Spatial Modeling of Atmospheric Icing Hazards

by

Luc Chouinard, McGill University
Reza Erfani, McGill University

Second IFED forum, April 26-29, Lake Louise
Plan of Presentation

• Background and issues
• Methodology
• Example
• Discussion of results
• Conclusions and recommendations
Design criteria

- Based on load combination scenarios for wind speed and ice accumulation
- Current codes are derived from synthetic storm data or direct observations at meteorological stations
  - Relatively small number of stations
  - Relatively short records
  - Grouping of stations and interpolation
Design criteria

• Structures most sensitive to wind and ice loads
  – Telecommunication tower
  – Electric transmission and distribution lines (higher exposure)
Design criteria

• Issues
  – Spatial variation of severity of ice storms (regional)
    • Ice accumulation
    • Wind speed
    • Wind direction
  – Local effects (topography)
  – Within storm variability
Background

• 1998 a major storm affected more than 3 million people in eastern Canada and caused major damage.
1998 Ice storm
1998 Ice storm footprint
Design criteria

- Extreme storms such as 1998 do not fit historical data
- No consensus on the return period to assign to these extreme storms
- Actual failure rate of transmission and distribution lines is large (estimated at 5 times the target value)
- Current design criteria does not account for the size of the footprint of major storms.
Objective

• Develop models that are based on a regional analysis of ice storm patterns (cyclones and anti-cyclones)
  – Types of possible storms
    • Recurrence rate
    • Severity (e.g. duration, footprint)

• Account for local effects
  – Topography
  – Within storm variability
Advantages

• Reduction of the uncertainty on the estimation of extreme events
• Can develop relationships with meteorological and climatic factors
• Can be used in climate change research (predictions)
Approach used for hurricane hazards

• Model recurrence rate of storms in space
• Model distribution of severity of storms in space
• Model effect of storms at a site
  – Significant wave height (offshore platforms)
• Many similarities with earthquake hazard models
Storm tracks

The 100 most severe hurricane tracks from 1900 to 1990
Random line process
Spatial effects associated with the recurrence rate of storms (statistically significant)

Second IFED forum, April 26-29, Lake Louise
Other source of spatial variability: storm severity
Spatial effect associated with storm severity (statistically significant)

99th Fractile Probability of Hurricane Severity (Lognormal)

Second IFED forum, April 26-29, Lake Louise
A physical explanation for the model

Mean subsurface water temperature

Longitude

Latitude

Second IFED forum, April 26-29,
Lake Louise
Significant wave height
\[ \rho[h_s(x)] = \int_{d=-\infty}^{\infty} \int_{\alpha=0}^{\infty} \lambda(d, \alpha) \cdot f(H_{s \max} | d, \alpha) \cdot P[H_s > h_s | H_{s \max}, d, \alpha] \cdot d\alpha \cdot dd \cdot dH_{s \max} \]

\( \lambda(d, \alpha) \) Annual recurrence rate of hurricane

\( f(H_{s \max} | d, \alpha) \): Probability distribution function of hurricane severity

\( P[H_s > h_s | H_{s \max}, d, \alpha] \): Attenuation function

- Can be easily be adapted to perform portfolio analysis of multiple platforms
Anatomy of an ice storm

The ice storm that has gripped Quebec and Eastern Ontario all week has been strong both in the amount of rain it has dropped and its endurance. Here's why:

1. One after another through the week, three warm-air masses move up from the Gulf of Mexico, taking moisture north to Ontario and Quebec.

2. A stationary mass of cold air forces the warm air to rise, causing precipitation to begin.

3. Precipitation falls in different forms depending on the temperature of the air that it meets on the way down:

- **Warm air**
  - Melts snow into rain over Quebec and eastern Ontario.
  - The bank of cold air supercools it, keeping it in liquid form but a few degrees below 0. When it hits cold objects on the ground, it freezes quickly—this is freezing rain.

- **Cold air**
  - Precipitation falls through cold air over P.E.I., causing a snow storm.

Diagrams are schematic
Cyclone tracks

- Cyclone tracks (warm moist air) during the months from December to March (Leech, McGill 1978)
Recurrence rate of cyclones

Strong regional dependency for the recurrence rate of cyclones
However, neglects the other element which is the presence of cold air
• Jones (2003) mapped the footprint of major ice storms.
• Confirms that recurrence rate of cyclones is incomplete predictor of ice storm severity
• Rauber et al. (2001) analysed 411 ice storms

• Identified 7 major patterns
  – Arctic front/anticyclone
  – Warm front/occlusion sector of cyclones
  – Cyclone/anticyclone
  – Western quadrant of Arctic high pressure
  – Cold air damming
  – Cold air damming with Atlantic cyclone
  – Cold air trapping

• A storm can be composed of a series of patterns (A,C)

• Patterns A and C generate storms with the longest duration

• Affects
  – Recurrence rate
  – Duration
  – Spatial extent
  – Location

• Subjective assessment of fronts
Objective identification of dominant storm patterns

- Collaboration with J. Gyakum – Atmospheric sciences, McGill University
  - Meteorological data (observation of ice storms)
  - NOAA reanalysis data
    - sea level pressure,
    - 1000-925 mb thickness anomalies
    - 1000-500 mb thickness anomalies
Temperature inversions

Lake Louise
1998 Ice Storm 1000-500 mb Anomaly

• Characteristic positive anomaly above Montreal (hot air aloft)
1997 Ice Storm 1000-500 mb Anomaly
Analysis of dominant patterns of 1000 to 500 mb anomalies

- Sample of major storms affecting southern Quebec
- Sample of 1000-500 mb anomalies for corresponding periods
- Principal component analysis of individual storms to develop a classification
Dominant patterns during the 1998 ice storm (storm evolution A-C)
• Correlations with footprints and duration
Local effects (topography)

- Traps cold air
- Redirects winds
- 12 to 17% increase in ice accumulation

Second IFED forum, April 26-29, Lake Louise
Within storm variability and footprint (R. Stewart – Atmospheric sciences)
Conclusions

• Analysis of extreme meteorological events is difficult on a local scale (stations) with small data sets.
• Using a regional approach helps increase the sample size and distinguish between storm populations.
• Spatial effects
  – Regional scale
  – Local scale
• Analysis of hazards is performed by integrating risk associated with each type of storm
  – Recurrence rate
  – Severity (duration)
  – Spatial extent
Thank you

Second IFED forum, April 26-29, Lake Louise