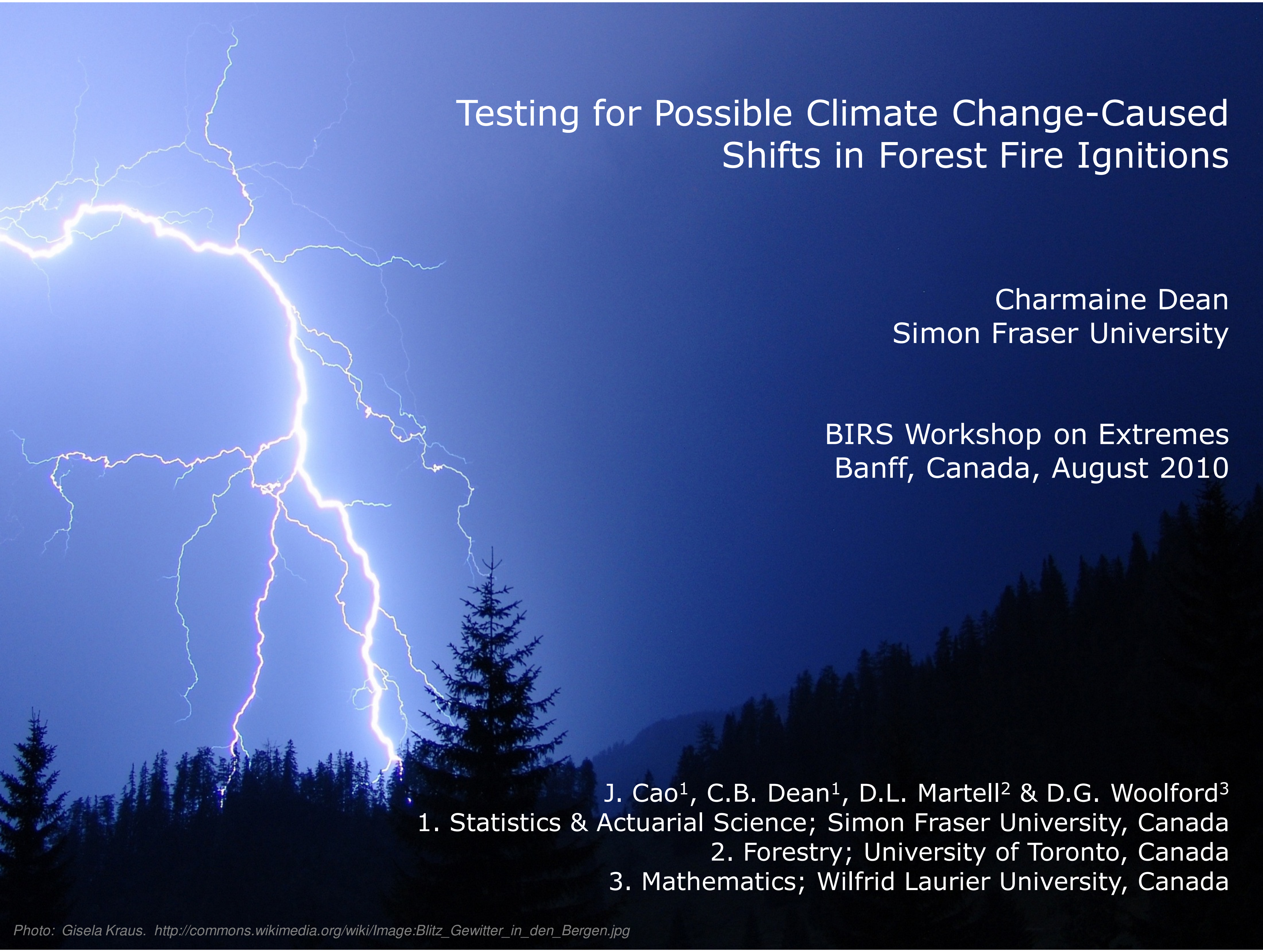

Testing for Possible Climate Change-Caused Shifts in Forest Fire Ignitions

Charmaine Dean
Simon Fraser University

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J. Cao[1], C.B. Dean[1], D.L. Martell[2] & D.G. Woolford[3]
1. Statistics & Actuarial Science; Simon Fraser University, Canada
2. Forestry; University of Toronto, Canada
3. Mathematics; Wilfrid Laurier University, Canada

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Canadian National Forestry Project

Currently, the project has three main areas...

1. Forest Fire Management
2. Forest Ecology
3. Prometheus Fire Growth Simulation Model

Historical Fire Data – Seasonality and Trends in Ignitions: Overview

- Introduction: climate change and forest fires
- Data and study area
- Exploratory work using generalized additive models
- Finite mixture modelling framework
- Ongoing Work
- Points for Discussion

Introduction

- Fires are a significant natural disturbance in forested ecosystems

- Ontario, Canada from 1996–2005:
  - ✓ ~ 13,000 wildfires
  - ✓ ~ 1.5 million hectares burned
  - ✓ ~ 54% due to lightning
  - ✓ lightning fires accounted for 80% of the total burned area

- There is a need to characterize these regimes, especially under the uncertainty of climate change

Photos:
Ontario Ministry of Natural Resources

Climate Change & Forest Fires

- Weber & Stocks (1998): increasing temperatures could
  - ✓ increase number of ignitions
  - ✓ extend fire season
  - ✓ increase amount of severe fire-weather


Thunder Bay Fire # 37 (May 2007).
Ontario Ministry of Natural Resources

- Studies using forecasts from climate model have suggested increased severity ratings[1], area burned[2] & ignitions[3]

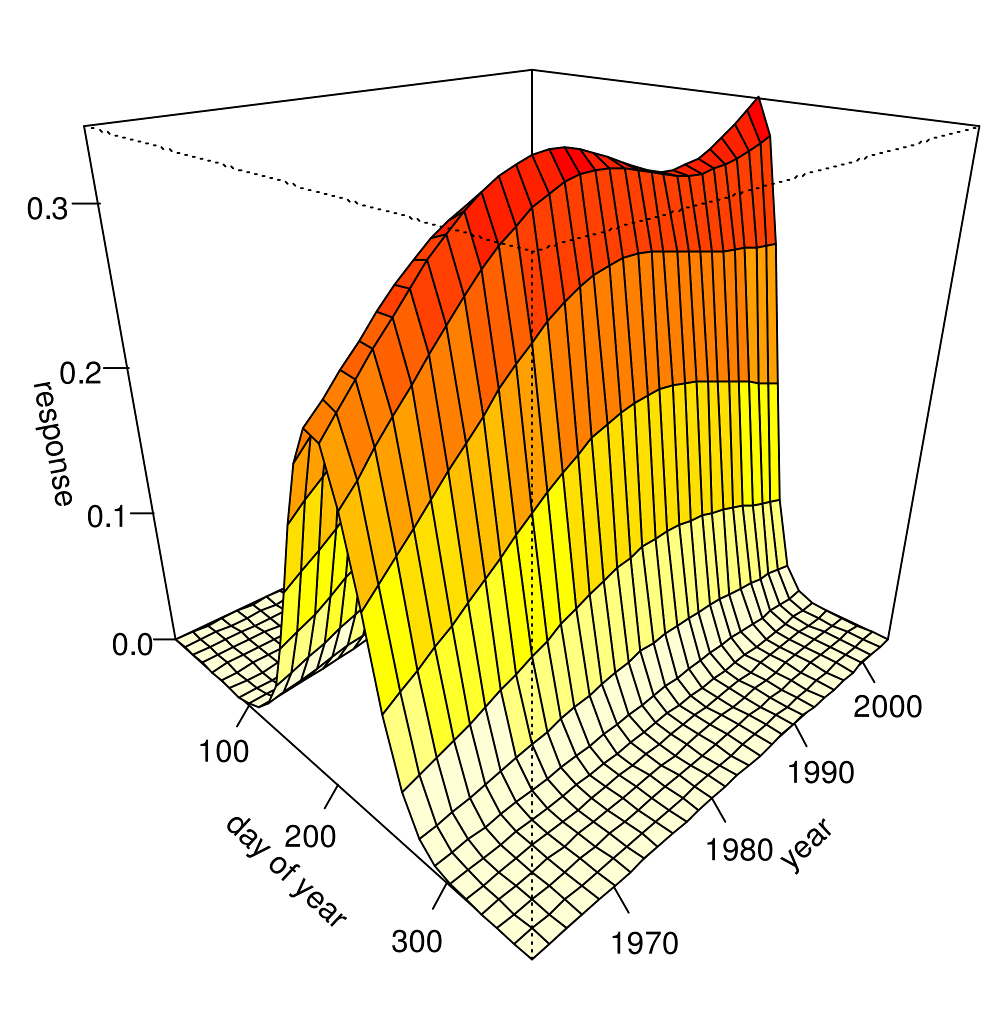
- A quality-control analysis of historical fire records found changes in variance for ignitions and area burned[4]

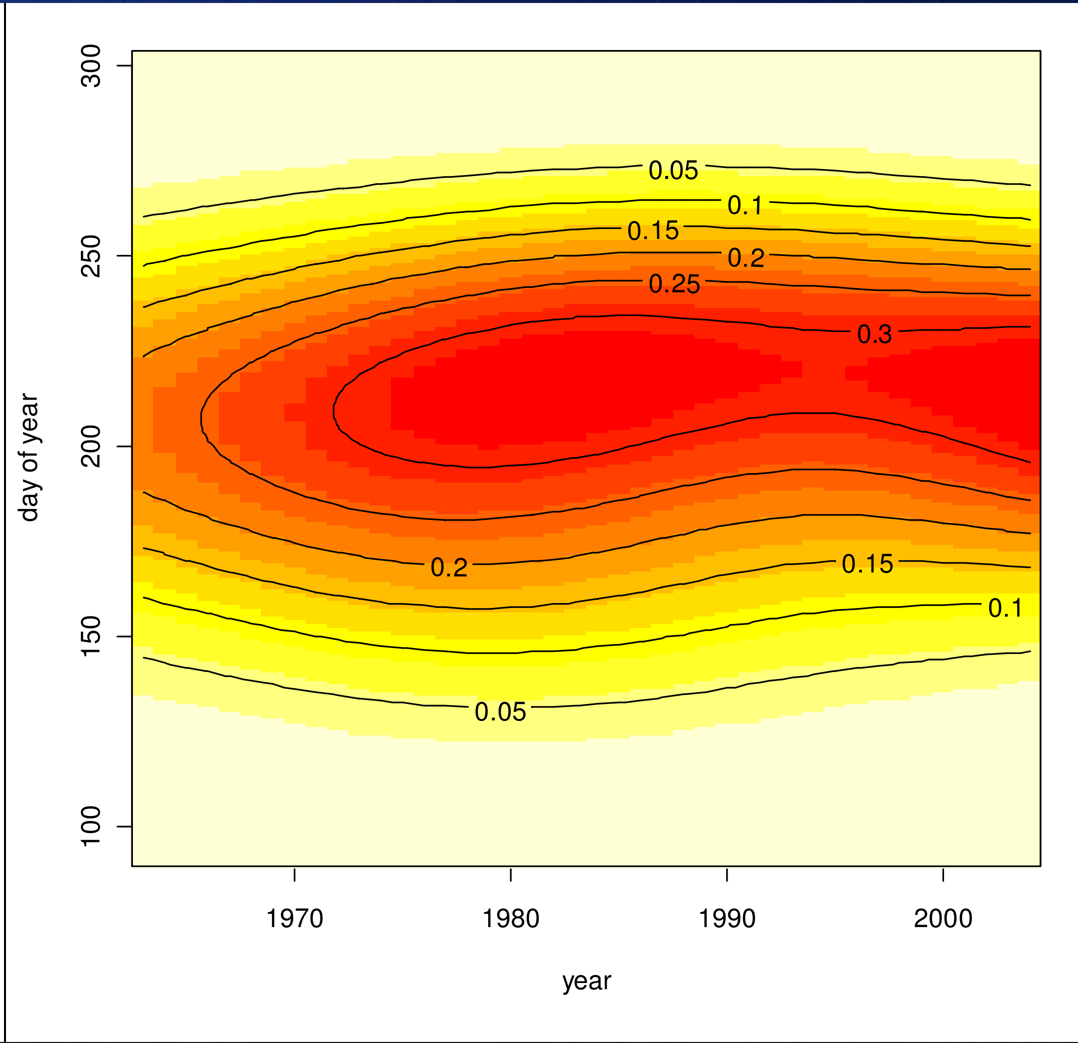
[1] Flannigan & Van Wagner (1990) *[2] Flannigan et al. (2005)*
[3] Wotton et al. (2003) *[4] Podur et al. (2002)*

The Data

- From Ontario Ministry of Natural Resources
- All reported lightning-caused forest fires from 1960 – 2004 for a region of boreal forest in northwestern Ontario, Canada
- Explore using generalized additive models

Exploratory model: $\mathrm{logit}(p_{day,\ year}) = f\,(\mathrm{day, year})$





fitted probabilities

corresponding contours

Explorations (continued)

- Changing detection efficiency a confounding factor
  - ✓ Lightning-caused fires can occur in more remote areas, may take longer to detect than people-caused fires, and would continue to grow until detected.
  - ✓ Size at detection appears to be higher in earlier years, suggesting that detection system performance may have improved in this study area over time.
- Runs of similar residuals within years
  - ✓ due to clusters of fire days, and non-fire days
- Propose the use of a finite mixture modelling framework to handle these concerns

Finite Mixture Models

- Assume the jth response variable Y_j comes from a population made up of a set of G distinct groups, each of which has a different distribution:

$$\boxed{Y_j \mid \boldsymbol{x}_j \sim \sum_{i=1}^{G} \pi_i(\boldsymbol{x}_j;\boldsymbol{\theta}_i) f_i(y \mid \boldsymbol{x}_j;\boldsymbol{\beta}_i)\,,\ j = 1,\ldots,n}$$

  where the $\pi_i(x_j\,;\boldsymbol{\theta}_i)$ are <u>non-linear</u> mixing proportions, representing the probability that the conditional distribution of Y_j given its observed set of covariates $\boldsymbol{x}_j$, comes from the ith component density $f_i(y \mid x\,;\boldsymbol{\beta}_j)$.

- Parameter estimation: MLE via EM algorithm

The Modelling Framework

Assume Z_t, the number of days during time $t = (week, year) = (w, y)$ when one or more fires are reported in a region, has the following mixed binomial distribution, with normal (N), extreme (E) and zero-heavy (0) components:

$$Z_t \sim \pi_N(y)\mathrm{B}(7, p_N(w)) + \pi_E(y)\mathrm{B}(7, p_E(w)) + \pi_0(y)\mathrm{B}(7, p_0{=}0)$$

where

$$\log\left(\frac{\pi_j(y)}{\pi_0(y)}\right) = \alpha_j + \beta_j y \quad , \quad j = N, E$$

The Modelling Framework (continued)

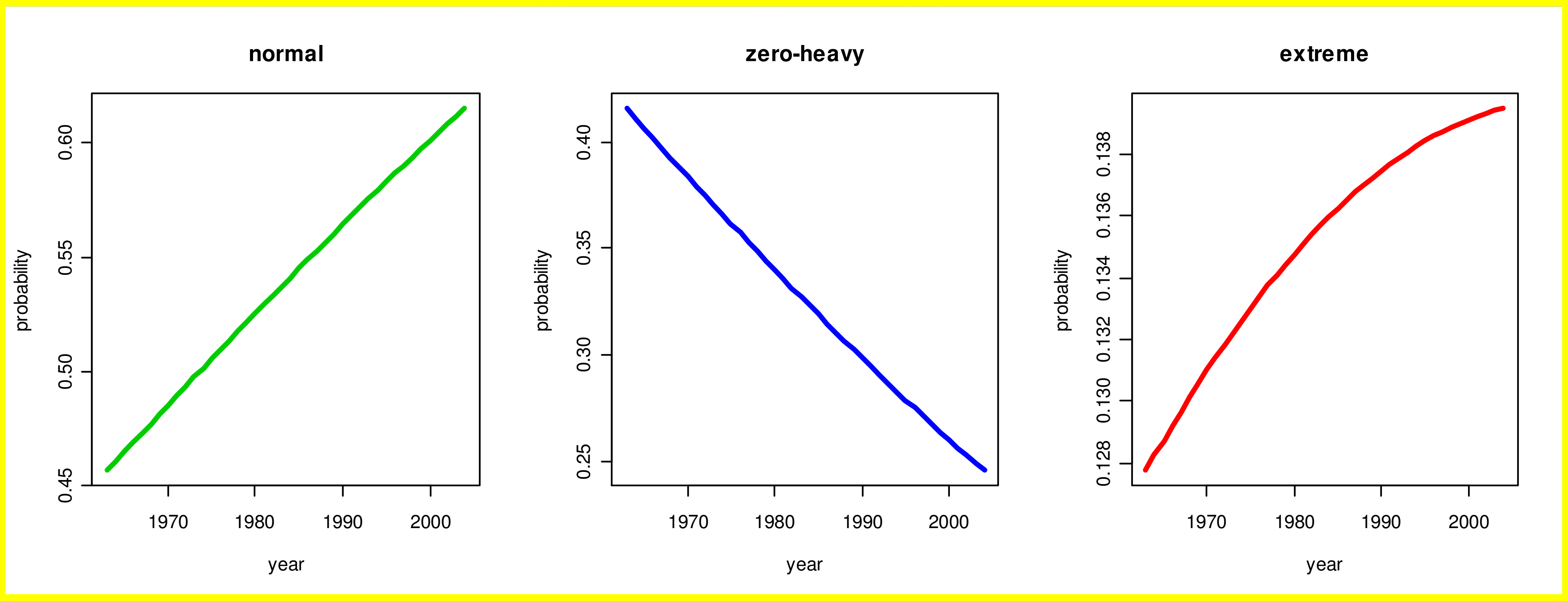
- The trend we are trying to isolate is one which could lead to:
  1. a reduction in the number of zeros,
  2. an increase in the number of extremes, or
  3. both 1. and 2.

- Considering the odds of extreme to zero probabilities allows investigation of the above.

- If both the numerator and denominator terms change slowly, considering the ratio will lead to large joint effects and hence better ability to distinguish them (i.e., more power).

- Given evidence of trend, considering individual plots of the component probabilities provide an indication of which of the above trend effects dominate.

Results: Estimated Mixing Probabilities



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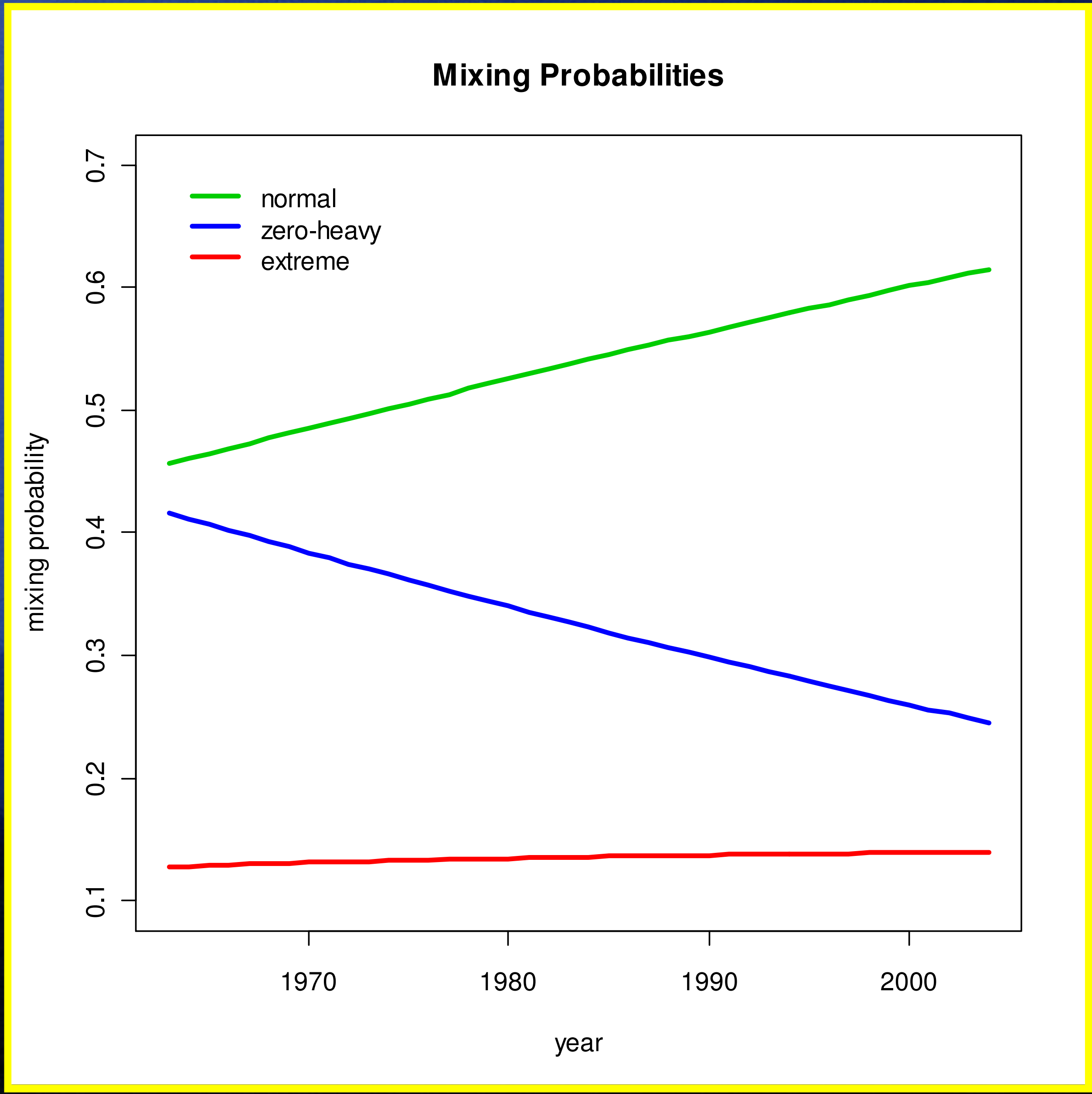
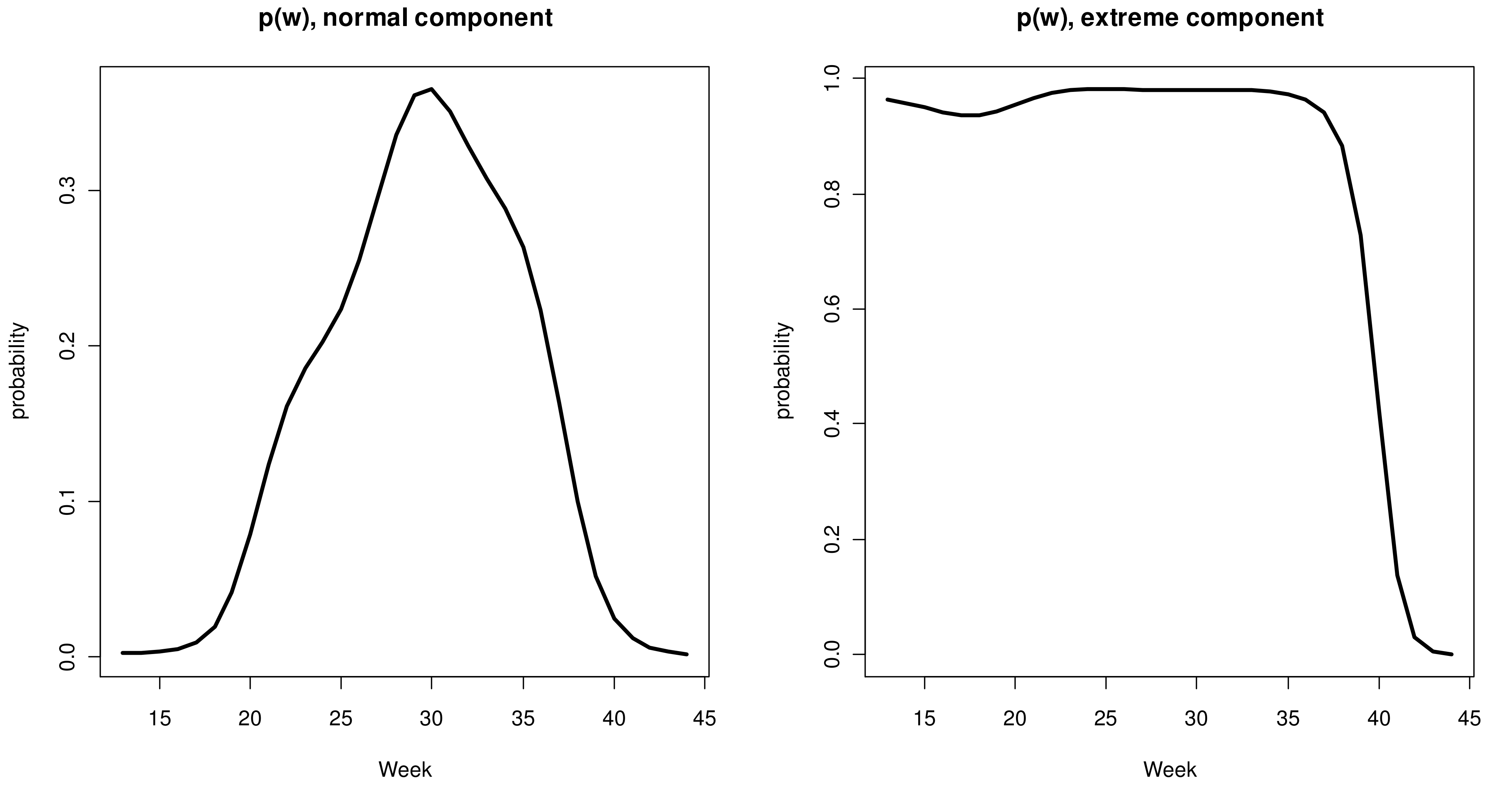
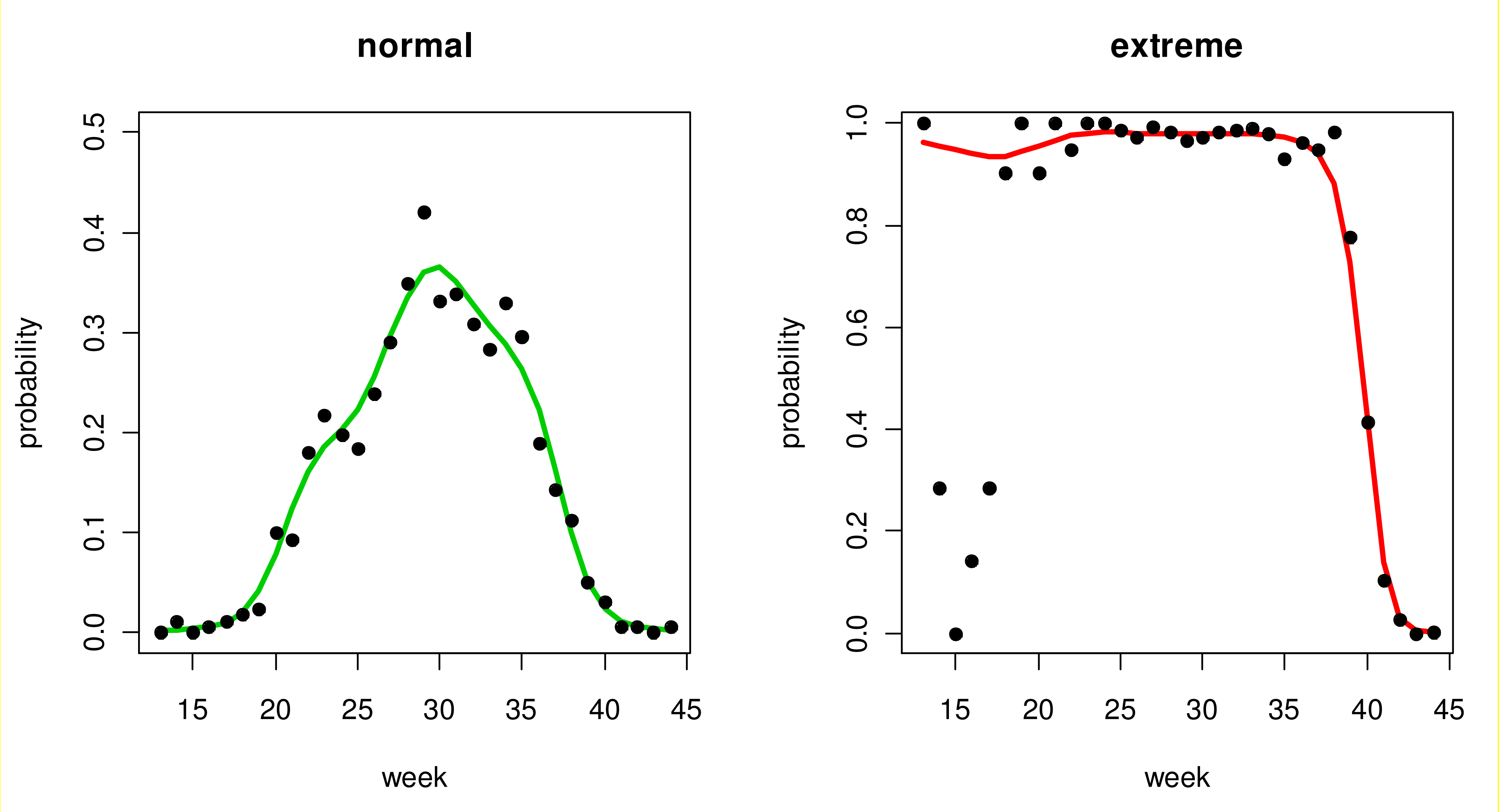


Results: Estimated Seasonal Ignition Probabilities

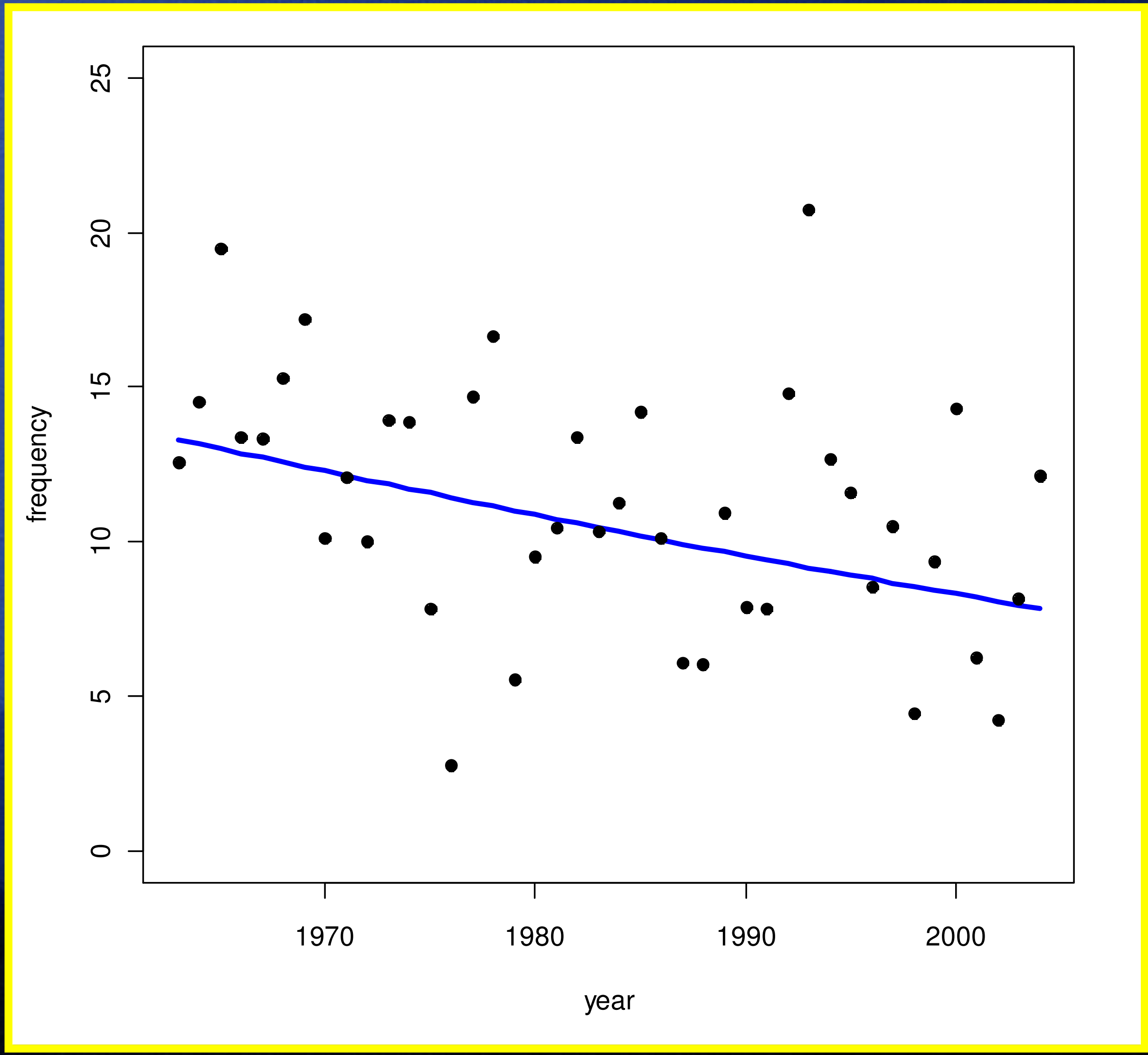


Results: Goodness of Fit



points = empirical weighted average of number of fire days per week over all years, weighted by posterior probability of membership in each component

Results: Goodness of Fit (continued)



line = expected number of zeros from the zero-heavy component
points = empirical number of excess zeros

Results (continued)

Parameter	Point Estimate	Standard Error	Wald Statistic	P-value*
α_N	0.0726	0.160	0.453	0.330
β_N	0.0201	7.80×10^{-3}	2.580	4.9×10^{-3}
α_E	-1.2000	0.234	-5.110	0.990
β_E	0.0150	9.95×10^{-3}	1.510	0.066

**p-value corresponds to testing $H_0: \theta = 0$, vs. $H_A: \theta > 0$*

Comparing p-values for tests of $H_0: \beta_E = 0$, vs. $H_A: \beta_E > 0$

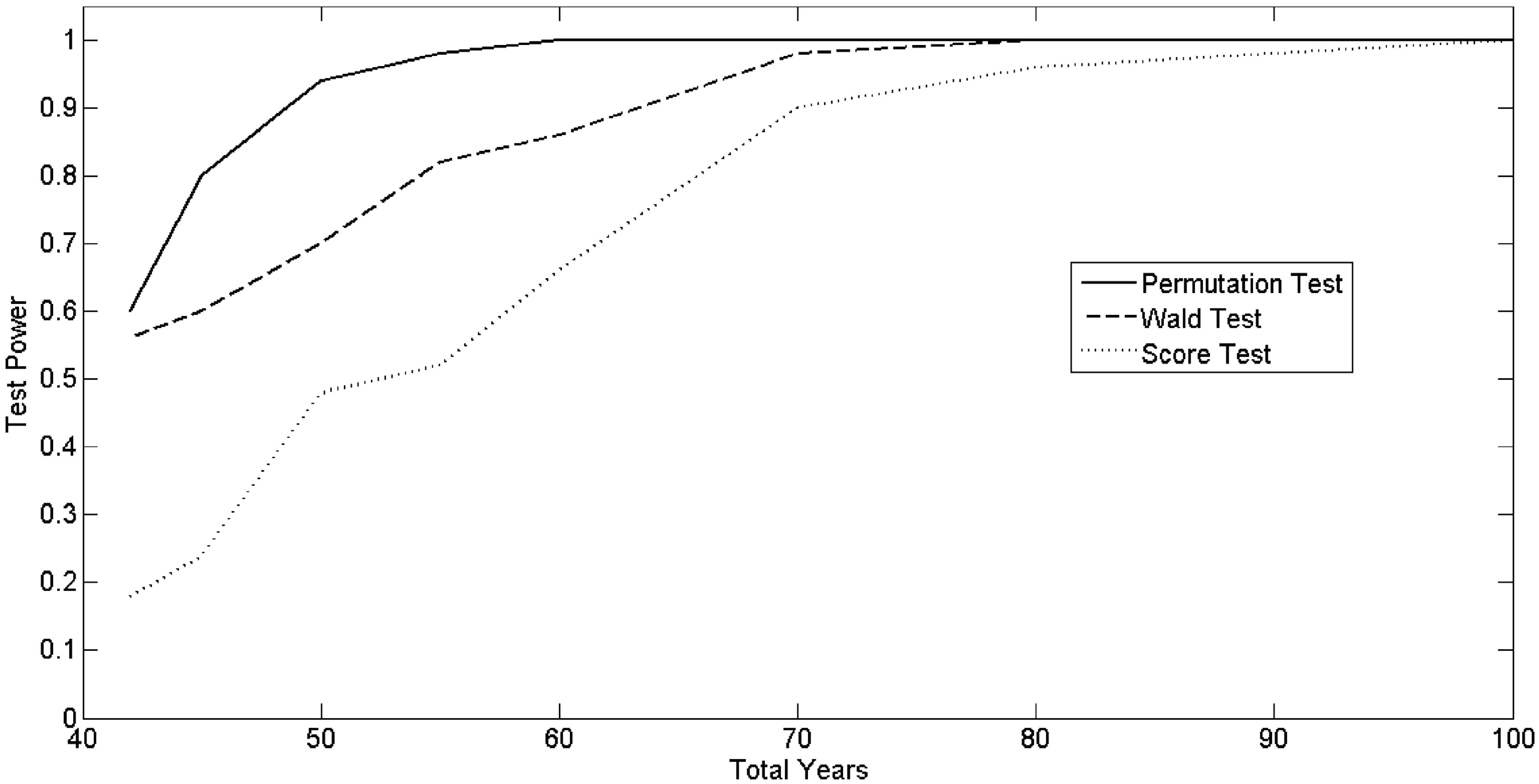
Wald	permutation	score
0.066	0.180	0.170 (score=1.88)

Some Data Considerations in Climate Change Studies

1. The origin and quality of historical data can be a challenge when looking for climate change signals
   a. from different sources (handwritten vs. digitized from maps)
   b. changing measurement methods/errors
   c. collected for a different purpose
   d. verification of historical records can be difficult

2. How does sample size (e.g., length of the time series and/or spatial extent) affect the <u>power</u> of the employed hypothesis test?

Power study for trend in extreme/zero



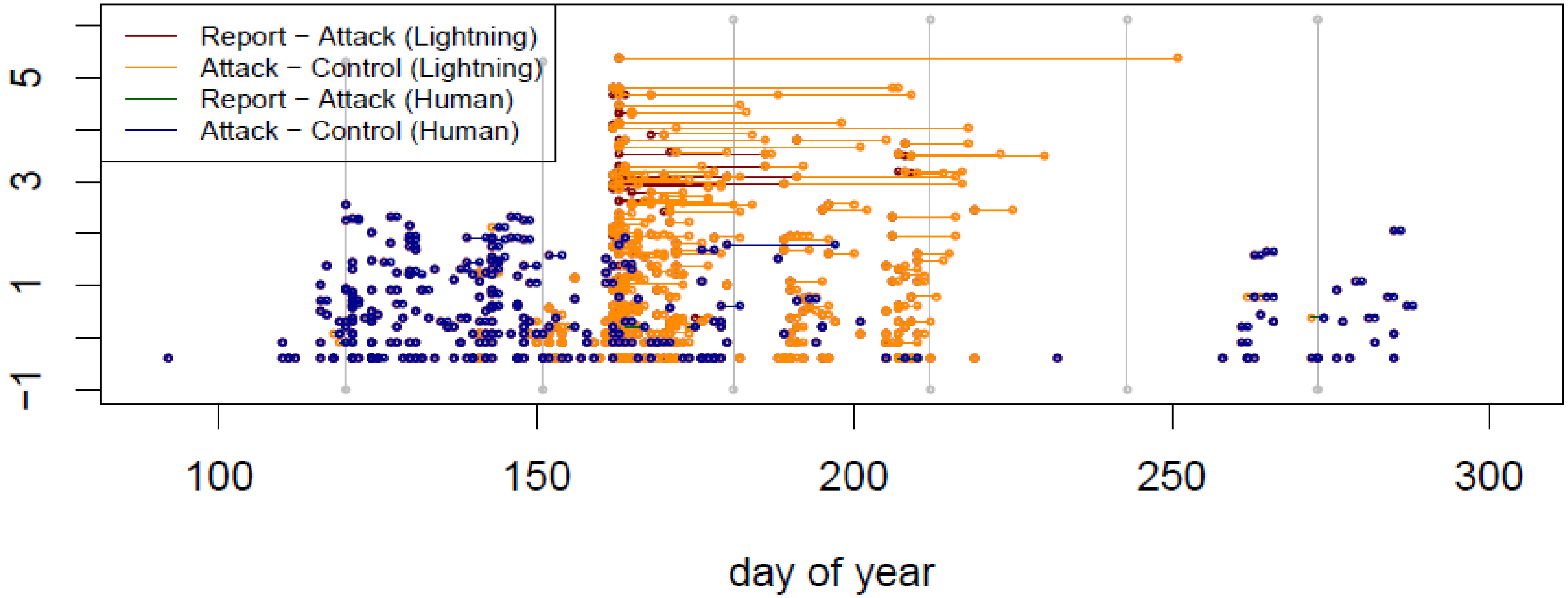
Data Considerations in the Forestry Context

- old data digitized from handwritten, post fire-fighting reports
- fire sizes/locations previously estimated (guesstimated), recent data on large fires can come from satellites
- detection efficiency has changed over time (more small fires in recent data sets)
- fire management strategies and equipment have changed over time
- locations and number of weather stations have changed
- resolution of spatially referenced data has been increasing

Discussion and Future Work

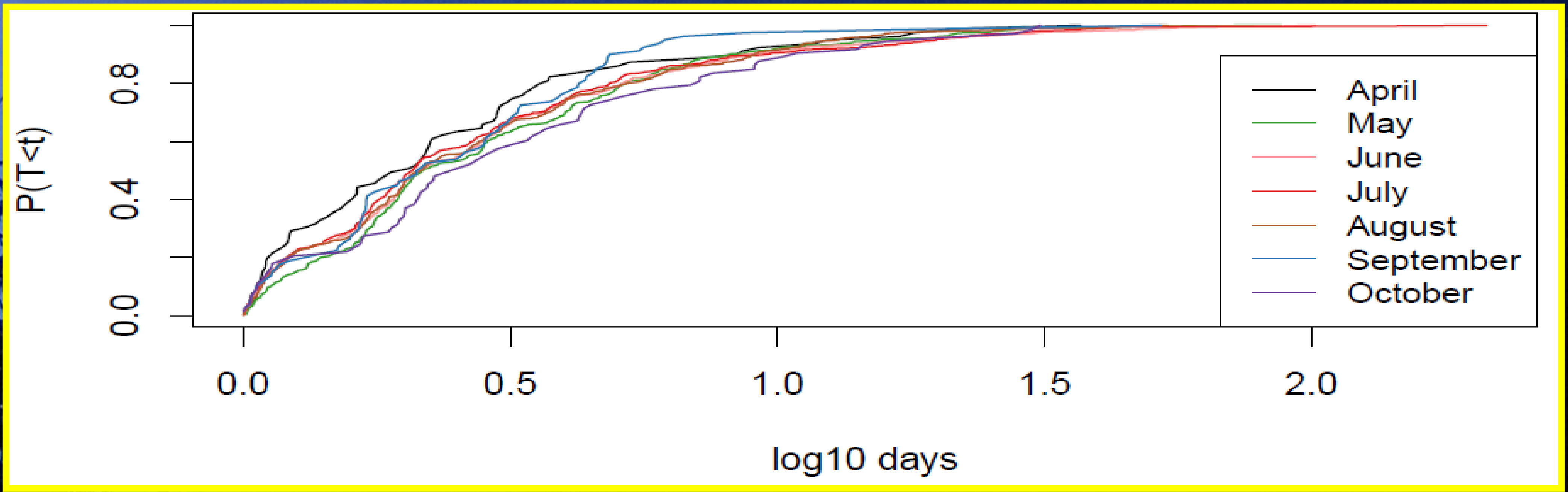
- modeling survival times
- incorporation of climate predictions under climate scenarios
- resampling for standard errors
- power: larger regions
- autoregressive and spatial effects
- gam mixture framework suitable for modeling wide variety of responses in climate change studies in forestry

Exploring survival: 1982’s fire season in Alberta, Canada



- length = duration (days), height = size ($\log_{10}$), colour = cause
- early June is hit by a barrage of lightning caused fires
- digit preference evident in small fires

Exploring survival: monthly survival curves for Alberta



- survival varies by year: fires in April and September have the shortest lifetimes

Discussion and Future Work

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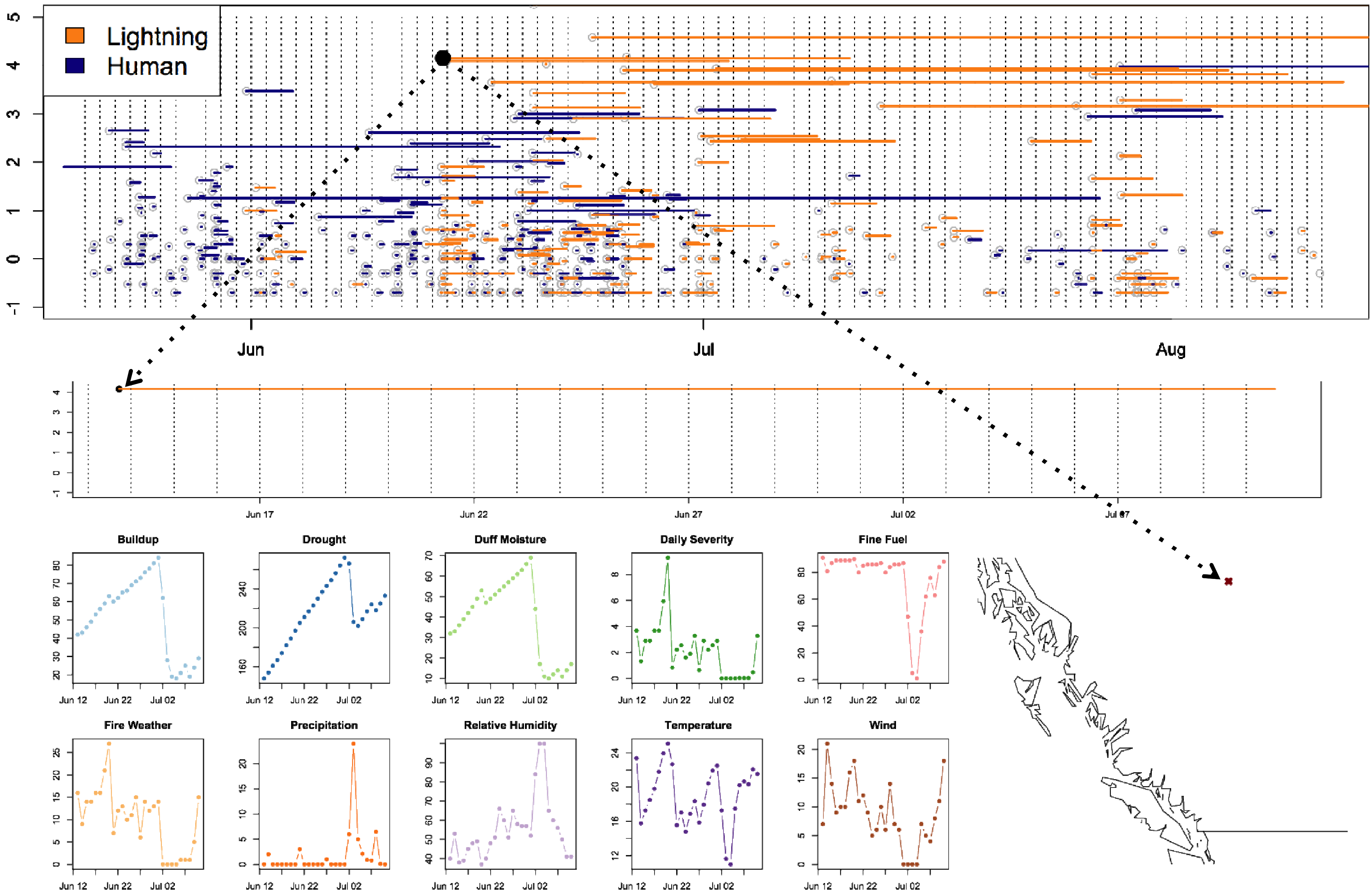
Examining weather for June 13 - July 10, 1982 fire in BC, Canada



Discussion and Future Work

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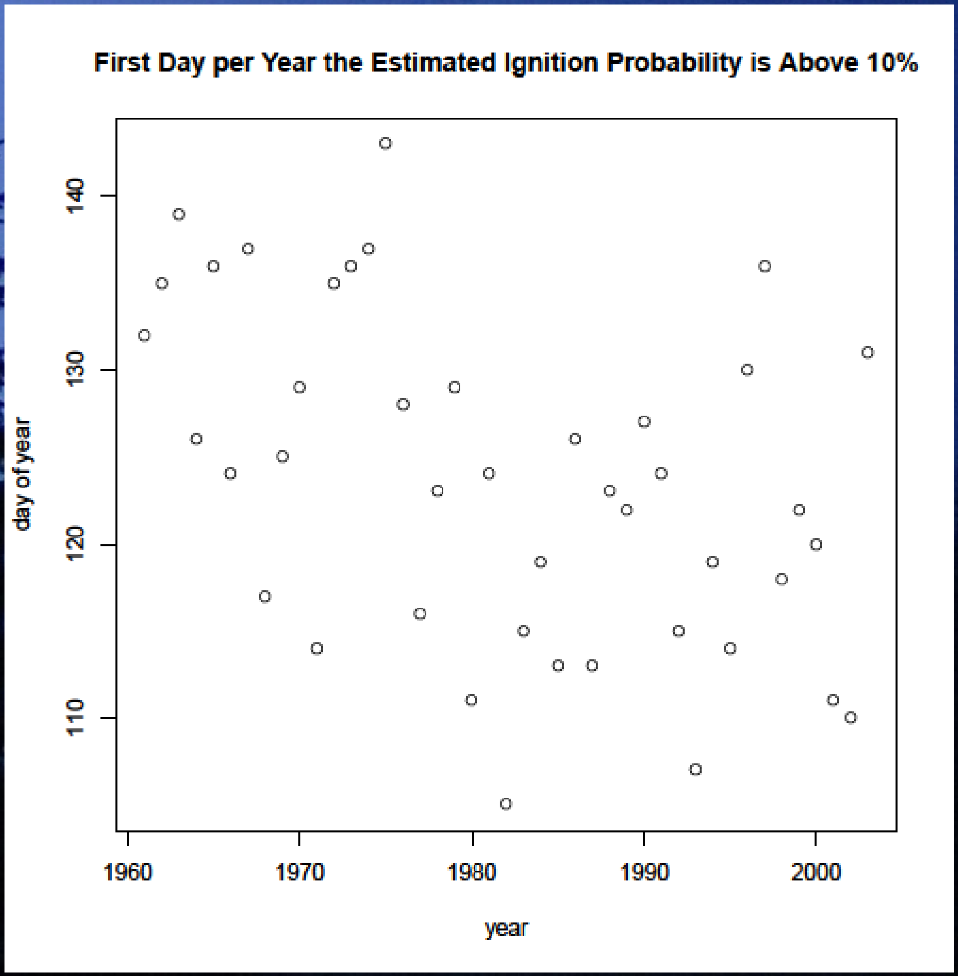
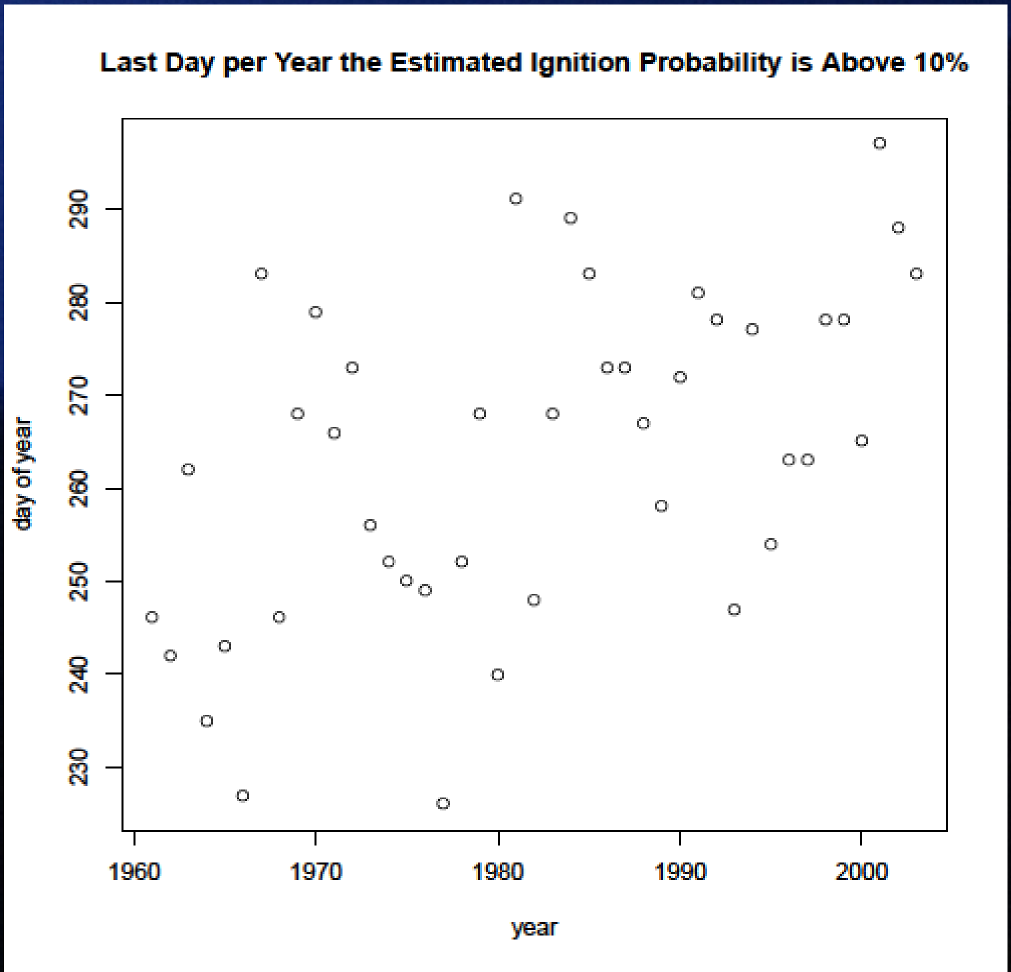
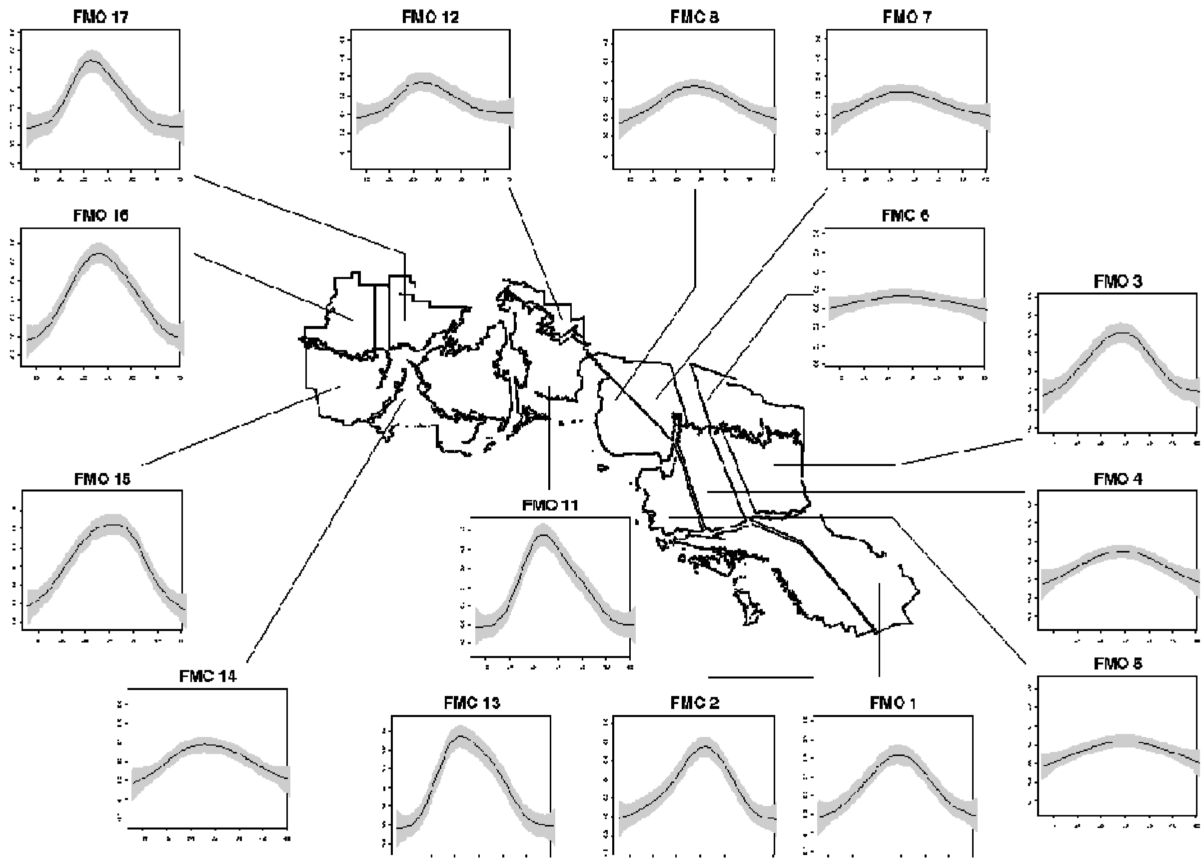
Fire Season Length





Seasonality terms in Ontario's ecozones



Discussion …

- Homogenization of long-term series
- Jointly consider two forms of extremes: zeros and many fires; as well as changing lengths of fire season
- Viewing the process as transitioning between states
- Best way to accommodate weather variables to evaluate impacts under future climate scenarios or focus on accessing how large a change in weather would lead to specific vulnerabilities
- Analysis of several eco-zones including main forested areas in Canada – clustering curves over space
- Short-term planning: modeling of Canadian fire management resource demand

Research Team

- Chris Bose, Victoria
- W. John Braun, Western Ontario
- Anne Bourlioux, Montréal
- Jiguo Cao, Simon Fraser
- Dave Campbell
- Steve Cumming, Laval
- Charmaine Dean, Simon Fraser
- Sylvia Esterby, UBC - Okanagan
- Fangliang He, Alberta
- Thomas Hillen, Alberta
- Gail Ivanoff, Ottawa
- Ed Johnson, Calgary
- Reg Kulperger, Western Ontario
- David Martell, Toronto
- Ian McLeod, Western Ontario
- Farouk Nathoo, Victoria
- Jeffrey Picka, New Brunswick
- William Reed, Victoria
- Rick Routledge, Simon Fraser
- Dave Stanford, Western Ontario
- Zilin Wang, Wilfrid Laurier
- Doug Woolford, Wilfrid Laurier
- Hao Yu, Western Ontario

Partners and Affiliates

- Hugh Barclay, Canadian Forest Service
- Kirsten Campbell, Terratree Forestry
- Nassif Ghoussoub, Banff International Research Station
- Jim Goudie BC Ministry of Forests and range
- Frank Liu, Timberline
- Paul Maczek, Saskatchewan Ministry of the Environment
- Rob McAlpine, Ontario Ministry of Natural Resources
- Joseph Nader, FP Innovations
- Gord Nigh, BC Ministry of Forests and Range
- Richard Reich, BC Ministry of Forests and Range
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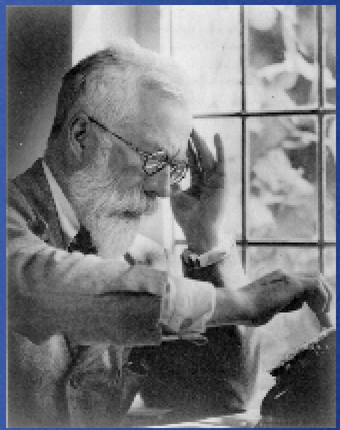

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