Learning Objectives

- After this class you should be able to
  - Recognize key cloud and precipitation features accompanying extratropical cyclones
  - Describe the processes responsible for these cloud and precipitation features

Extratropical Cyclones

Definitions

Extratropical Cyclone
- a cyclonic storm deriving its energy primarily from the horizontal temperature gradient that exists in the midlatitudes (a.k.a. midlatitude, baroclinic, or frontal cyclone)

Variants
- Polar lows and Medicanes, which typically are accompanied by upper-level troughs but develop tropical-cyclone-like characteristics due to air-sea interactions

Extratropical Transition (ET)
- Development pathway involving the transition of a tropical cyclone into an extratropical cyclone

Group Activity

Identify the following:
- Comma cloud
- Dry Slot
- Warm, cold, and occluded front
- Expected precipitation areas
- Possible precipitation bands

DRY SLOT
Comma Shape
Group Discussion

What processes contribute to the development of these precipitation features? Specifically, the comma shape, dry slot, warm-frontal precipitation, NCFR, WCFR, occluded band, surge band, and warm-frontal bands?

Houze (2014)

Multiscale Processes

- Geostrophic Adjustment
- Airstream transport
- Comma Cloud
- Dry slot
- Semigeostrophic Frontogenesis
- Diabatic Feedbacks
- Frontal Zones
- Upright and Slantwise Convection
- NCFR
- WCFR
- Other Rainbands
- Hydrometeor growth, transport, fallout
- Scale Funnel

Geostrophic Adjustment

- The mutual adjustment of wind and pressure fields to a geostrophically balanced state
  - i.e., balance between the pressure gradient and Coriolis accelerations
  - Implies thermal wind balance

Discussion

- Flow out of page
- Flow into page
- Geostrophically balanced initial state
- Impulsively change temperature gradient
- What Happens?
Discussion

- Impulsive change in temperature gradient changes thickness and pressure gradients
- PGF overwhelms Coriolis — Oppositely directed ageostrophic winds develop at upper and lower levels
- By continuity warm air ascends and cold air sinks — Ageostrophic secondary circulation
- Secondary circulation relaxes atmosphere back toward thermal wind balance — Warm air cools, cold air warms — Coriolis acting on ageostrophic winds enhances flow aloft and weakens flow near surface, enhancing shear

Geostrophic Paradox

How does the geostrophic flow affect the thermal wind balance in the entrance and exit regions of this jet streak?

Diagnose the secondary circulations and determine if they relax the atmosphere toward geostrophic balance

Diagnosing Large-Scale Ascent

Assuming quasigeostrophy, the vertical motion needed to maintain thermal wind balance is given by the Q-vector form of the omega equation

\[ \frac{\partial^2 \mathbf{Q}}{\partial z^2} + \frac{\partial}{\partial x} \left( \frac{\partial}{\partial y} \mathbf{Q} \right) \mathbf{\omega} = -2V \mathbf{\nabla} \cdot \mathbf{\Omega} \]

Q is given by

\[ \mathbf{\Omega} = \frac{\mathbf{\nabla}}{\rho} \left( \frac{\partial}{\partial x} \left( \frac{\partial}{\partial y} \mathbf{V} \right) \right) = \frac{\mathbf{\nabla}}{\rho} \left( \frac{\partial}{\partial x} \left( \frac{\partial}{\partial y} \mathbf{V} \right) \right) \]

Rate of change of \( \mathbf{V} \) following geostrophic motion

With vertical velocity (w) proportional to the divergence of the Q vector

\[ w \propto \mathbf{\omega} \propto \mathbf{\nabla} \cdot \mathbf{\Omega} \]

Diagnosing Q and w

1. Determine the vector change of the geostrophic wind along an isotherm
2. Rotate 90˚
3. Q-vector "points" toward rising motion

Airstream Perspective: Conveyor Belts

- Simple depictions of the airflow associated with midlatitude frontal cyclones
  - **Warm Conveyor Belt** — A coherent airstream originating in the warm sector that moves poleward, rises vigorously over the warm frontal zone, and turns anticyclonically or fans out at upper levels
  - **Cold Conveyor Belt** — A coherent airstream that moves toward the low center poleward of the occluded and warm fronts and splits into two branches, one that turns anticyclonically, ascends, and forms the comma cloud head, the other that wraps cyclonically around the low center, contributing to strong winds along the bent back front — Anticyclonic branch may be thought of as an intrusion airstream between the cyclonic cold conveyor belt branch and the warm conveyor belt
  - **Dry Airstream** — A coherent mid-level airstream of descended origin that forms the dry slot

**Approximate Comma Shape Ascent Zone**

**Subsidence Behind Low Center**

700 mb 10 November 1975

Hoskins and Pedder (1980)

Carlson (1980); Schultz (2001); Schemm and Wernli (2014)
Conveyor Belts

Class Activity

Image Source: NOAA, COMET

Annotate fronts and conveyor belts on this image and explain your analysis.

Nice, but...

- Only explains general comma shape
- Does not account for details, especially fine-scale frontal structure and circulation
- Fine-scale details better captured if ageostrophic advection is included in the cross-front direction

Multiscale Processes

QG vs. SG Fronts

Multiscale Processes

Scale Funnel

Synoptic Scale

Frontal Scale

Convective Scale

Microscale

Process

Geostrophic Adjustment
Airstream transport

Demiageostrophic Frontogenesis
Diabatic Feedbacks

Upright and Slantwise Convection

Hydrometeor growth, transport, fallout

Cloud and Precipitation Feature(s)

Comma Cloud
Dry slot

Frontal Zones

NCFR
WCFR

Other Rainbands

QG
Unrealistic vertical orientation (and slow development)

SG
More realistic frontal tilt (and more rapid development)

Houze (2014)
SG Dry vs. Wet

Latent heating concentrates lifting into a narrow zone
More consistent with observations

Emanuel (1985); Houze (2014)

Precipitation Bands

Multiscale Processes

Cloud and Precipitation Feature(s)

Geostrophic Adjustment
Comma Cloud
Dry slot

Semigeostrophic Frontogenesis
Frontal Zones

Diabatic Feedbacks

Narrow Cold-Frontal Rainband (NCFR)

Hydrometeor growth, transport, fallout

NCFR – band of intense forced or free convection associated with the density-current-like structure at the leading edge of a cold front

Houze (2014); https://www.wunderground.com/blog/24hourprof/narrow-coldfrontal-rainbands.html

Narrow Cold-Frontal Rainband (NCFR)

Fine-Scale Structure: FASTEX IOP2

Carbone (1982)

Wakimoto and Bosart (2000)
Core and Gap Structure

Wakimoto and Bosart (2000)

Vorticity and Vertical Velocity

Wakimoto and Bosart (2000)

Conceptual Model

Wakimoto and Bosart (2000)

Wide Cold-Frontal Rainband (WCFR)

Houze (2014); https://www.wunderground.com/blog/24hourprof/narrow-cold-frontal-rainbands.html

Wide Cold-Frontal Rainband

Houze (2014), adapted from Matejka et al. (1980)

Warm-Frontal Precipitation

Houze (2014); https://www.education.psu.edu/weather/book/export/html/2026

WCFR – region of enhanced stratiform precipitation associated with ascent aloft; sometimes trails the NCFR

Region of precipitation associated with broad ascent accompanying warm front that may contain embedded bands or convective elements
Warm Front Example: FASTEX IOP11

Wakimoto and Bosart (2001)

Mesoscale Structure

• Weak wind shift across front at low levels (800 m AGL)
• Precipitation (inferred from dBZ) strongest ahead (poleward) of warm front

Wakimoto and Bosart (2001)

Vertical Structure

• Sloping region of enhanced horizontal and vertical $\theta_e$ gradient
• Veering winds with height
• No distinct frontal discontinuity at surface (front best defined aloft)

Wakimoto and Bosart (2001)

Vertical Structure

• Front-relative winds show strong veering with height
• Cross-front $\theta_e$ gradient delineates frontal zone
  – Weak near surface
• Strong sloping region of front-relative cross-frontal flow
  – Warm sector air ascending underlying cold air

Wakimoto and Bosart (2001)

Vertical Structure

• Strip of high vertical vorticity with localized maxima in frontal zone
• Highest vorticity also found aloft, not at the surface

Wakimoto and Bosart (2001)

Warm-Frontal, Surge, & Occlusion Bands


Single

Multi

Warm frontal, surge, and occlusion bands
Single and multi bands that form in warm frontal zone or comma head. Typically align parallel to isotherms

Warm-Frontal, Surge, & Occlusion Bands

- Key mechanisms:
  - Lower- to mid-level frontogenesis (red)
  - Often associated with horizontal deformation
  - Associated secondary circulation with slantwise ascent
  - Surrounding layer of conditional instability (blue), weak conditional stability, or conditional symmetric instability

- Strong frontogenesis increases likelihood of single band forming
- Single bands often form at edge of upper-level PV "hook"

Real-Time Examples (Hopefully!)

References