Lake-Effect
Characteristics, Processes and Lake-Orographic Interactions

Atmos 6530: Mountain Meteorology
Jim Steenburgh
Department of Atmospheric Sciences
University of Utah
Jim.Steenburgh@utah.edu

Learning Objectives
• After this class you should be able to
  – Recognize several ways that lakes and complex terrain affect the morphology and intensity of lake-effect storms
  – Use this recognition to better analyze and predict lake-effect storms
  – Be prepared to help us advance our understanding of lake-effect storms in areas of complex terrain!

Outline
• Introduction
• The Great Salt Lake (GSL)
  • The GSL-effect
    – Morphology and climatology
    – Environmental conditions
    – Shoreline band dynamics
  • Orographic effects
  • Japan
  • Mechanisms of Orographic Enhancement

Introduction

What Is Lake Effect Snow?
• "Lake effect snow is produced when cold winds move across long expanses of warmer lake water, picking up water vapor, which freezes and is deposited on the lee shores" – Wikipedia.com (2006)
• "Precipitation occurring near or downwind from the shore of a lake resulting from the warming (destabilization) and moistening of relatively cold air during passage over a warm body of water" – Glossary of Meteorology (2000)

Additional Factors
• Lake-lake interactions & aggregate effects (Great Lakes)
• Boundary layer & thermally driven circulations
• Orography
  – Mountains, hills, plateaus, and windward/leeward coastal geometry
• Surface roughness contrasts
• Ice cover
Lake-Effect Regions

Great Lakes Climatology

Lake Ontario and Tug Hill

Great Lakes Snowfall Records

• 24 h: 77" @ Montague, NY
• Storm: 95" @ Montague, NY (10-14 Jan 97)
• Month: 192" @ Bennett Bridges, NY (Jan 1978)
• Winter: 466.9" @ Hooker, NY (1976-77)

Event Types

• Wide-area coverage
  – Wind parallel bands (a.k.a. cloud streets)
  – Horizontal roll convection
  – Rolls oriented along boundary layer shear vector

Event Types

• Shore-parallel bands
  – Type I: MidLake
  – Flow along major lake axis
  – Large lake-land temperature difference
  – Land-breeze fronts form one convergence zone
**Event Types**

- Shore-parallel bands
  - Type II: Shoreline bands
  - Form near lee shore
  - Land breeze opposes large-scale flow

**The Great Salt Lake**

**GSL Physiography**

- Length: 120 km
  - Lake Ontario: 311 km
- Width: 45 km
  - Lake Ontario: 85 km
- Area: \( 2500-5900 \text{ km}^2 \)
  - Lake Ontario: \( 19,000 \text{ km}^2 \)
- Average depth: 4.5 m
  - Lake Ontario: \( 86 \text{ m} \)
- Surrounded by steeply sloped mountains
  - Lake Ontario: Tug Hill (500 m above lake level)
- Salinity
  - Gilbert Bay: 6-12%
  - Cowhorn Bay: 15%

**Elevation, Depth, and Area**

**Salinity**

- South arm salinity: 13%
- North arm salinity: 27%

**Temperature Climatology**

- GSL
- SLC
- SLC
- SLC
The GSL-Effect
Morphology and Climatology

Morphology

Pure and “Contaminated”

Weakly or Non Banded Event

Banded Event
Cloud Band

Discussion

Seasonality

Mean Cool Season SWE

Rare but Intense Events Dominate

- Bimodal seasonality in event frequency
- Primary LEP SWE peak in fall

Without 100 inch storm

Lots of small events

Rare but Intense Events Dominate
Interannual Variability

Key Ingredients

- Instability
  - lake–700-mb ΔT>16°C
  - 16°C is approximately a dry adiabatic lapse rate
  - Alcott et al. (2012) show important exceptions exist
    - Events are moist and exclusively in Dec–Feb

- Upstream Moisture
- Wind Direction/Fetch
- Land-Breeze Convergence

Moisture

More on Instability/Moisture
Wind Direction/Fetch

Diurnal Variability

Diurnal Variability

Lake–Land ΔT

Discussion

Why is the correlation between environmental conditions and the occurrence and intensity of lake-effect so limited?

What does this mean for weather prediction?

The GSL-Effect

Shoreline Band Dynamics
7 December 1998 Event

- Two lake-effect snowbands merged into a shoreline band
- Heaviest snow (up to 36 cm) concentrated in a narrow, 10-km wide band over Tooele County

Total Snowfall (cm)

Initiation Phase

Mature Phase
Mature Phase

Moisture Flux Sensitivity

Moisture Flux Sensitivity

Orographic Effects

Potential Orographic Effects

- Precipitation enhancement
- Modification of the lake-effect system
  - Initiation, intensity, morphology
- Lake-effect systems can be altered by upstream and downstream topography

Precipitation Enhancement
System Modification: 27 Oct 2010

Terrain Sensitivity

Upstream Influences

Upstream Influences

Upstream Influences

Downstream Influences
Blocking

Microphysical Considerations

27 Oct 2010 Summary

Discussion

Lake Dominated

Orographic Dominated

What controls the relative contribution of lake and orographic effects on lake-effect systems?

Why are some events "lake-dominated"?

Why are others influenced strongly by lake-orographic interactions?

Hokuriku District

Japan

Lake

Orographic

Elevation: sea level

Population: 205,000

Annual SWE: 108" (276 cm)

Annual Snow: 248" (630 cm)

Record Snow: 590" (1499 cm)

Probably the snowiest urban area in the world

Steenburgh (2014), GoogleEarth, JMA via Wikipedia
Hokkaido Island


Kutchan, Hokkaido Island
Elevation: 180 m
Population: 15,000
Annual Snow: 480” (1220 cm)

Mountains

Probably the snowiest near-sea-level location in the world


Orographic Enhancement

Saito et al. (1996) increased upward motion

Sub-cloud sublimation

Sea of Japan

More ice nucleation at colder temperatures

Orographic Enhancement

Importance of the CAP

Magono et al. (1966)

CAP = Capping Inversion or Stable Layer

Hypothesis: Height of CAP relative to mountain crest affects orographic ratio

Yamayuki Storms: Produce more snow in the mountains
Satoyuki Storms: Produce more snow in the coastal lowlands

Hypothesis: Height of CAP relative to mountain crest affects orographic ratio

Mechanisms of Orographic Enhancement

Mechanisms of Orographic Enhancement

Conventional Wisdom

Lackmann (2011)

Orographic lifting invigorates convection
(i.e., larger updrafts speeds and cloud depths)
OWLeS Orographic Transect

Sandy Island Beach (83 m)
Sandy Creek (162 m)
North Redfield (385 m)
Upper Plateau (543 m)

MicroRainRadars (MRRs)

IOP7 Thundersnow
24 lightning flashes 0630–1120 UTC
Surface Temps -10 to -19ºC

Snow and Water Equivalent Obs
Collected at Sandy Creek (lowland, 162 m MSL) and North Redfield (upland, 385 m MSL)

Automated Met, Snow Depth, SWE
Manual Snow Depth, SWE

SnowCam

IOP2: MRRs

Surface Temps -10 to -19ºC

IOP2 CFADs

All 29 Events @ SIB & NR

NR: echoes shallower, more consistent (narrower IQR), and more frequent near ground
Conventional Wisdom

Orographic lifting invigorates convection
Lackmann (2011)

Summary

- Many processes influence lake-effect systems
  - Upstream instability and moisture
  - Lake conditions (surface temperature, sub-surface temperature, salinity, ice cover)
  - Land breezes and PBL circulations
  - Orography

- Orographic influences not only include precipitation enhancement, but also the initiation, intensity, and morphology of lake-effect systems

Unresolved Issues

- Morphological controls
- Role of the CAP in modulating orographic enhancement
- Mechanisms of orographic enhancement
- Understanding (and predicting) the spectrum of lake-driven and terrain-driven processes that influence lake-effect storms in areas of complex terrain
- GSL: Interdecadal variability & lake size

References


