
</tr>
</tbody>
</table>

Warm Front

- Occurs at the leading edge of an advancing warm, moist, subtropical air mass (mT) from the Gulf replacing a retreating cold, maritime, polar air mass from the North Atlantic (mP).
- Slowly advances as cold air recedes; moves at about half the speed of an average cold front.
  - Speed may increase due to daytime mixing.
  - Speed may decrease due to nighttime radiational cooling.
- Smaller vertical slope than cold front.
Warm Front

- Warmer, less-dense air rides up and over the colder, more-dense surface air
  - “Overrunning”
  - Produces clouds and precipitation well in advance of the front

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<th>After</th>
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<tbody>
<tr>
<td>Winds</td>
<td>S-SE</td>
<td>Variable</td>
<td>S-SW</td>
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<tr>
<td>Temperature</td>
<td>Cool-cold</td>
<td>Slowly warming</td>
<td>Steady rise</td>
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<tr>
<td>Pressure</td>
<td>Falling</td>
<td>Leveling off</td>
<td>Slight rise, followed by fall</td>
</tr>
<tr>
<td>Clouds</td>
<td>(in order) Ci, Cs, As, Ns, St, fog (Cb in summer)</td>
<td>Stratus-type</td>
<td>Clearing with scattered Sc</td>
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<tr>
<td>Precipitation</td>
<td>Light-to-moderate</td>
<td>Drizzle or none</td>
<td>Usually none</td>
</tr>
<tr>
<td>Visibility</td>
<td>Poor</td>
<td>Improving</td>
<td>Fair</td>
</tr>
<tr>
<td>Dew Point</td>
<td>Steady rise</td>
<td>Steady</td>
<td>Rise, then steady</td>
</tr>
</tbody>
</table>

Stationary Front

- Essentially no movement
- Surface winds blow parallel to front, but in opposite directions on either side of it
- Separates two air masses
- Seen often along mountain ranges when cold air cannot make it over the ridge
Occluded Fronts

- Cold fronts generally move faster than warm fronts
- Occlusion occurs when cold front catches up to and overtakes a warm front
- Occlusions can be warm or cold

Dry Lines

- Think of a dry line as a moisture boundary
- Separates warm, humid mT air from the southern Great Plains from warm, dry cT air
- Drier air behind dry lines lifts the moist air ahead of it, triggering storms along and ahead of it
  - Induces lifting along front
  - Often produces severe thunderstorms in OK & TX
- Unique to southern great plains of US because of the Rocky mountains and the Gulf of Mexico
A guide to the symbols for weather fronts that may be found on a weather map:

1. Cold front
2. Warm front
3. Stationary front
4. Occluded front
5. Surface trough
6. Squall/shear line
7. Dry line
8. Tropical wave

Features of a Mid-latitude Cyclone

- Deep low pressure area with attached cold and warm fronts
- Often an occlusion forms, the triple point lending to the formation of severe weather
- Precipitation associated with the cold and warm fronts organizes in typical “comma cloud” structure

Stages in Wave Cyclone Development
**Polar Front Theory**

- Initially, there is a stationary front that acts as the boundary separating cold, continental polar air from warm, maritime tropical air.
- Winds blow parallel to this front on either side.
- Polar Fronts are discontinuous.

**Cyclogenesis**

- A wave forms on the front due to a shortwave disturbance
  - Frontal Wave
  - Incipient Cyclone
- The front develops a “kink” where the wave is developing.
- Precipitation will begin to develop along the front
  - Overrunning and lifting.

**Strengthening**

- The cyclonic circulation around the low becomes more defined.
- The central pressure intensifies.
- The cold front and warm front have more organized motion.
- Cyclone usually pushed east or northeast by the winds aloft.
Mature Cyclone

- The cold front catches up with the warm front and an occlusion forms
- The cyclone is at its strongest at this point
- Severe weather often develops near the "triple point"

Dissipation

- The occlusion grows with time
- Eventually, the occlusion is so great that the supply of warm, moist air into the low is cut off
  - Cold air on both sides
- When this happens, the system starts to dissipate