Upper-Level Fronts

Atmos 5210/6210
Synoptic–Dynamic Meteorology II
Jim Steenburgh
University of Utah
Jim.Steenburgh@utah.edu
What Is an Upper-Level Front?

• A zone of strong quasihorizontal temperature gradient and high static stability in the middle and upper troposphere which does not necessarily extend to the surface

• Not called “cold” or “warm” since the isentropes are typically aligned along the flow

• Why care?
  – Clear-air turbulence (CAT)
  – Stratospheric–tropospheric exchange
  – Develop concurrently with upper-level jets, troughs, and tropopause folds
Upper Level Fronts, Jets, and the Tropopause

JET

Upper-level front

Tropopause
Example

Source: Shapiro (1983)
Example

- Vertical wind shear = $30 \text{ m s}^{-1} (100 \text{ mb})^{-1}$

- Horizontal shear = $35 \text{ s}^{-1} (100 \text{ km})^{-1}$

- Two jet cores
  - Polar jet $\sim 300 \text{ hPa}$
  - Subtropical $\sim 250 \text{ hPa}$

- Folded trop beneath both jet cores – produced by secondary circulation

Source: Shapiro (1983)
Example

- Ozone concentrations illustrate folding of stratospheric air to mid levels

Source: Shapiro (1983)
Another Example

- Single jet core, but similar horizontal and vertical shear
- Strong gradient in rop height (2 PVU) across jet core

Source: Shapiro (1981)
Key Characteristics

• Strong horizontal and vertical wind shear, particularly below and on the cyclonic side of the jet core

• Clear-air turbulence (CAT) arising from shear

• Tropopause steeply sloped on cyclonic side of jet and folded beneath jet core
  – Large gradient in dynamic tropopause height across jet core
Conceptual Model

Jet Core

Tropopause Fold (if stratospheric air folds under tropospheric air)
Development Mechanisms

• If $y$ is positive toward the cold air, frontogenesis is given mathematically as

$$Fr = \frac{D}{DT} |\nabla\theta| = \frac{\partial\theta/\partial y}{|\partial\theta/\partial y|} \left[ \frac{\partial}{\partial y} \left( \frac{D\theta}{Dt} \right) - \frac{\partial\theta}{\partial y} \frac{\partial v}{\partial y} - \frac{\partial\theta}{\partial z} \frac{\partial w}{\partial y} \right]$$

• In northwesterly large-scale flow, upper-level frontogenesis is initiated by horizontal variations in subsidence (i.e., the tilting term)
Tilting Term

- Differential vertical motion tilts a vertically oriented potential temperature gradient into the horizontal.

\[
Fr = \frac{D}{DT} \left| \nabla^2 \theta \right| = - \left[ - \frac{\partial \theta \partial w}{\partial z \partial y} \right]
\]

Strong Subsidence

Weak Subsidence
Tilting Term

- Differential vertical motion tilts a vertically oriented potential temperature gradient into the horizontal

\[ Fr = \frac{D}{DT} |\nabla^2 \theta| = - \left[ - \frac{\partial \theta}{\partial z} \frac{\partial w}{\partial y} \right] \]
Vorticity Advection Example

Jet

Max AVA & Subsidence

Tilting Frontogenesis

Downstream of a ridge on the cyclonic side of a jet
Temperature Advection Example

Downstream of a ridge on the cyclonic side of a jet

Max Cold Advection & Subsidence

Tilting Frontogenesis

$\theta$

$\theta + \Delta \theta$

$\theta + 2\Delta \theta$

$\theta + 3\Delta \theta$

540 dm

546 dm

552 dm

558 dm
Feedback Mechanism

Vorticity associated with vertical wind shear is tilted into the vertical by differential subsidence, intensifying jet, AVA, and tilting frontogenesis.

Source: Mudrick (1974)
Feedback Mechanism

Cross-jet differential AVA

Cross-jet variation in subsidence

Tilting frontogenesis & tilting of vorticity into vertical

Jet core & differential AVA strengthen

Conceptual Model

Tilting frontogenesis

Mature upper-level front/amplified trof

Max Cold Advection & Subsidence

Vort-max intensifies (e.g., Mudrick ‘74)

Now warm advection along ULF except near/ahead of vort max

Schultz and Doswell (1999)
Class Activity

• Open the IDV Bundle Bundles -> Real-Time-WX -> Diagnostics -> PV-Thinking

• Locate an upper-level front

• Orient vertical cross sections so they are normal to the front

• Identify the following features in the cross section
  – Upper-level front
    • Identify both the strong potential temperature gradient and strong wind shear
    • Jet core
    • Tropopause fold

• How do these characteristics compare to the conceptual models and examples provided in this talk?