Precipitation Modulation by the St. Lawrence River Valley in Association with Transitioning Tropical Cyclones

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Outline

- Motivation
- Orographic impacts of the St. Lawrence River Valley (SLRV)
- Case selection, data and methods used
- Frontogenesis and precipitation
- Synoptic-dynamic analysis
- Future work
Katrina (2005)

29 August 2005
Montreal, Quebec (CYUL): 74 mm, 55% of August 2005 precipitation on 31 August

31 August 2005

Sources: UCAR Satellite Archive, Environment Canada
Ike (2008)

Source: Canadian Hurricane Centre
SLRV Orography

- Montreal (CYUL): Located at the confluence of 3 valleys
- SLRV, Ottawa River Valley, Lake Champlain Valley

From Razy et al. (2012)
Wind Channeling

- Wind rose of hourly surface winds at CYUL (1979-2002)

From Razy et al. (2012)
Wind Channeling

• Pressure-driven channeling in the SLRV
  • Anticyclone to the northeast, cyclone to the south/southwest
  • Synoptic-scale sea-level pressure (SLP) gradient
  • Surface wind blows from high to low pressure along the axis of the valley → NE surface winds
  • SE geostrophic winds

SLP/1000–500 hPa Thickness

Geostrophic winds at CYUL

Composite of 55 long-lived (6+ hours) NE surface wind events at CYUL

From Razy et al. (2012)
Wind Channeling and Frontogenesis

NE surface winds + SE geostrophic winds → ageostrophic frontogenesis in the SLRV → enhanced precipitation?

30 m frontogenesis (shaded), SLP (contours) for a composite of 20 cool-season cyclones that tracked through the SLRV

From Milrad et al. (2012)
Impacts of Wind Channeling

Composite soundings: Cool-season

From Razy et al. (2012)
Impacts of Wind Channeling

1 February 2012: 14 consecutive hours of freezing rain or freezing drizzle at CYUL

Source: RAP/UCAR, Plymouth State University
Research Questions and Objectives

  - Ageostrophic frontogenesis due to the orography of the St. Lawrence River Valley (SLRV)
  - Enhanced precipitation

- **Warm season: Fewer cyclones to induce a synoptic-scale SLP gradient in the SLRV**
  - Are Extratropical Transition (ET) events the exception?

- **Pressure-driven channeling during ET events**
  - precipitation distribution modulation?
  - Ageostrophic frontogenesis
  - Physical pathway
A comparison of SLRV-convergence induced precipitation rates, as a function of season (air mass)

Normalized precipitation amounts, according to seasonal air masses
Data

- **Case selection**
  - National Hurricane Center (NHC) Best Track data

- **Synoptic-dynamic analysis**
  - NCEP North American Regional Reanalysis (NARR) (Mesinger et al. 2006): 32 km horizontal resolution, 3-hourly

- **Precipitation**
  - Environment Canada Canadian Precipitation Analysis (CaPA) (Mahfouf et al. 2007): 15 km horizontal resolution, 6-hourly
  - NARR precipitation problems in Canada
Data: NARR Terrain

From Razy et al. (2012)
Data: NARR Precipitation in Canada

Record November 1996 rainfall event at CYUL: NARR 6-hr accumulated precipitation (shaded), SLP (contours), and observed precipitation amounts at CYUL (text)
Case Selection

- **Study period:** 1979–2010
  - NARR availability

- **Storm must have tracked with 500 km of SLRV at any point**
  - NHC Best Track data

- **Results:** 39 cases
Case Selection

1979–2010: 39 cases

Source: NHC Best Track Data/NOAA Coastal Services Center
Primary diagnostic: NARR surface ageostrophic frontogenesis

- Ageostrophic wind = 30 m wind – SLP geostrophic wind
- \( t = 0 \) h: time (3-hour) of maximum ageostrophic frontogenesis in the SLRV (or time of closest approach)
- Threshold value of ageostrophic frontogenesis
  - \( 100 \times 10^{-2} \) K (100 km\(^{-1}\) (3 hr\(^{-1}\))
Case Partitioning

• **Results: 3 groups**
  
  • **Group A: 27 cases**
    - Ageostrophic frontogenesis at $t = 0$ h $\geq$ threshold value and is oriented parallel to the long axis of the SLRV
    - Cyclone center identifiable
  
  • **Group B: 8 cases**
    - Ageostrophic frontogenesis at $t = 0$ h $< $ threshold value OR was due to synoptic-scale systems far removed from the cyclone
  
  • **Group C: 4 cases**
    - Ageostrophic frontogenesis at $t = 0$ h $\geq$ threshold value
    - Cyclone center NOT identifiable
Case Partitioning

NARR surface ageostrophic frontogenesis (shaded), SLP (contoured) at t = 0 h

Group A: \( \geq \) threshold
- Frances (2004)
- Barry (2007)

Group B: \(<\) threshold
- Floyd (1999)
- Gordon (2000)

Group C:
- Dennis (1999)

\[ t = -6 \text{ h} \]

\[ Plymouth State Weather Center \]

Surface Winds (knt) Analysis for 06Z 9 SEP 04

Motivation  SLRV  Cases  Fronto/precip  Synoptic-Dynamic Analysis  Future Work

\[ t = +6 \text{ h} \]

Plymouth State Weather Center

Surface Winds (knt)  Analysis for 18Z 9 SEP 04
Group B Example: Floyd (1999)

Motivation

SLRV

Cases

Fronto/precip

Synoptic-Dynamic Analysis

Future Work

t = -6 h

Plymouth State Weather Center

Surface Winds (knt)  Analysis for 03Z 17 SEP 99
Group B Example: Floyd (1999)

\[ t = 0 \text{ h} \]

Plymouth State Weather Center

Surface Winds (knt) Analysis for 09Z 17 SEP 99
Group B Example: Floyd (1999)

\[ t = +6 \, \text{h} \]

Plymouth State Weather Center

Surface Winds (knt)

Analysis for 15Z 17 SEP 99
The pressure gradient

NARR SLP gradient in the SLRV (hPa/100 km) for Groups A and B at t = 0 h

SLP gradient = [SLP (U) – SLP (L)]/100 km

Frontogenesis and Precipitation

• Hypothesis: Synoptic-scale SLP gradient $\rightarrow$ pressure-driven wind channeling $\rightarrow$ ageostrophic frontogenesis $\rightarrow$ enhanced precipitation

• Strategy
  • Individual case analysis
  • Focus: 10 Group A cases from 2004–2009
  • Composite analysis
The Ageostrophic Frontogenesis: Composites

NARR surface ageostrophic frontogenesis (shaded)

Group A composite (n = 27)

Group B composite (n = 8)
The Precipitation: Individual Cases

Left-hand panels: NARR SLP and ageostrophic frontogenesis (t = 0 h)
Right-hand panels: CaPA 6-hr precipitation (t = 0 h to t = +6 h)

10 Group A cases (2004–2009)
The Precipitation: Composites

10 Group A cases (2004–2009)
CaPA 6-hr accumulated precipitation composite (mm, shaded)
NARR lowest closed SLP contour (hPa, contours)
The Precipitation: Composite Analysis

CaPA 6-hr accumulated precipitation composite (mm, shaded)
NARR lowest closed SLP contour (hPa, contours)
Final Step

- Identify a physical pathway to enhanced precipitation in the SLRV

Hypothesis
- Near-surface ageostrophic frontogenesis + low stability $\rightarrow$ enhanced ascent/precipitation

Strategy
- Quasi-geostrophic theory
- Cross-sections
- Soundings
Synoptic-dynamic Analysis

- Relating frontogenesis to ascent
  - Gyakum and Barker (1988)
    - Ageostrophic frontogenesis can contribute substantially to ascent
  - Quasi-geostrophic “forcing” for ascent
    - Preferential along SLRV?
  - Potential (convective) instability
    - \( \frac{d\theta_e}{dz} < 0 \)
Quasi-geostrophic perspective

10 Group A cases (2004–2009) at $t = 0$ h:
NARR 1000-500 hPa Q-vector divergence (shaded, cool colors QG ascent),
SLP (hPa, solid), 1000–500 hPa thickness (dam, dashed)
Cross-sections (Composite)

NARR surface ageostrophic frontogenesis (shaded) at $t = 0\ h$

Group A composite ($n = 27$)  
Group B composite ($n = 8$)
Cross-sections (Composite)

Group A (n = 27) NARR composite cross-sections at t = 0 h
Equivalent potential temperature (K, red contours),
Frontogenesis (10^{-2} K [100 km]^{-1} [3 hr]^{-1}, shaded)

Ageostrophic frontogenesis (shaded) | Geostrophic frontogenesis (shaded)
Cross-sections (Individual Cases)

Left-hand panels: NARR SLP and ageostrophic frontogenesis \((t = 0 \text{ h})\)
Right-hand panels: CaPA 6-hour precipitation \((t = 0 \text{ h} \text{ to } t = +6 \text{ h})\)

10 Group A cases (2004-2009)

- Frances 2004
- Arlene 2005
- Cindy 2005
- Katrina 2005
- Rita 2005
- Beryl 2006
- Ernesto 2006
- Barry 2007
- Ike 2008
- Kyle 2008
Cross-sections (Individual Cases)

Representative Group A individual cases at $t = 0$ h: Frances (2004), Arlene (2005)

Equivalent potential temperature (K, red contours),
Frontogenesis ($10^{-2}$ K [100 km]$^{-1}$ [3 hr]$^{-1}$, shaded)

Ageostrophic frontogenesis (shaded)
Geostrophic frontogenesis (shaded)
Ageostrophic frontogenesis (shaded)
Geostrophic frontogenesis (shaded)
Group A cases from 2004-2009 (n = 10): NARR composite sounding at t = 0 h
Temperature (K, red), Dewpoint Temperature (K, blue)
Sounding (Individual Cases)

Group A cases from 2004-2009 (n = 10): NARR soundings at t = 0 h
Temperature (K, red), Dewpoint Temperature (K, blue)
Dynamical Conclusions

- Q-vector convergence not preferential to SLRV (area of heaviest precipitation)
  - Some cases: Q-vector divergence

- Ageostrophic frontogenesis >> geostrophic frontogenesis in the SLRV
  - Usually contained in the lowest 75-100 mb

- Potential (convective) instability
  - Low static stability
  - “More value for your dollar”
• Cyclone approaches SLRV
  • Induces synoptic-scale SLP gradient
• Near-surface ageostrophic frontogenesis
  • No preferential QG forcing for ascent
• Potential (convective instability)
  • Near-surface frontogenesis

Result: Enhanced precipitation
Future Research Directions

- Warm-season precipitation in the SLRV
  - Only modulated during ET events?

- Impacts of orography:
  - Lake Champlain Valley
  - Hudson Valley
  - Beyond the Northeast

[Map of a region with labels such as Ottawa River Valley, St. Lawrence River Valley, and Lake Champlain Valley]
Future Research Directions

- Warm-season precipitation in the SLRV
- Only modulated during ET events?

Montreal (CYUL) warm-season heavy (top 10%) precipitation events

- NARR 10 m winds
- NARR 925 hPa geostrophic wind

From Dookhie (2011)
Future Research Directions

- **Warm-season precipitation in the SLRV**
  - Only modulated during ET events?

Montreal (CYUL) warm-season heavy (top 10%) precipitation events

From Dookhie (2011)
Future Research Directions

- **Research Questions: Wind channeling**
  - Other ‘types’ of channeling?
  - Pressure-driven channeling and stability

- **Research Questions: Modeling**
  - Gap flow?
  - Precipitation distributions without the SLRV?
References


