Tree-Related Line Faults On the Power Distribution Grid During Windstorms That Affect Southwest British Columbia, Canada

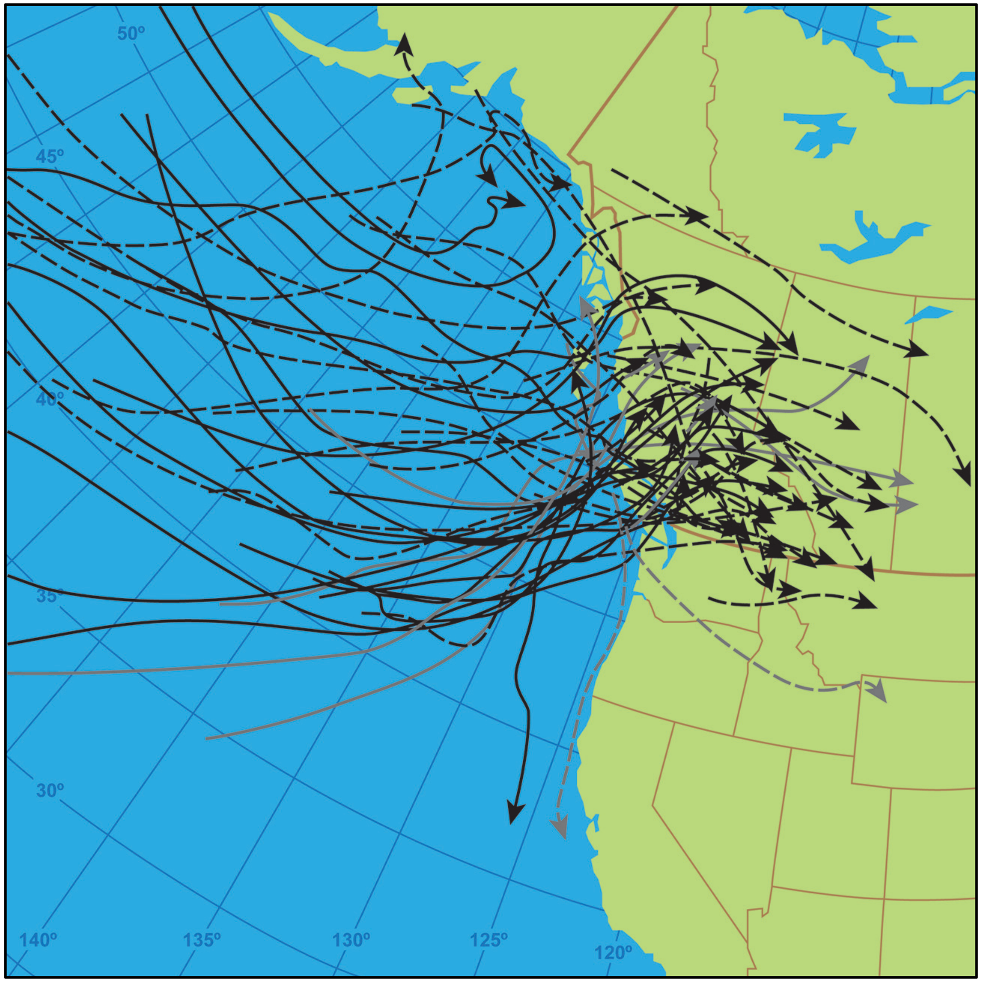
Wolf Read
PhD Candidate
Forest and Conservation Sciences
University of British Columbia
wolf@alumni.ubc.ca

Outline

- Introduction: Windstorms that affect southwest British Columbia (BC)
  - The 1962 Columbus Day Storm
- Methods
- Independent storm peak 2-min wind and associated line faults
  - Projections for a repeat of the 1962 Columbus Day Storm
- Conclusions

Southwest BC Windstorms

- Windstorms are an endemic feature of BC climate
- Low-center tracks of all high-wind storms that affected Greater Vancouver and/or Victoria 1994-2012
- Line type based on peak wind direction at Vancouver:
  - Solid black, SE
  - Dashed black, W
  - Solid gray, S & SW
  - Dashed gray, E



Southwest BC Windstorms

- These windstorms typically produce wind gusts in the range of 90-105 km h^{-1} in the major urban centers, rarely ≥125 km h^{-1}
- Can cause widespread destruction of property
- All high windstorms cause damage to the electrical distribution grid
  - Threatens life (e.g. hospitals on emergency power, home heating with improperly ventilated generators)
  - Disrupts commerce (e.g. computers and cash registers shut off)
  - Disrupts traffic (e.g. traffic signals off)

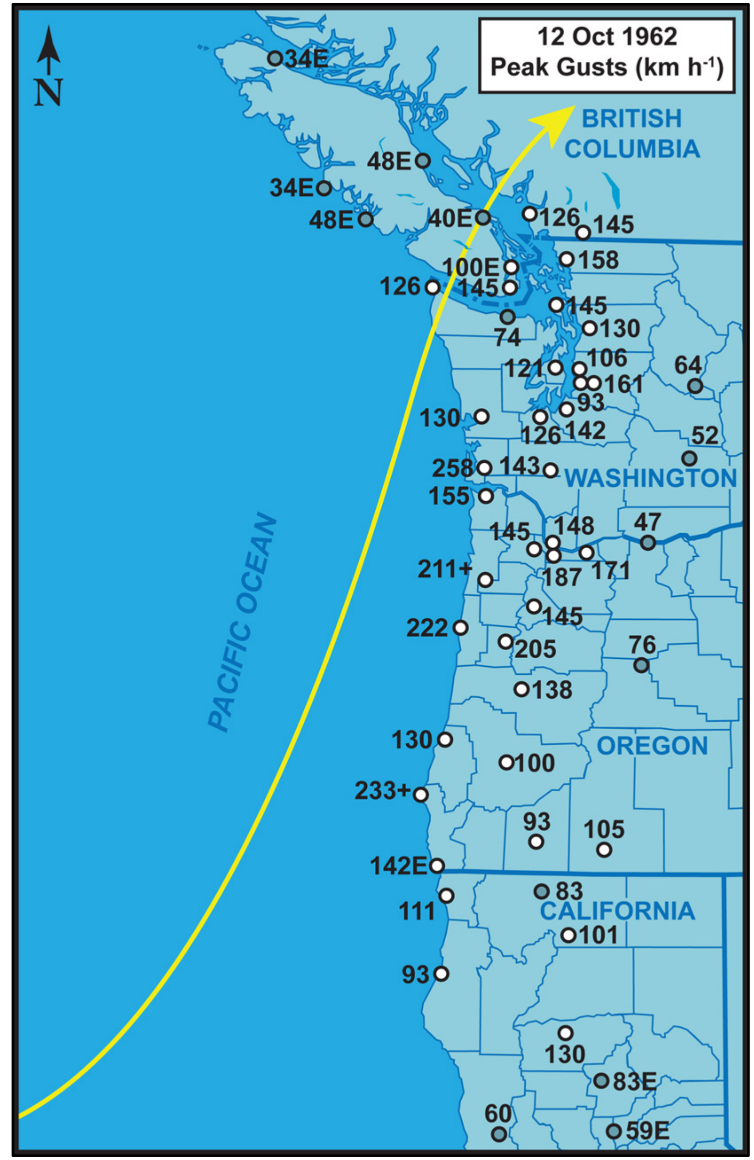
Southwest BC Windstorms

The 1962 Columbus Day Storm
(AKA Typhoon Freda)

- The most destructive windstorm on record for the region

- Peak gusts include:
    - 126 km h^{-1} at Vancouver
    - 145 km h^{-1} at Abbotsford
    - 145 km h^{-1} at Victoria Gonzales

- Catastrophic damage to the power grid:
    - 67% of the entire BC Hydro customer base without power
    - 15% during the 15 Dec 2006 Hanukkah Eve Storm



Methods

- Hourly and Special observations from Environment Canada for stations in southwest BC, including:
  - Vancouver (CYVR)
  - Abbotsford (CYXX)

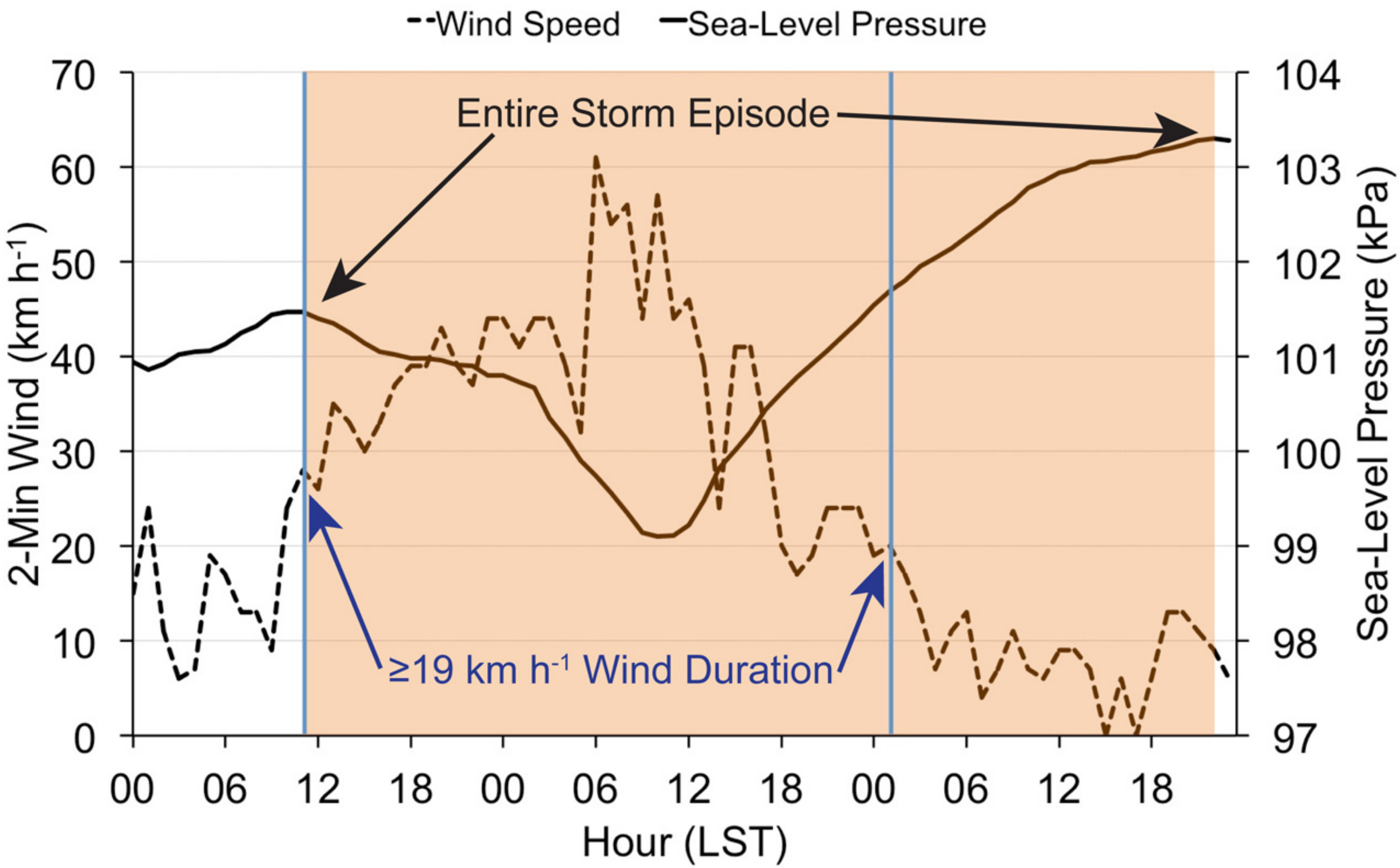
- Power outage dataset from BC Hydro covering the period October 2005 to August 2009, including:
  - Time of outage
  - Outage type (e.g. forced, planned)
  - Cause of outage (e.g. tree/branch, wildlife)
  - Location information (circuit number, equipment ID, lat/long)
  - Number of customers affected

Methods

- For the Oct 2005 to Aug 2009 period:
- Manually determined all independent storms with a peak wind of >40 km h^{-1} (22 knots) at either CYVR or CYXX
  - Isolated 119 events
- Wind duration was bounded by the first and last observation of ≥19 km h^{-1} (10 knots, 80^{th} percentile) within the pressure fall and rise phase of a given storm
- Wind duration is the range of time in which all outages were counted
  - Allowed two extra hours at each end to account for spatial variation in wind across the Lower Mainland

Methods

11-13 November 2007 Windstorm at CYVR



Methods

Line Faults

- For the purposes of this analysis, a line fault is when any tree or branch impacts a line
- May not result in an outage, though most do
- Line faults that do not cause an outage tend to occur on the service drops (i.e. the line that goes from the utility pole to the home or business of a customer)
- Line faults not associated with an outage still have to be dealt with by line crews (e.g. removal of a branch hanging from wires)

Methods

Study Region

- 50 km radius of CYVR (dark red)
- Excludes Vancouver Island, some Gulf Islands and Washington State
- 491 individual distribution circuits

Methods

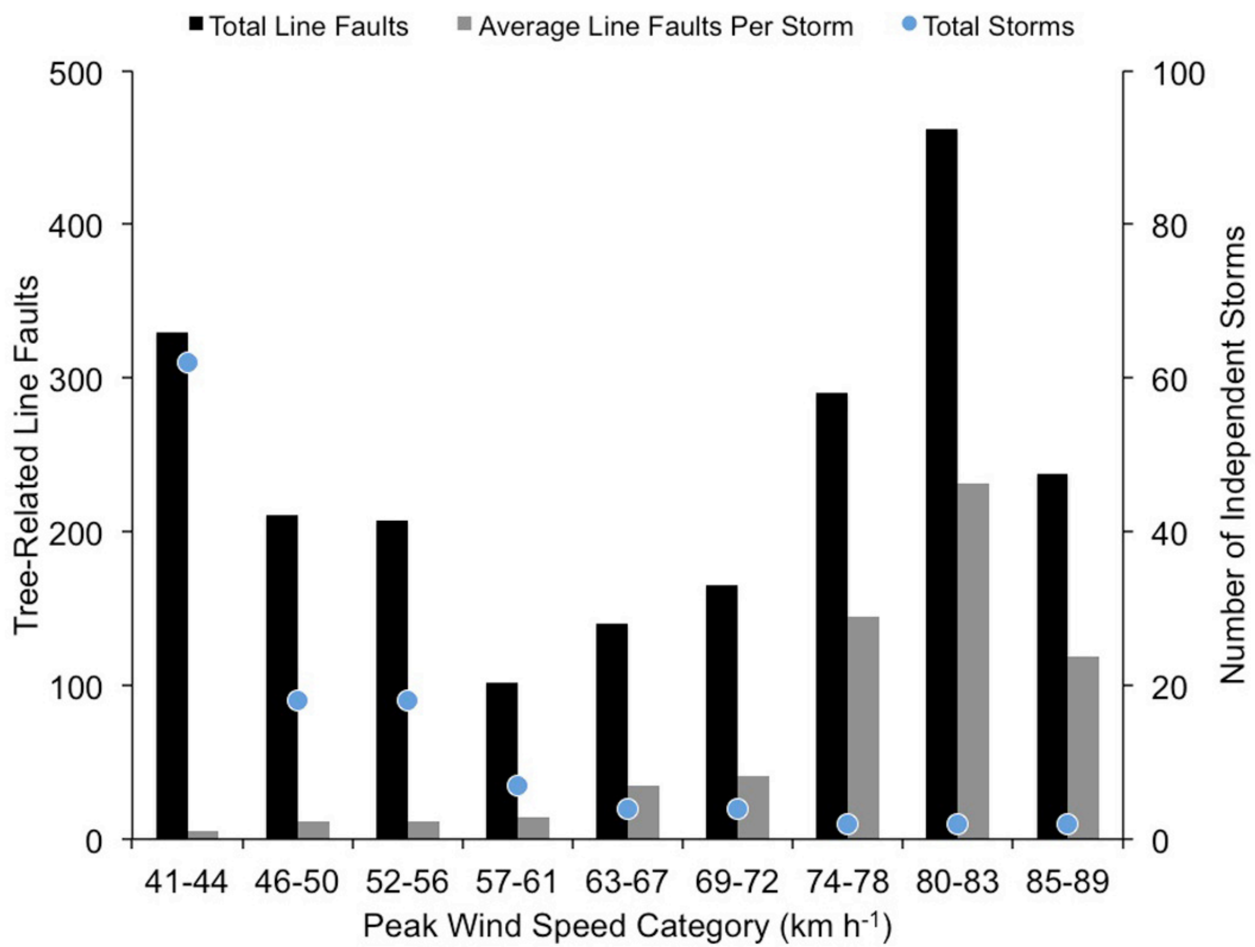
- For the Oct 2005 to Aug 2009 period:
- Isolated all tree-related line faults within a 50 km radius of CYVR
  - Returned 2146 incidents for the 119 storms
- Used this data to build linear and Poisson regression models
- Poisson regression is preferred because number of line faults is count data, and outage data do appear to have a Poisson distribution (Zhou et al. 2006)

Zhou, Y., Pahwa, A. and S. Yang, 2006: Modeling weather-related failures of overhead distribution lines. *Trans. Power Syst.*, 21, 2270-2279

Independent Storm Peak Wind and Line Faults

Line Fault Frequency For Given Wind Speeds

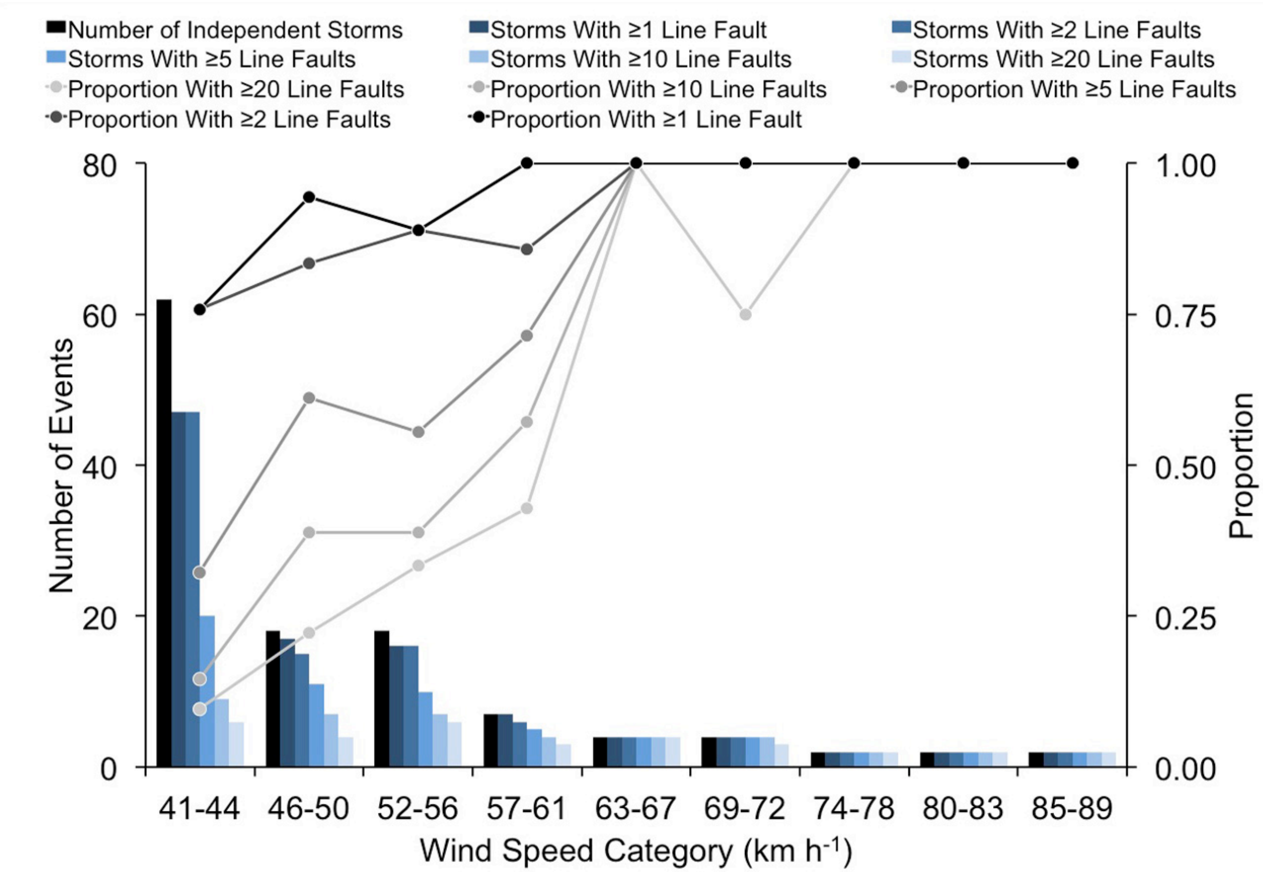
- Weaker storms produce a few line faults, but given the number of events the total is significant relative to other categories
- Strong windstorms ($\geq$ 74 km h^{-1}) tend to produce a high number of line faults per event
- There are only a few events at the top end



Independent Storm Peak Wind and Line Faults

Proportion of Events for a Given Line-Fault Magnitude

- Proportion of storms meeting the various line fault cutoffs approaches 100% at 63-67 km h^{-1}
- Right at minimum high-wind criteria (~65 km h^{-1})
- This appears to be a critical threshold
- Again, the sample size is small at the top end of the wind speed range



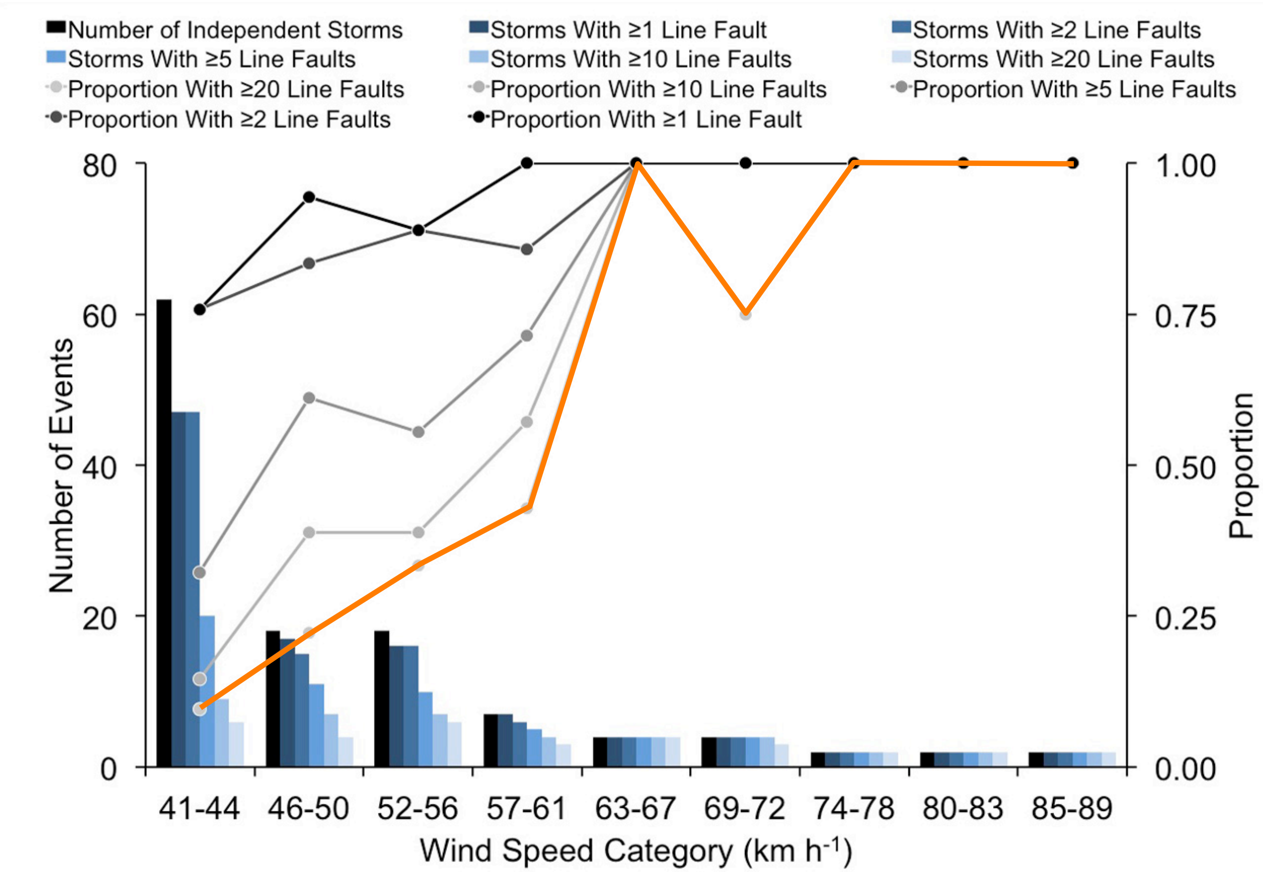
Independent Storm Peak Wind and Line Faults

Proportion of Events for a Given Line-Fault Magnitude

- A high percentage of storms producing ≥20 or more line faults in the study area were classified as "major disasters" by BC Hydro

- Especially for events with peak winds >50 km h^{-1}

- Major disaster = ≥100,000 customers affected (BC Hydro 2007)

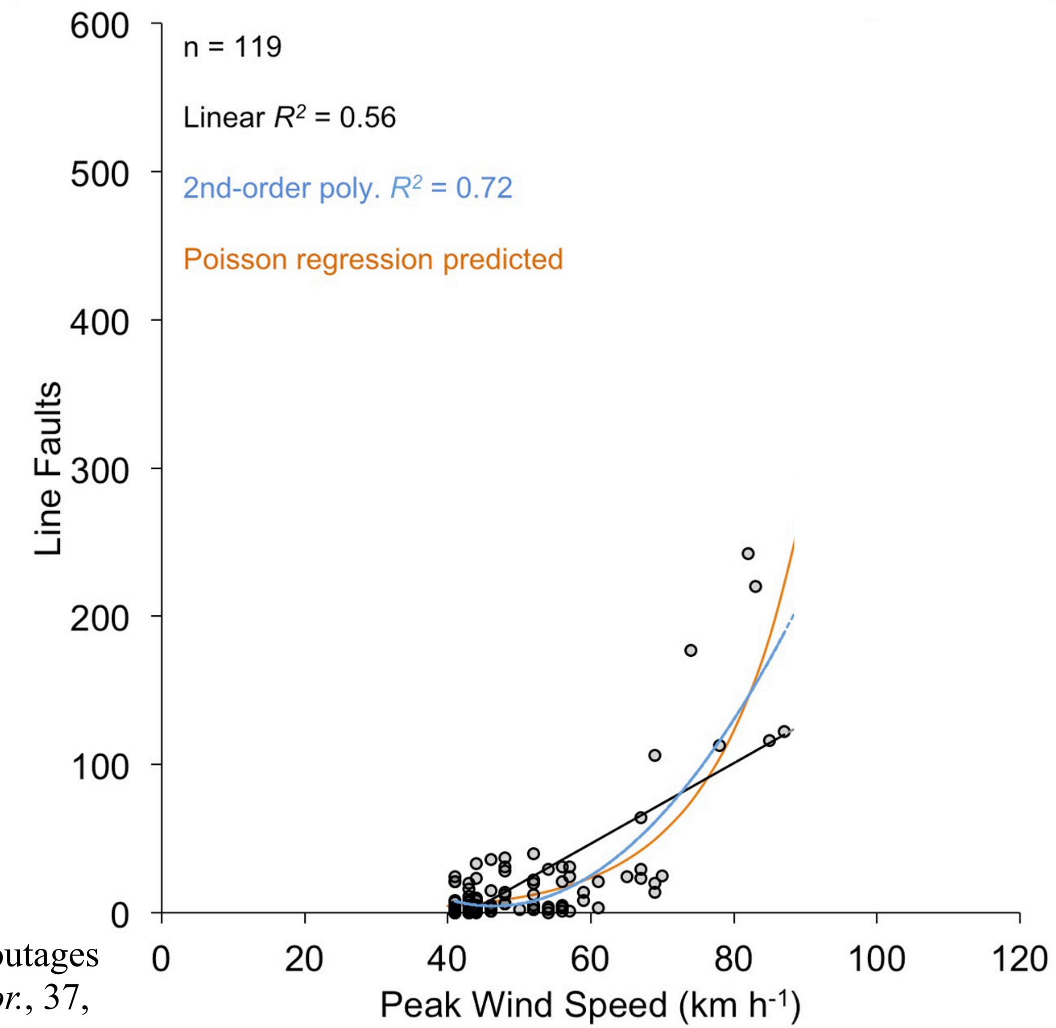


BC Hydro, 2007: BC Hydro winter storm report October 2006-January 2007. British Columbia Hydro, 108 pp.

Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

- Linear and polynomial regression show a moderate to moderately strong relationship (respectively)
- The Poisson regression predicted (and the polynomial best-fit) suggest that damage to the power grid increases exponentially with wind speed
- An exponential increase in damage has been reported in other studies (e.g. Guggenmoos 2011)

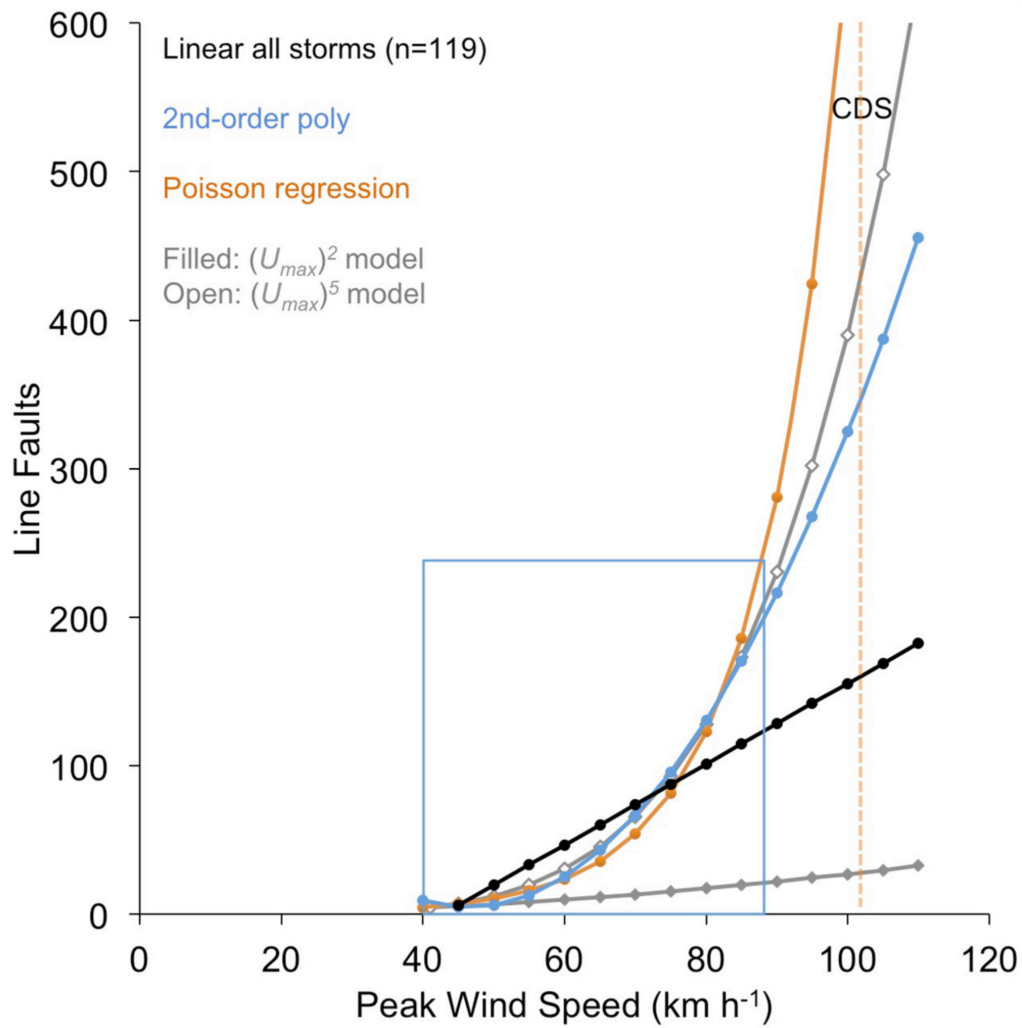


Guggenmoos, S., 2011: Tree-related electric outages due to wind loading. *Aboric. and Urban For.*, 37, 147-151.

Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

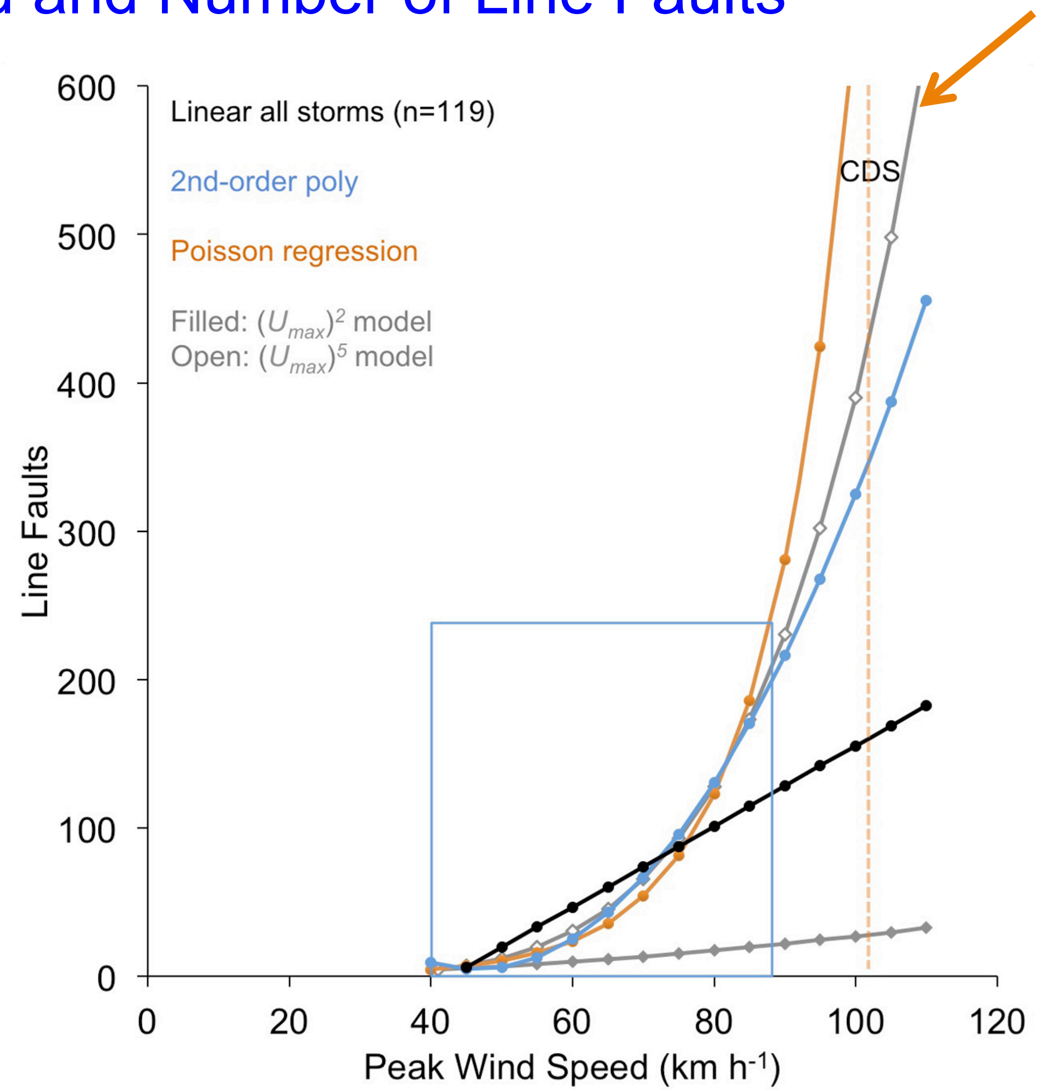
- Comparison of different models
- Blue box outlines the data range



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

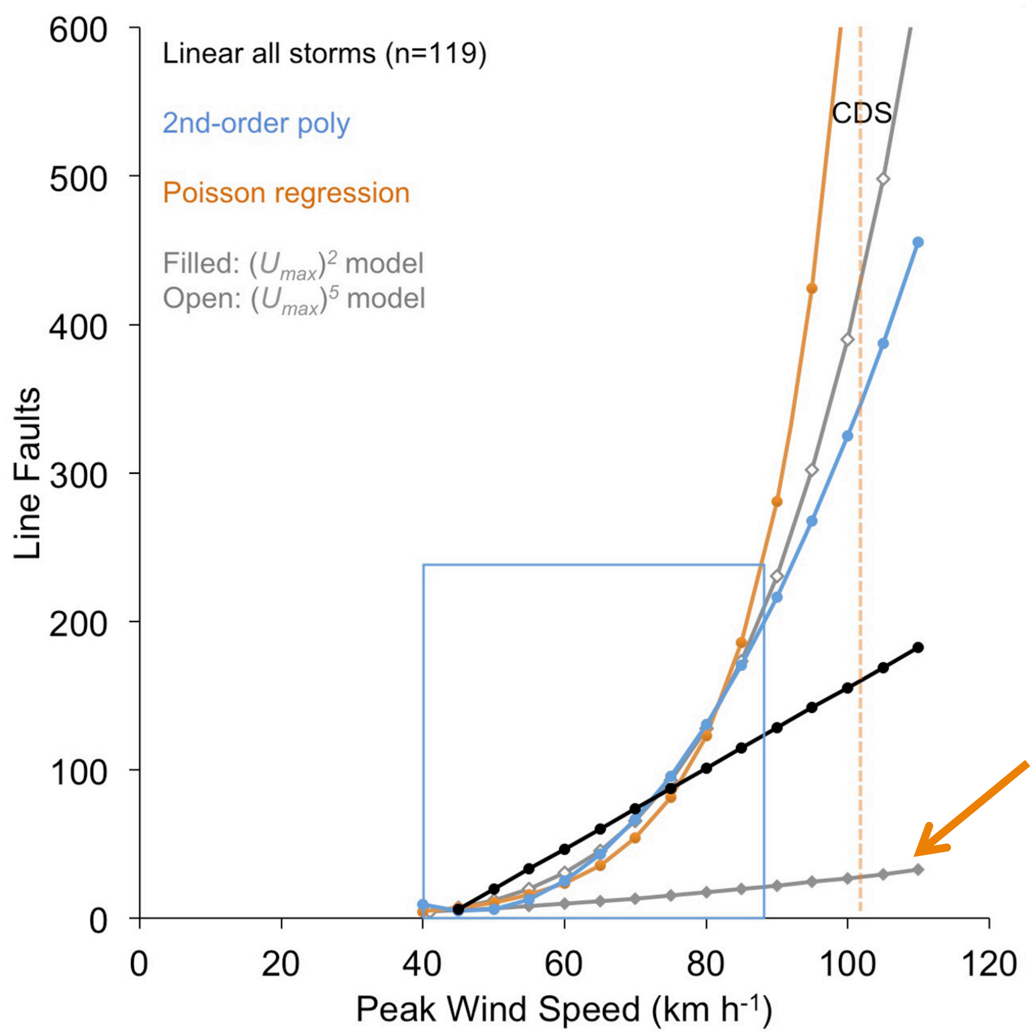
- A simple $(U_{max})^5$ model roughly approximates the Poisson regression predicted



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

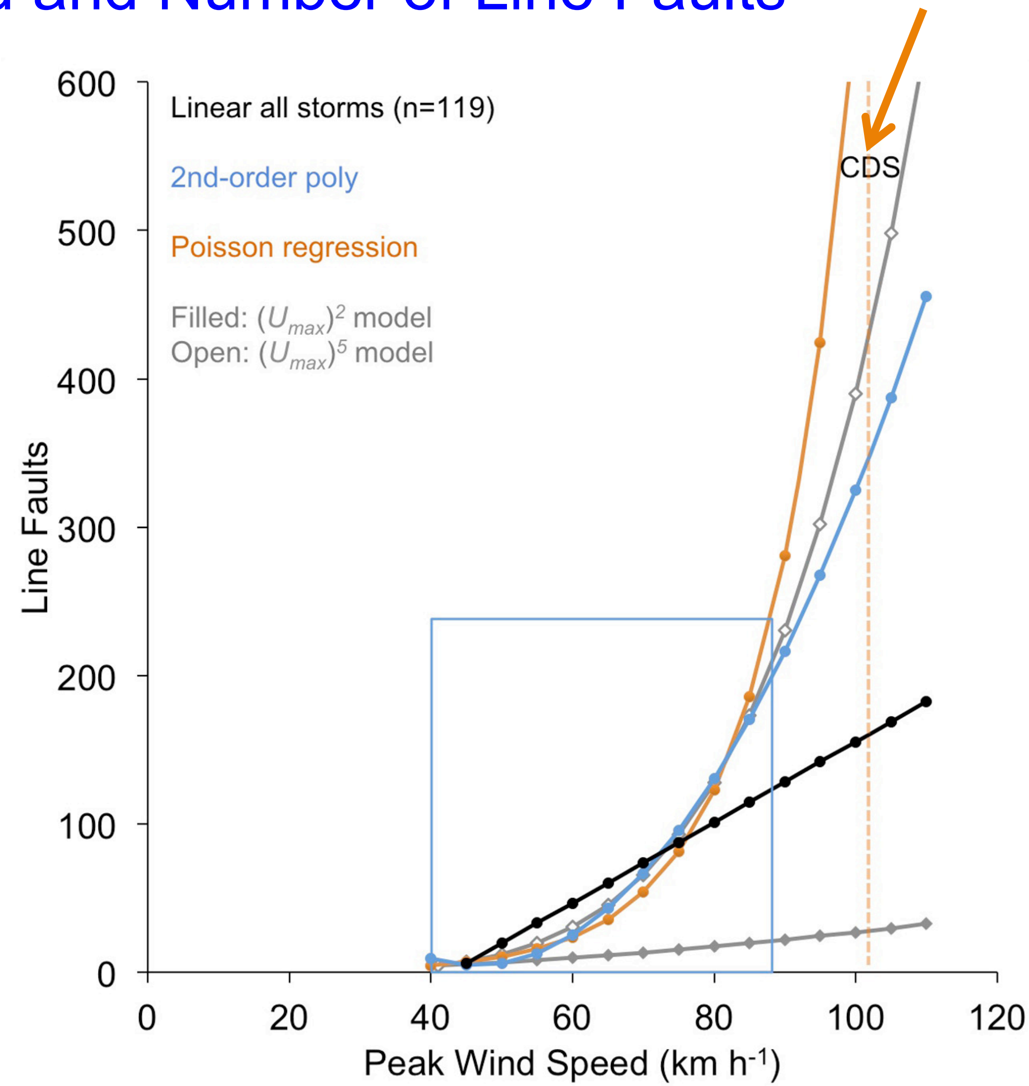
- A simple $(U_{max})^5$ model roughly approximates the Poisson regression predicted
- $(U_{max})^2$ (wind force increases with the square of velocity) is not close
- Both of these models are started from the average number of line faults for storms with a peak wind of 41 km h^{-1} (~4.5)



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

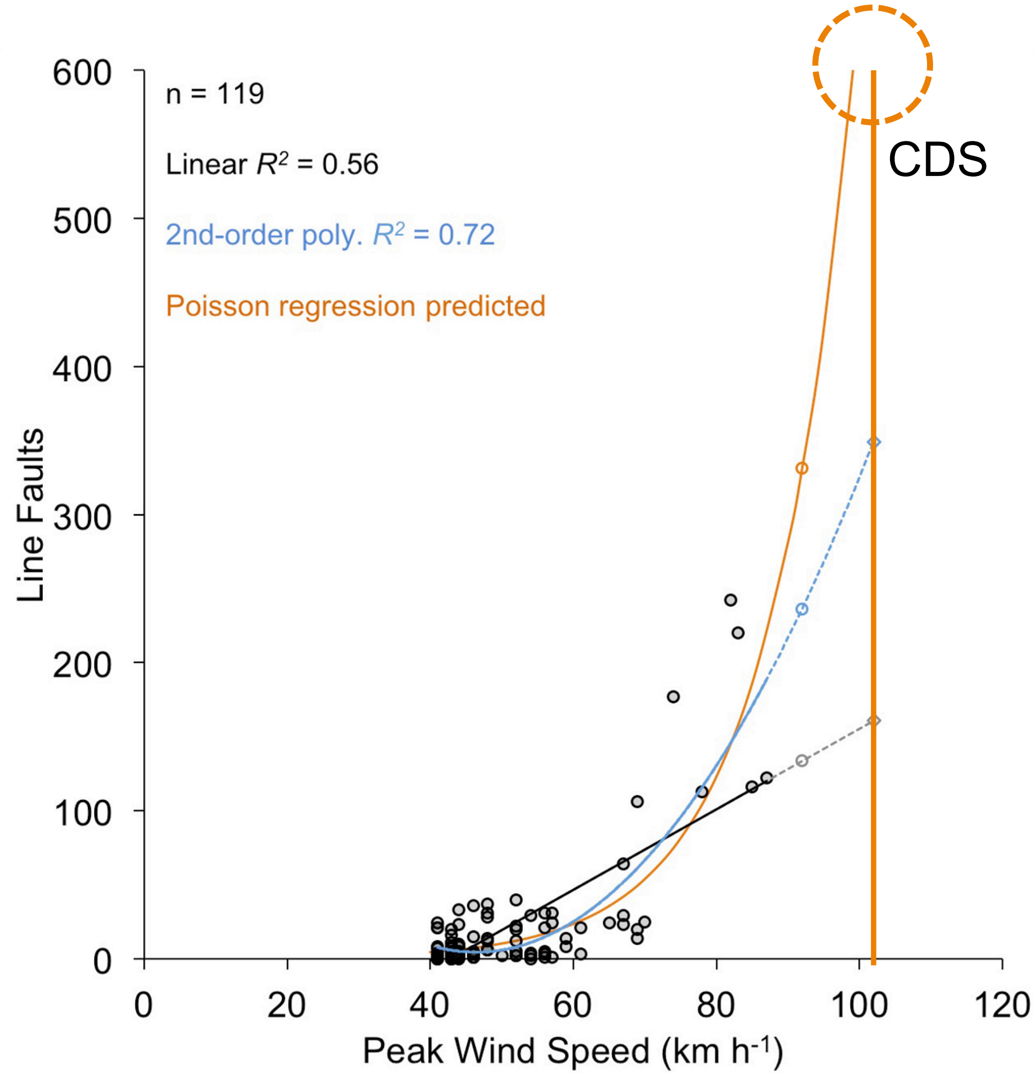
- CDS = Columbus Day Storm
- Estimated peak 2-min wind for CYXX (102 km h^{-1}), based on peak gust



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

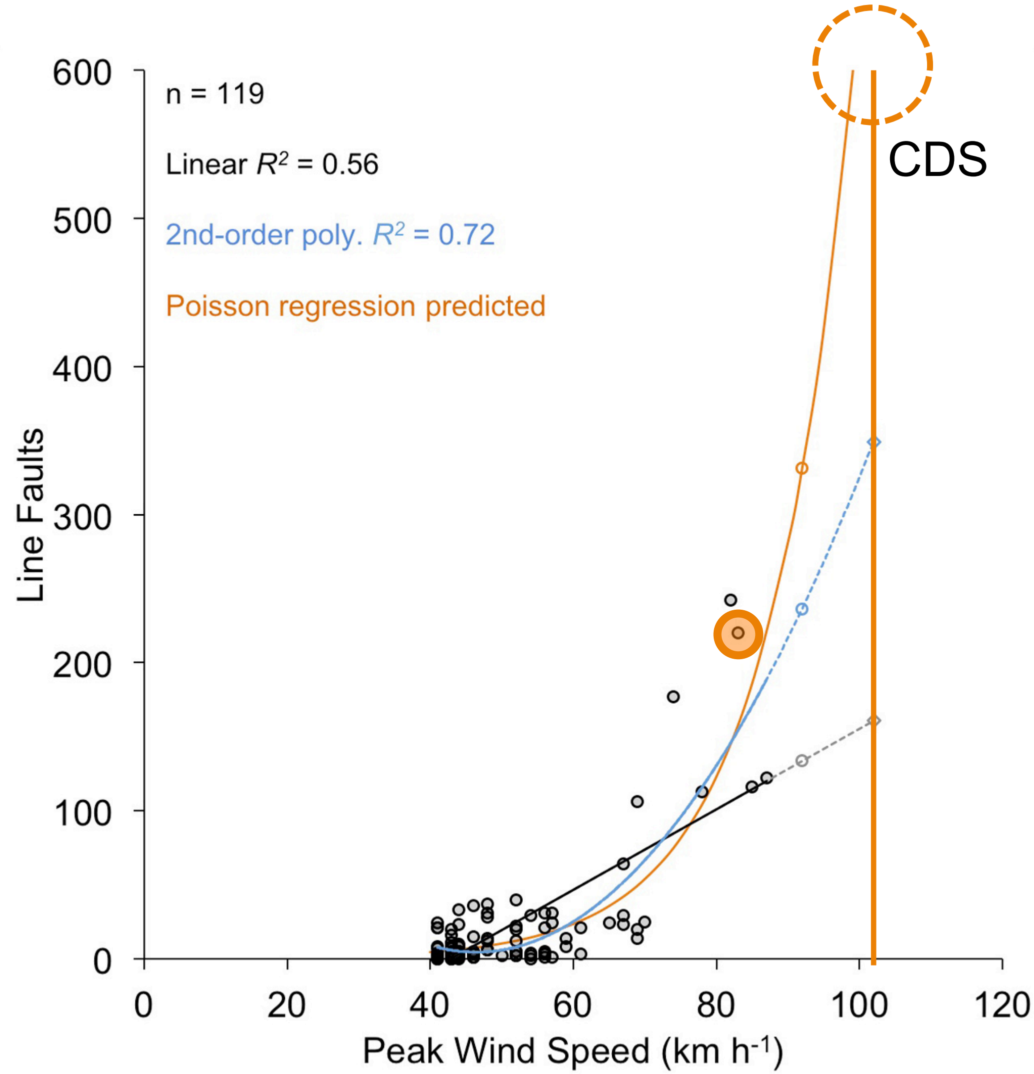
- When projected beyond the data range, the Poisson regression model suggests a catastrophic power grid impact for a repeat of the Columbus Day Storm
  - The predicted number of line faults, 757, is off the chart



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

- When projected beyond the data range, the Poisson regression model suggests a catastrophic power grid impact for a repeat of the Columbus Day Storm
  - The predicted number of line faults, 757, is off-chart
- Compare this to the 2006 Hanukkah Eve Storm, one of the most disruptive to the power grid in recent memory
  - 757 / 220 = 3.4 times



Independent Storm Peak Wind and Line Faults

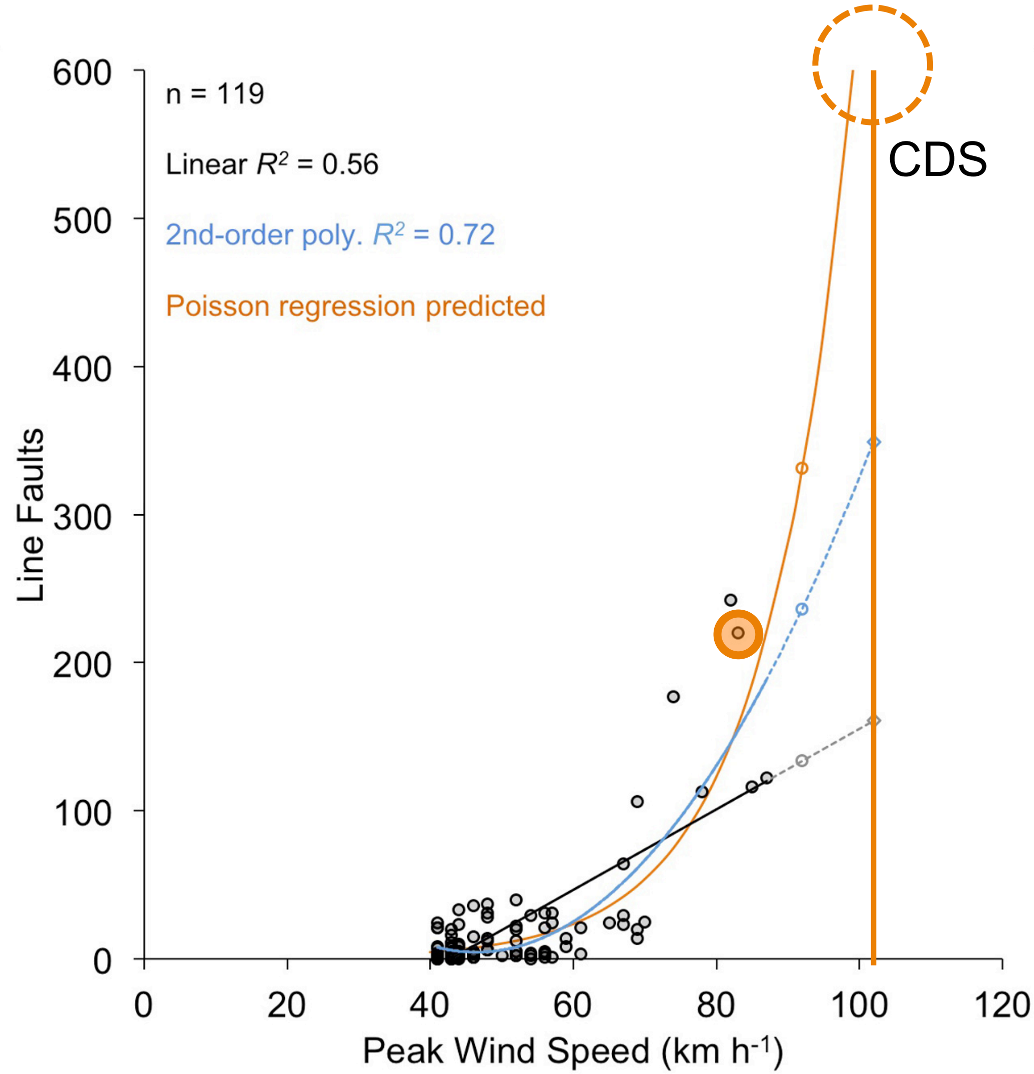
Peak Wind Speed and Number of Line Faults

- Multivariate Poisson regression models using combinations of

  i. peak gust;
  ii. peak wind direction;
  iii. storm total rainfall; and
  iv. storm duration

  suggest even higher tree-related line faults for a windstorm like the 1962 event

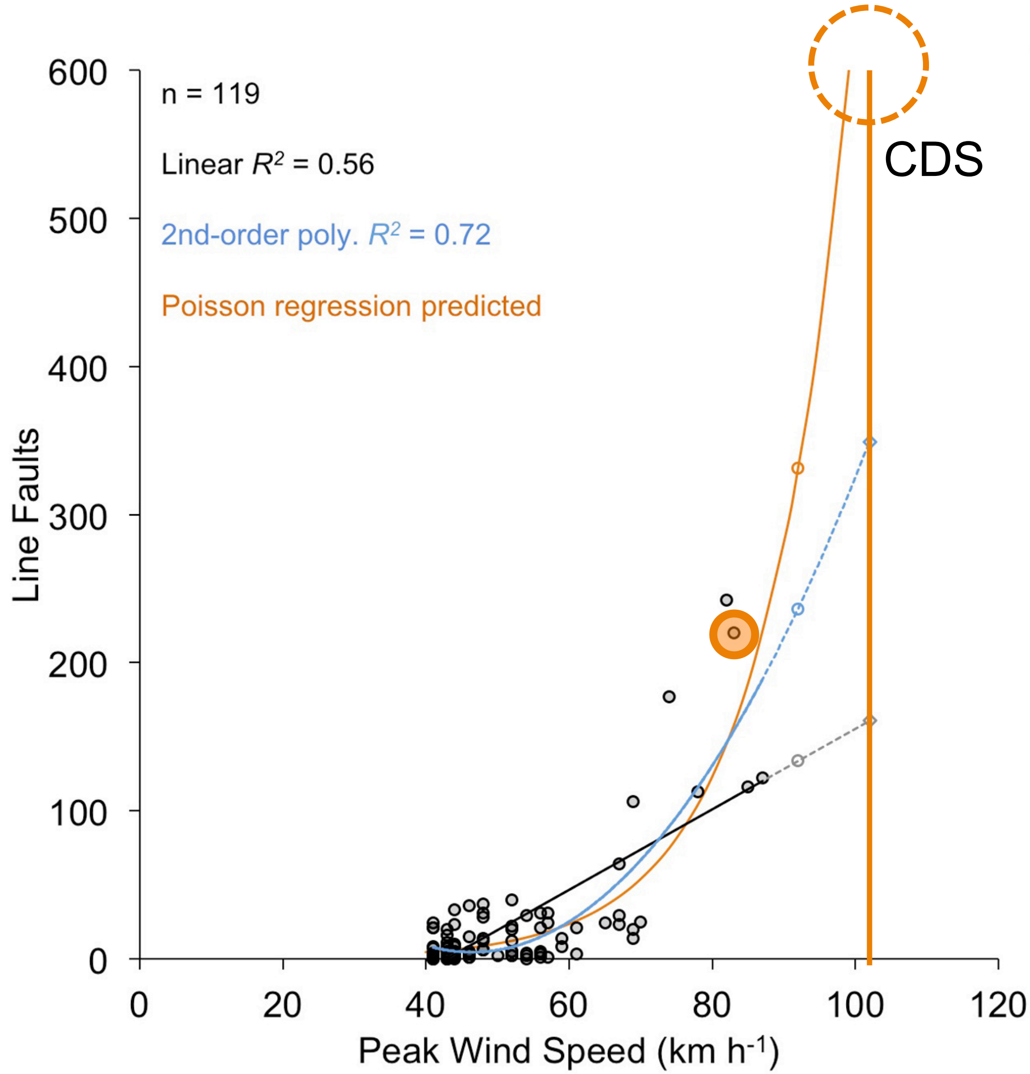
- 5 to 9 times the Hanukkah Eve Storm



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

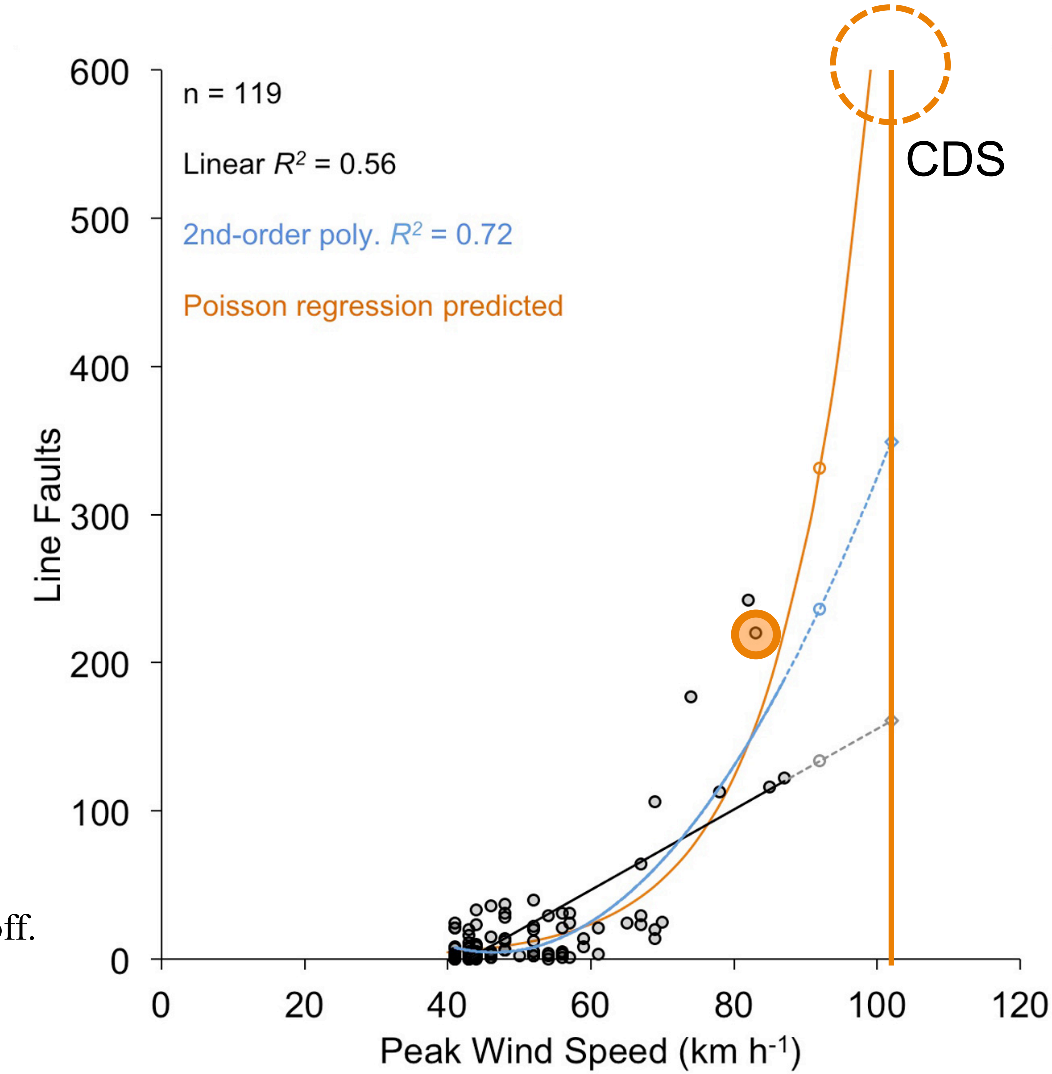
- Model projection beyond the data range is risky
- Especially for multivariate models
- And this dataset only has a few storms at the upper end, reducing confidence in projections



Independent Storm Peak Wind and Line Faults

Peak Wind Speed and Number of Line Faults

- However, anecdotal evidence supports a major disruption to the power grid (Bolwell 1962, Franklin n.d.):
  - 300,000 customers without power, 67% of the BCH customer base in 1962
  - 2006 storm 240,000 customers, only 15%
  - 67 / 15 = 4.5 times
  - People without power for a month
  - Steel lattice transmission towers destroyed
  - All-time record loss of trees



Bolwell, E., 1962: B.C. storm fatal to 6; power off. *The Globe and Mail*, 15 Oct 1962, 1.

Franklin, D., n.d.: West Coast Disaster. Gann Publishing Co., 180 pp.

Conclusions

- Modest storms with peak winds of 41-44 km h^{-1} can cause tree-related line faults in the study area, sometimes ≥20

- Moving up the range of peak winds from ~40-65 km h^{-1}, the probability of producing ≥20 line faults, a useful but imperfect indicator for a BC Hydro “major disaster”, in the study area approaches 100%

- There appears to be a moderately strong relationship between independent storm peak wind and total number of line faults

- The Poisson regression model indicates that the number of line faults increases exponentially with wind speed

- Model projections suggest catastrophic damage—outside anything seen in recent decades—to the power grid for a windstorm approaching the 1962 Columbus Day Storm in strength

Thank You

- Questions / Comments

Wolf Read
PhD Candidate
Forest and Conservation Sciences
University of British Columbia
wolf@alumni.ubc.ca

References:

BC Hydro, 2007: BC Hydro winter storm report October 2006-January 2007. British Columbia Hydro, 108 pp.

Bolwell, E., 1962: B.C. storm fatal to 6; power off. *The Globe and Mail*, 15 Oct 1962, 1.

Franklin, D., n.d.: West Coast Disaster. Gann Publishing Co., 180 pp.

Guggenmoos, S., 2011: Tree-related electric outages due to wind loading. *Aboric. and Urban For.*, 37, 147-151.

Zhou, Y., Pahwa, A. and S. Yang, 2006: Modeling weather-related failures of overhead distribution lines. *Trans. Power Syst.*, 21, 2270-2279

Project funded in part by:

- MITACS
- NSERC
- BCTC (Now folded into BC Hydro)

Appendix

- The following slides were excluded to shorten the presentation

Methods

- In addition, summed up the number of line faults per hour during four strong windstorms:
  - 15 Nov 2006
  - 11 Dec 2006
  - 15 Dec 2006
  - 12 Nov 2007

- The start and beginning points of the wind surge for a given storm were determined by: (1 / Euler's Number) • U_{max}

- Hourly 2-min wind speed was related to hourly line faults using linear regression
  - To look for possible lag effects, wind observations were shifted up to 3 hr in either direction from the designated zero time
  - E.g. For *t* 0, outages for 1401-1500 HRS were compared to the 1500 wind report, *t*-1 1400 and *t*+1 1600

Independent Storm Peak Wind And Line Faults