Identifying Changes in the Timing of Heavy Rainfall Occurrence in Ontario, Canada

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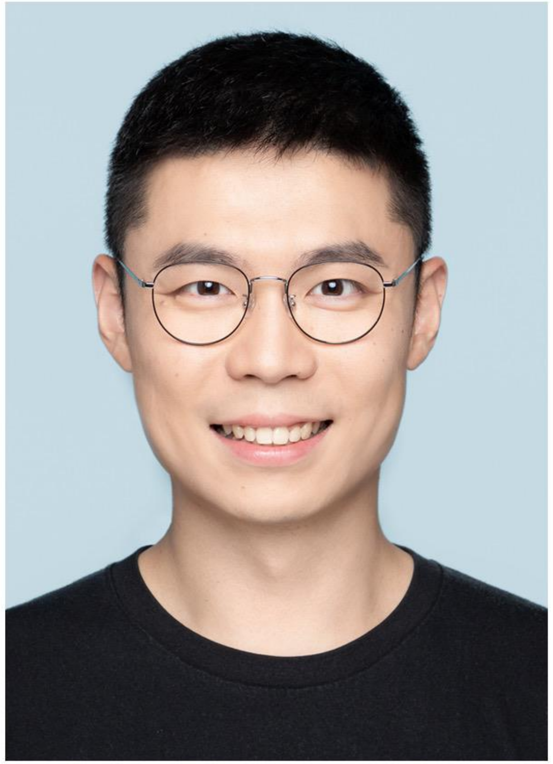

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- PhD candidate, Water Resources Engineering
- School of Engineering, University of Guelph, Ontario, Canada
- B.Eng (2017) / M.A.Sc (2019) – University of Guelph
- Thesis submission expected in April 2023
- Research interests:
  - Statistical data analysis
  - Climate change
  - Stormwater management
  - Big data / Data mining
  - Engineering education
- Teaching experiences
  - Engineering mechanics, Engineering analysis (1st year)
  - Hydrology, Soil mechanics, Thermodynamics (2nd – 3rd year)
  - Assessment of Engineering Risk (4th year)

Content

Change In Heavy Rainfall Patterns

Magnitude

- Increasing magnitude
- High intensity rainfalls

Frequency

- Increasing frequency
- More frequent heavy rainfalls

- Major research focuses are on magnitude and frequency change
- Climate change impact will continue
- Other parameters may also have changed …

Change In Heavy Rainfall Patterns

What about the timing…

- More heavy rainfalls, but when?
- What if the time of heavy rainfalls has changed?

  - Erosion protection
  - Crop planning
  - Drought management
  - Groundwater recharge
  - Flooding
  - Landslide occurrence
  - Traffic accidents

‘New’ Change In Heavy Rainfall Patterns

New conditions and scenarios are needed

- Characterize rainfall from a different perspective
- Improve the characterization of hydrologic responses
- Provide improved knowledge regarding the timing of rainfall

New methods/parameters can expand the existing climate change research network

- Provide a new aspect for future research
- Better strategy comes with better time management
  - Engineers
  - Scientists
  - Government authorities

The dataset

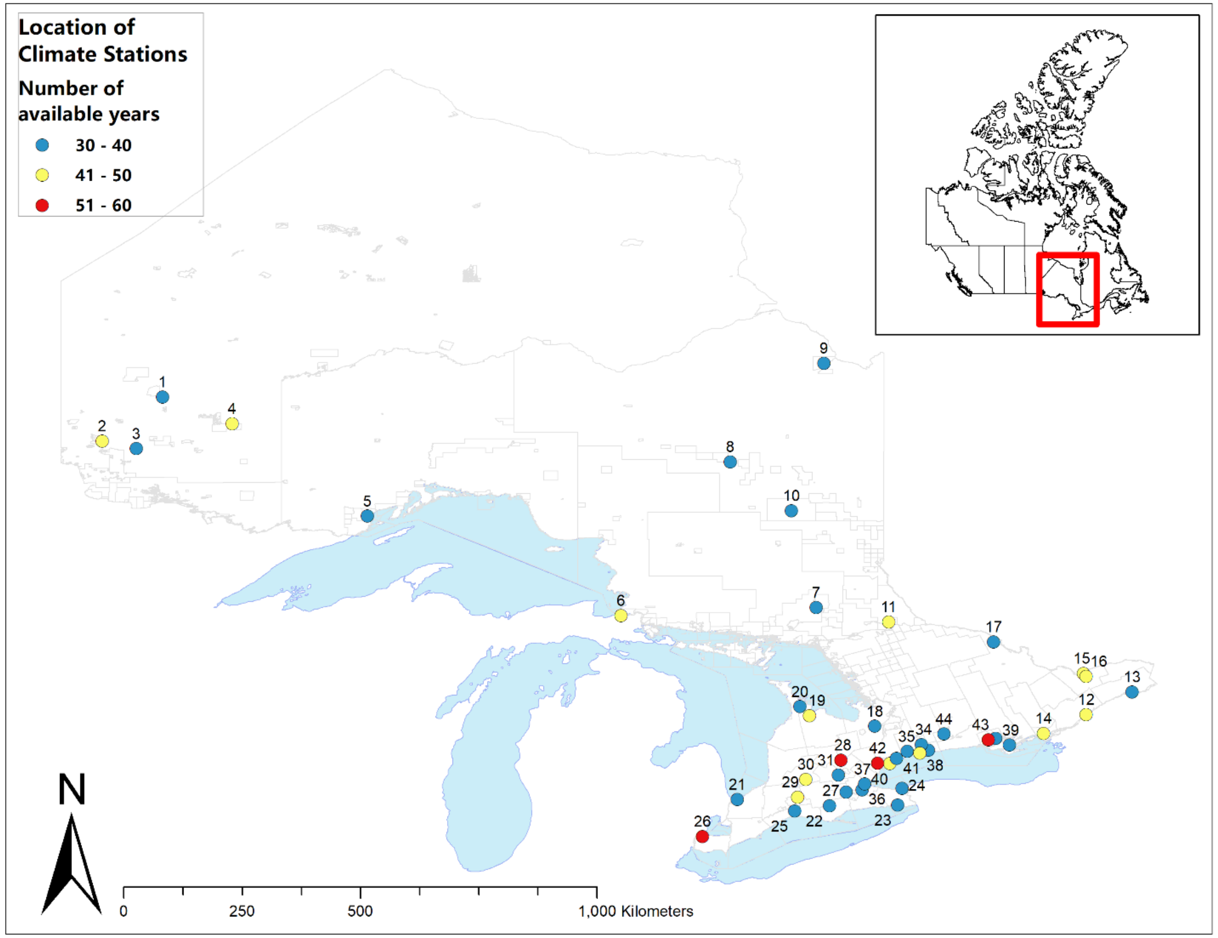
There are lots of data types can be used to describe heavy rainfalls

- Annual Maximum Series (AMS)
  - Measured in depth - mm
  - The single highest rainfall event recorded for the duration
    - 5min, 10min, 15min, 30min, 1hr, 2hr, 6hr, 12hr, 24hr
  - Each data point contains:
    - Rainfall depth
    - Occurring date (Day of the Year)
  - Only considering April to October

Questions to answer:

- How climate change has influenced the time of occurrence of heavy rainfall events?
- How has the variability of the time of occurrence of heavy rainfall events changed?
- Are heavy rainfall events occurrences more or less predictable?

The dataset



- Environment and Climate Change Canada
- 44 stations in Ontario, Canada
- Minimum 30 years of data
  - 1960 – 2017 (58 years)
  - Except 24hr duration
- Nine time intervals
  - 5min, 10min, 15min, 30min, 1hr, 2hr, 6hr, 12hr, 24hr
- Time window length
  - 10-years
  - Moving time window technique

Duration	5min	10min	15min	30min	1hr	2hr	6hr	12hr	24hr
Average no. of years available	39	39	39	39	39	41	41	39	25

The dataset

Questions to answer:

- How climate change has influenced the time of occurrence of heavy rainfall events? – Mean
- How has the variability of the time of occurrence of heavy rainfall events changed? – Variance
- Are heavy rainfall events occurrences more or less predictable? – Coefficient of Variation

Statistical parameters

- Mean ($\overline{x}$) – measures the time of occurrence in the past and present
  - Day of the year (early vs. late in the year)
- Variance (σ^2) – measures the spread of rainfall occurrence time
  - Wider vs. narrower time window
- Coefficient of variation (CV)
  - Increased vs. decreased variability

The method

Comparing the past and the present

- Standard t-test
- F-test

Trend from the past to the present

- Rolling time window technique
- Linear regression and Sen’s slope
- Mann-Kendall test
- Coefficient of variation

Year (1)	Value (2)	Month (3)	Day (4)	Day of the Year (5)	Past and Present (6)	Rolling Time Windows (7)			
1960	6.4	7	24	205	Past	Group 1			
1961	3.8	7	23	204			Group 2		
1962	5.6	8	14	226				Group 3	
1963	9.9	6	4	155					
1964	6.1	9	9	252					
1965	4.1	9	4	247					
1966	5.8	7	17	198					
1967	7.1	7	21	202					
1968	5.1	7	6	187					
1969	4.8	6	26	177					
1970	11.7	9	7	250					
1971	6.6	9	26	269					
…	…	…	…	…	…	…	…	…	
1984	6.4	8	8	220				Group 25	
1985	6.4	7	18	199			Group 26		
1986	6.9	7	28	209	Present	Group 27			
1987	10	5	13	133					
1988	8.4	6	1	152					
1989	11.2	8	2	214					
1990	1.1	6	1	152					
1991	6.9	8	24	236					
1992	10.1	9	12	255					
1993	5.5	7	27	208					
1994	8.9	6	24	175					
1995	10.9	7	27	208					

Sample dataset

- Ear Falls (ECCC Climate ID 6012198)
- 5min duration
- 1960 – 1995 (35 years)
- Quick comparison between the past and present group
  - Standard t-test
  - F test
- Each group, calculate:
  - Mean
  - Variance
- Connect all groups, trend analysis:
  - Mann-Kendall (MK) trend test
  - Linear regression and Sen's slope
    - Mean
    - Variance
    - Coefficient of variation

Results – the mean (x̄)

- 22 out 44 stations have significant changes in mean AMS occurrence time ($p < 0.1$)
- All significant changes are negative – AMS occurrence time has shifted forward
  - $\Delta = present\ mean\ - past\ mean$
  - $\Delta > 0$: present rainfall occurrence is later in the year
  - $\Delta < 0$: present rainfall occurrence is earlier in the year
- Average difference: -44 days
- Largest difference: -86 days
- Smallest difference: -21 days

Station ID	5min	10 min	15 min	30 min	1hr	2hr	6hr	12hr	24hr
4	-	-21	-27	-33	-33	-41	-39	-52	-
8	-	-25	-	-	-	-42	-34	-34	-
9	-33	-	-	-	-	-	-	-	-
11	-	-36	-35	-44	-42	-37	-	-	-
12	-45	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-27	-28	-	-
18	-	-	-	-	-	-	-32	-	-
19	-70	-85	-72	-62	-53	-86	-69	-79	-86
24	-32	-26	-26	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-54	-
29	-	-	-	-	-	-	-	-	-71
31	-	-	-	-	-	-	-	-54	-45
32	-	-	-	-	-	-	-44	-	-
36	-	-	-	-	-	-36	-46	-37	-
37	-	-	-	-31	-	-	-	-	-
38	-	-40	-53	-58	-52	-	-	-	-41
39	-	-	-	-	-	-	-	-41	-
40	-	-	-	-	-	-	-	-	-42
41	-	-35	-	-	-	-	-	-	-
42	-	-	-	-	-	-40	-	-	-
43	-	-	-	-	-	-	-56	-68	-
44	-	-	-	-31	-	-28	-30	-35	-

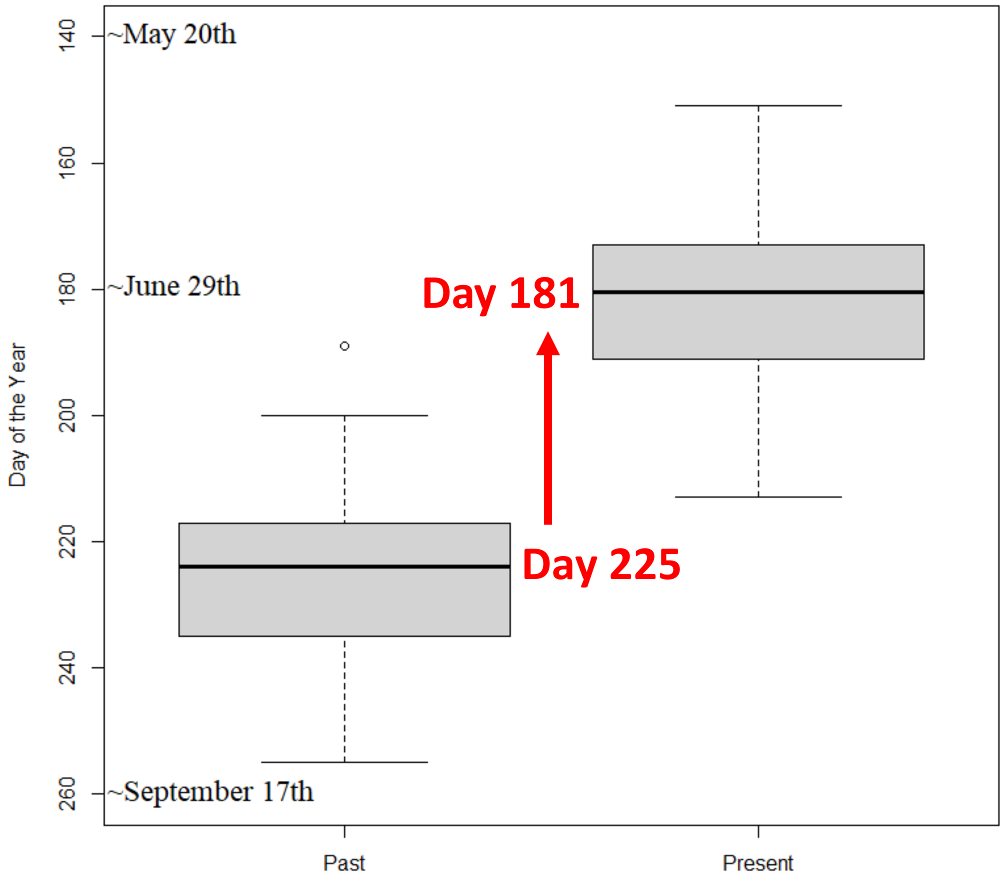
Results – the mean ($\bar{x}$)

Plot a box plot with two columns
- 22 identified stations
- The past column
  - All AMS occurrence date of the past
- The present column
  - All AMS occurrence data of the present

Average difference: -44 days

Largest difference: -86 days

Smallest difference: -21 days



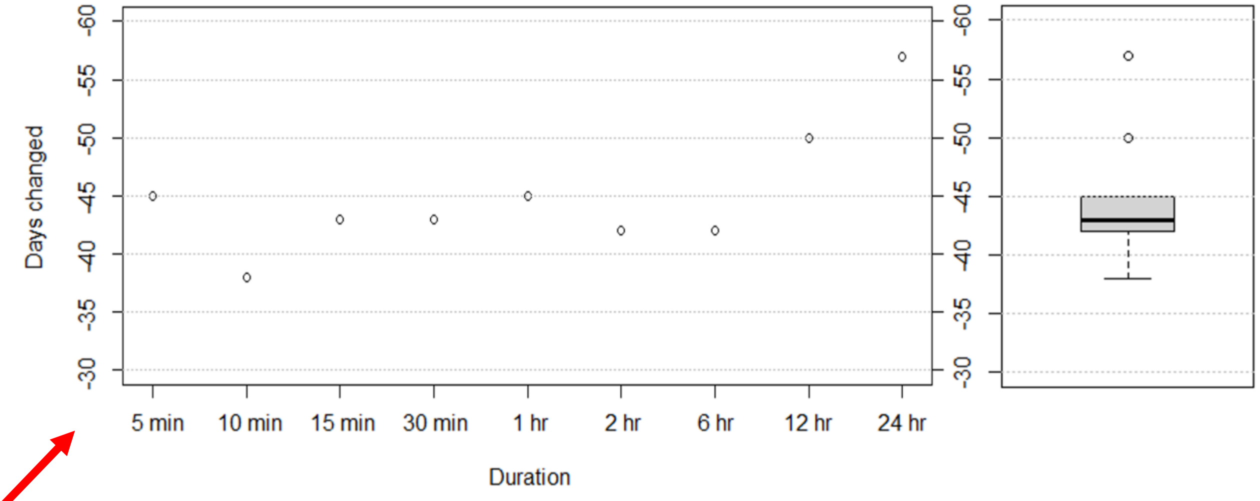
Results – the mean (x̄)

Station ID	5min	10min	15min	30min	1hr	2hr	6hr	12hr	24hr
4	-	-21	-27	-33	-33	-41	-39	-52	-
8	-	-25	-	-	-	-42	-34	-34	-
9	-33	-	-	-	-	-	-	-	-
11	-	-36	-35	-44	-42	-37	-	-	-
12	-45	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-27	-28	-	-
18	-	-	-	-	-	-	-32	-	-
19	-70	-85	-72	-62	-53	-86	-69	-79	-86
24	-32	-26	-26	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-54	-
29	-	-	-	-	-	-	-	-	-71
31	-	-	-	-	-	-	-	-54	-45
32	-	-	-	-	-	-	-44	-	-
36	-	-	-	-	-	-36	-46	-37	-
37	-	-	-	-31	-	-	-	-	-
38	-	-40	-53	-58	-52	-	-	-	-41
39	-	-	-	-	-	-	-	-41	-
40	-	-	-	-	-	-	-	-	-42
41	-	-35	-	-	-	-	-	-	-
42	-	-	-	-	-	-40	-	-	-
43	-	-	-	-	-	-	-56	-68	-
44	-	-	-	-31	-	-28	-30	-35	-
Duration average	-45	-38	-43	-43	-45	-42	-42	-50	-57

5min – 6hr: average around -40 days of shift

12hr: -50 days

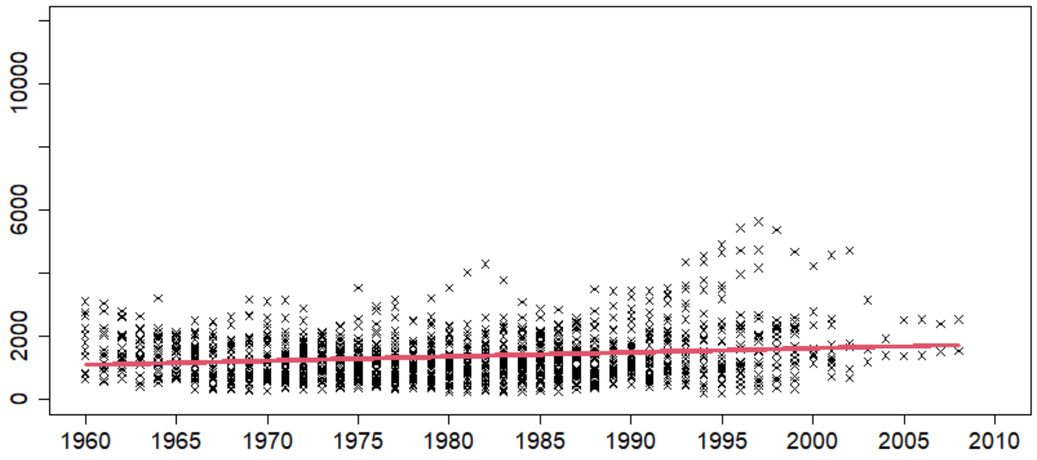
24hr: -57 days



Results – the variance (σ^2)

$$F = \frac{Past\ group\ variance\ (\sigma^2_{past})}{Present\ group\ variance\ (\sigma^2_{present})}$$

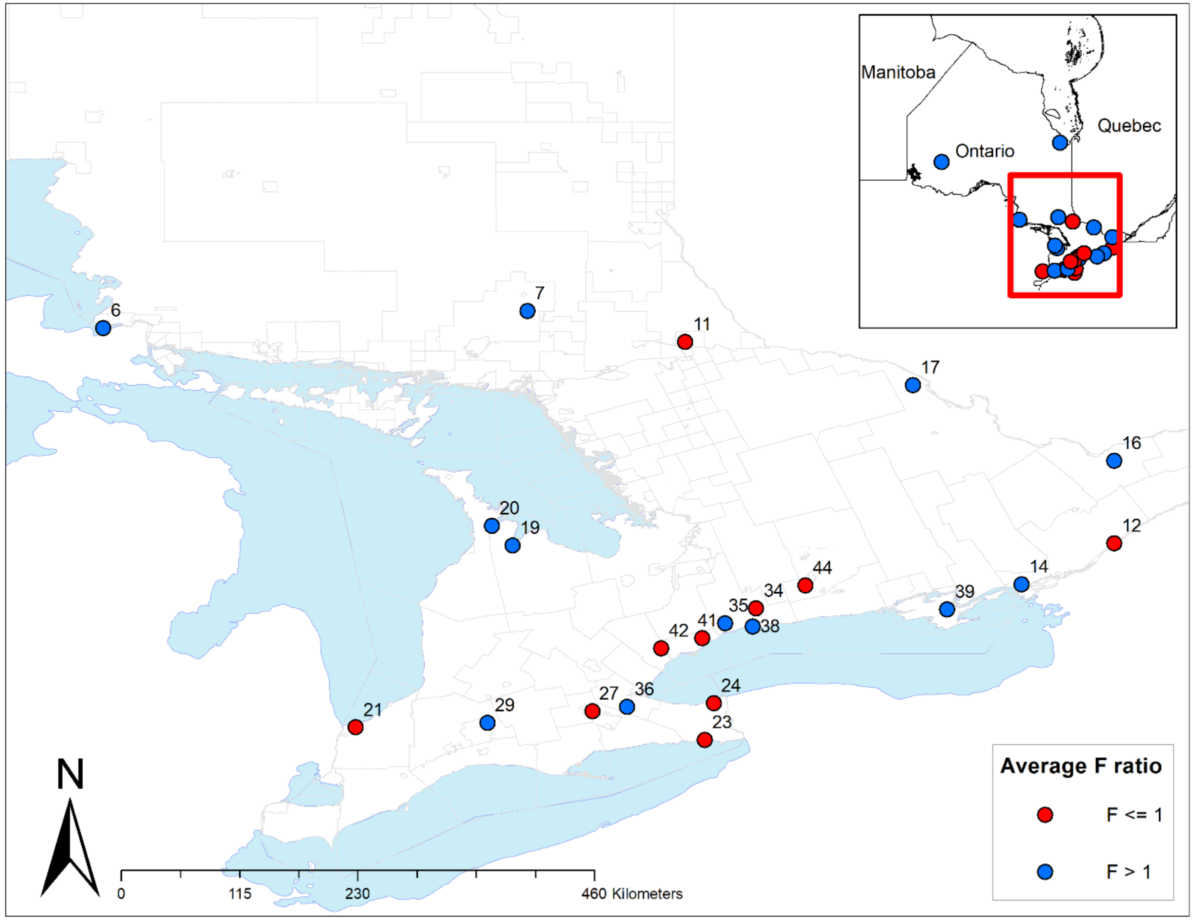
- F > 1: present AMS occurrence time is stable (low fluctuation)
  - The heaviest rainfall events are occurring within a narrower time period of the year
- F < 1: present AMS occurrence time is less stable (high fluctuation)
  - The heaviest rainfall events are occurring within a wider time period of the year



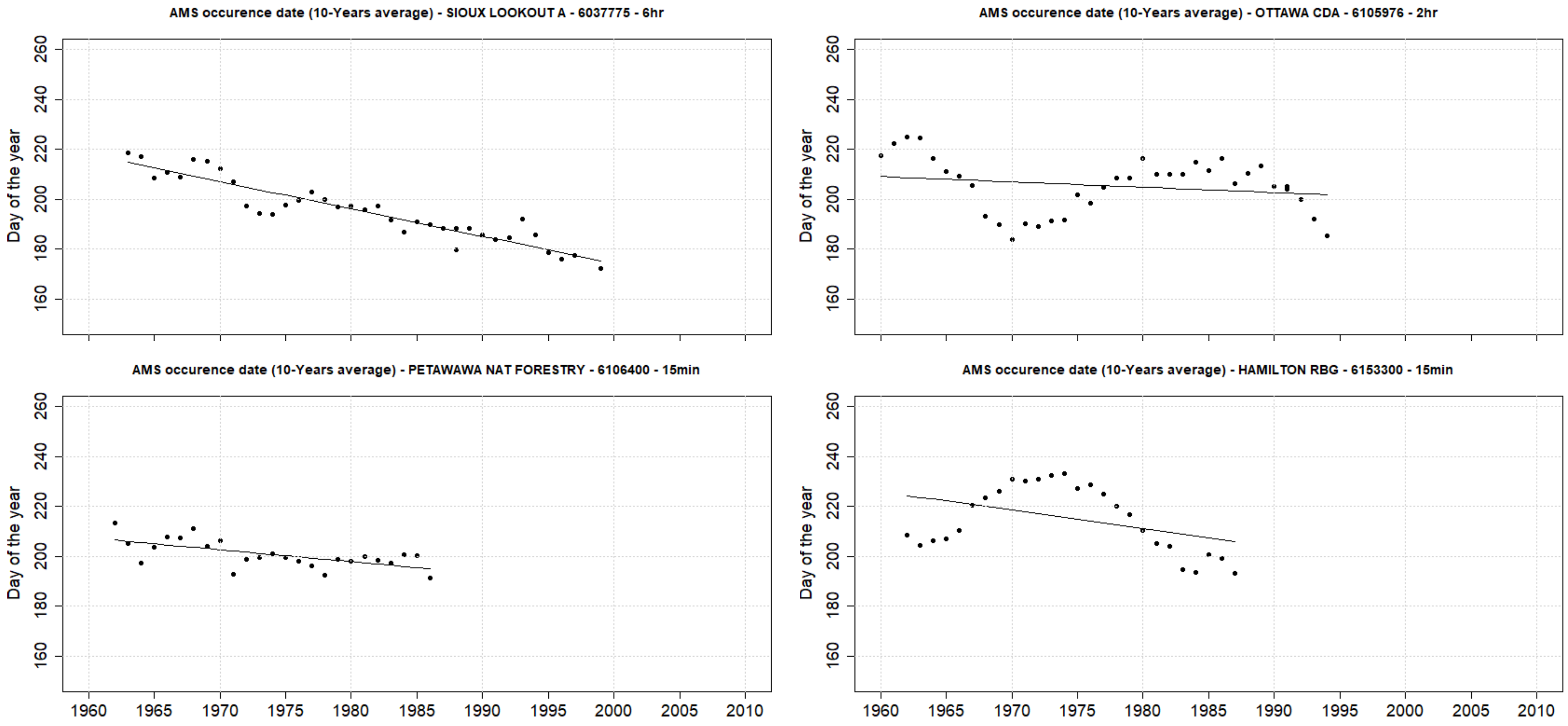
Results – the variance (σ^2)

- F > 1: present AMS occurrence time is stable (low fluctuation)
  - The heaviest rainfall events are occurring within a narrower time period of the year
- F < 1: present AMS occurrence time is less stable (high fluctuation)
  - The heaviest rainfall events are occurring within a wider time period of the year

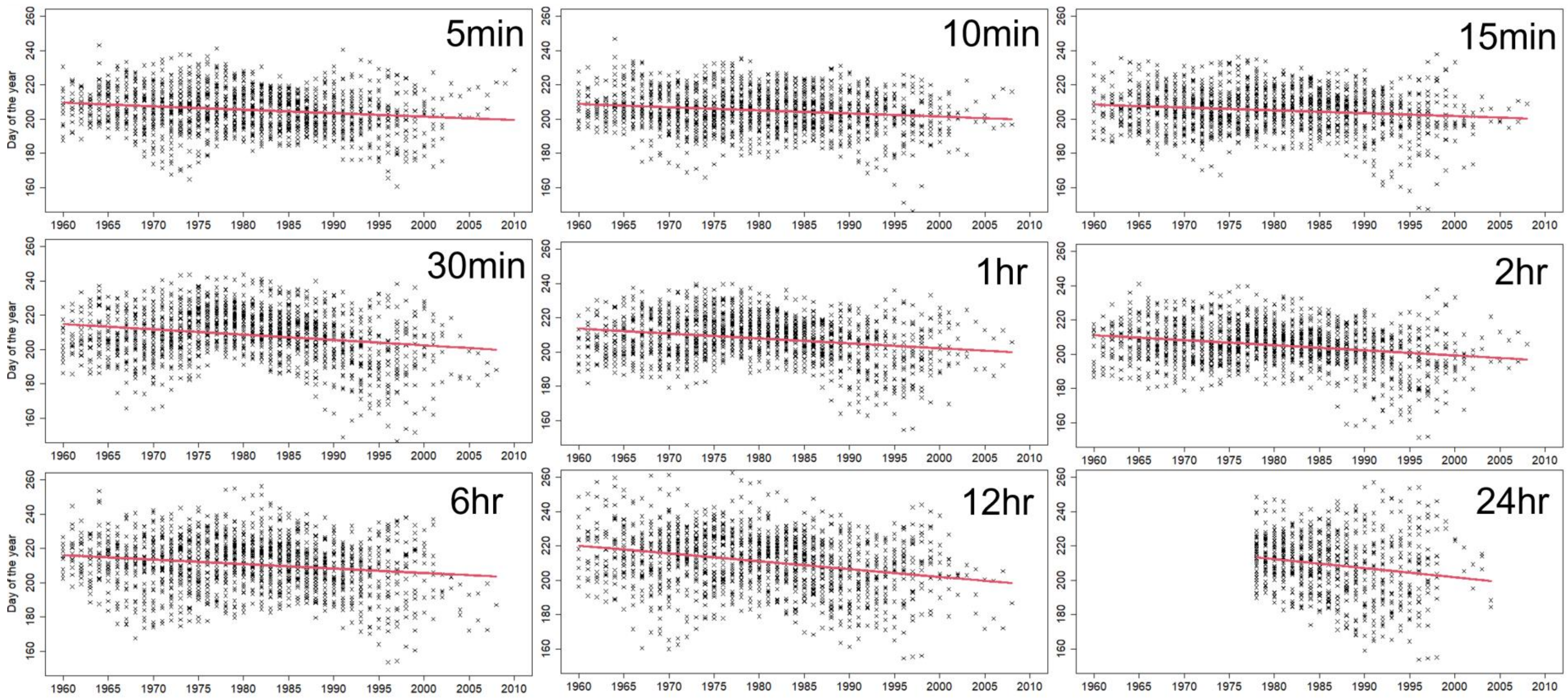
- 24 out 44 stations have significant changes in variance
  - 14 stations have F > 1
  - 10 stations have F < 1
- Most stations are near the Great Lakes



Results – trend of the mean



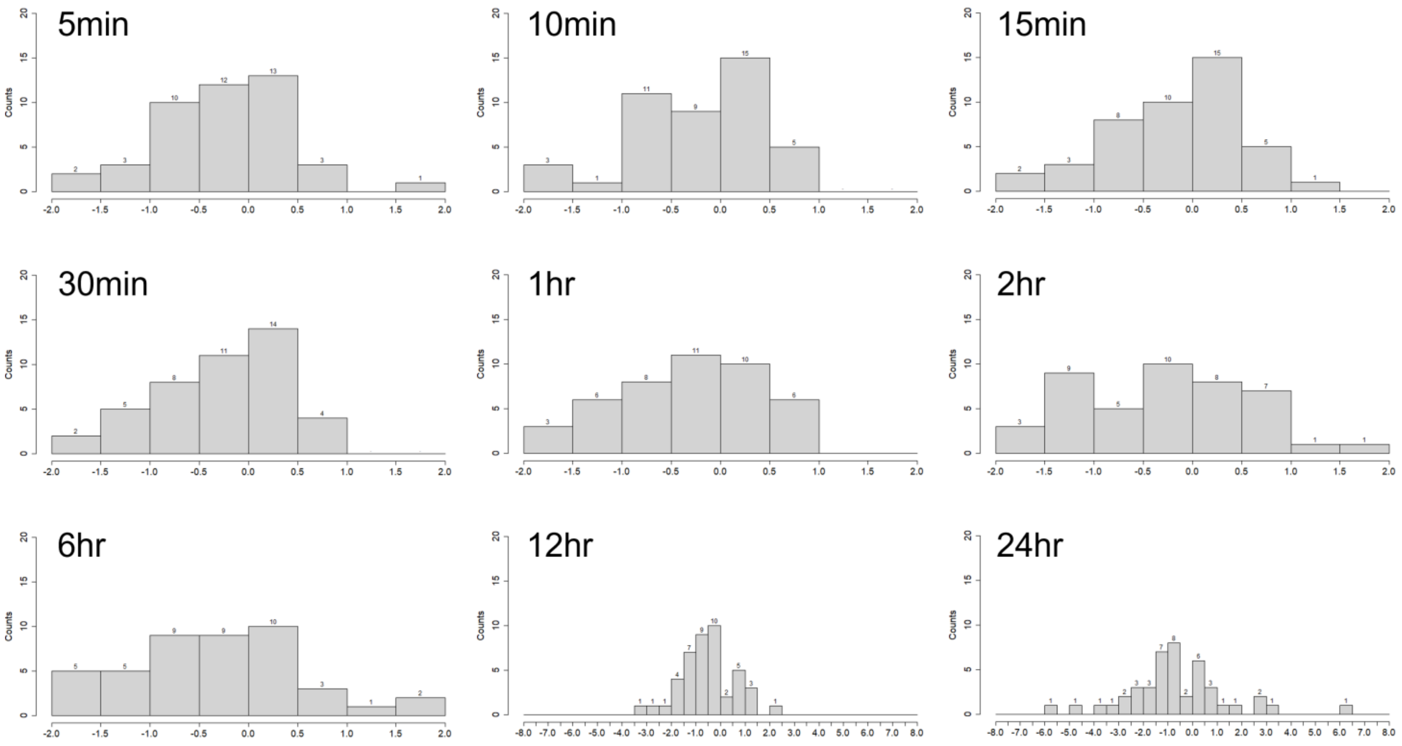
Results – trend of the mean



Results – trend of the mean

Summary of slopes

- Linear regression
- All left skewed
- Indicates most stations have negative slopes of changing – AMS occurrence time has advanced
- Some positive slopes exist
  - They are near zero
  - They have low τ values (MK test)
  - Climate research involves inevitable natural variations



Results – trend of the coefficient of variation (CV)

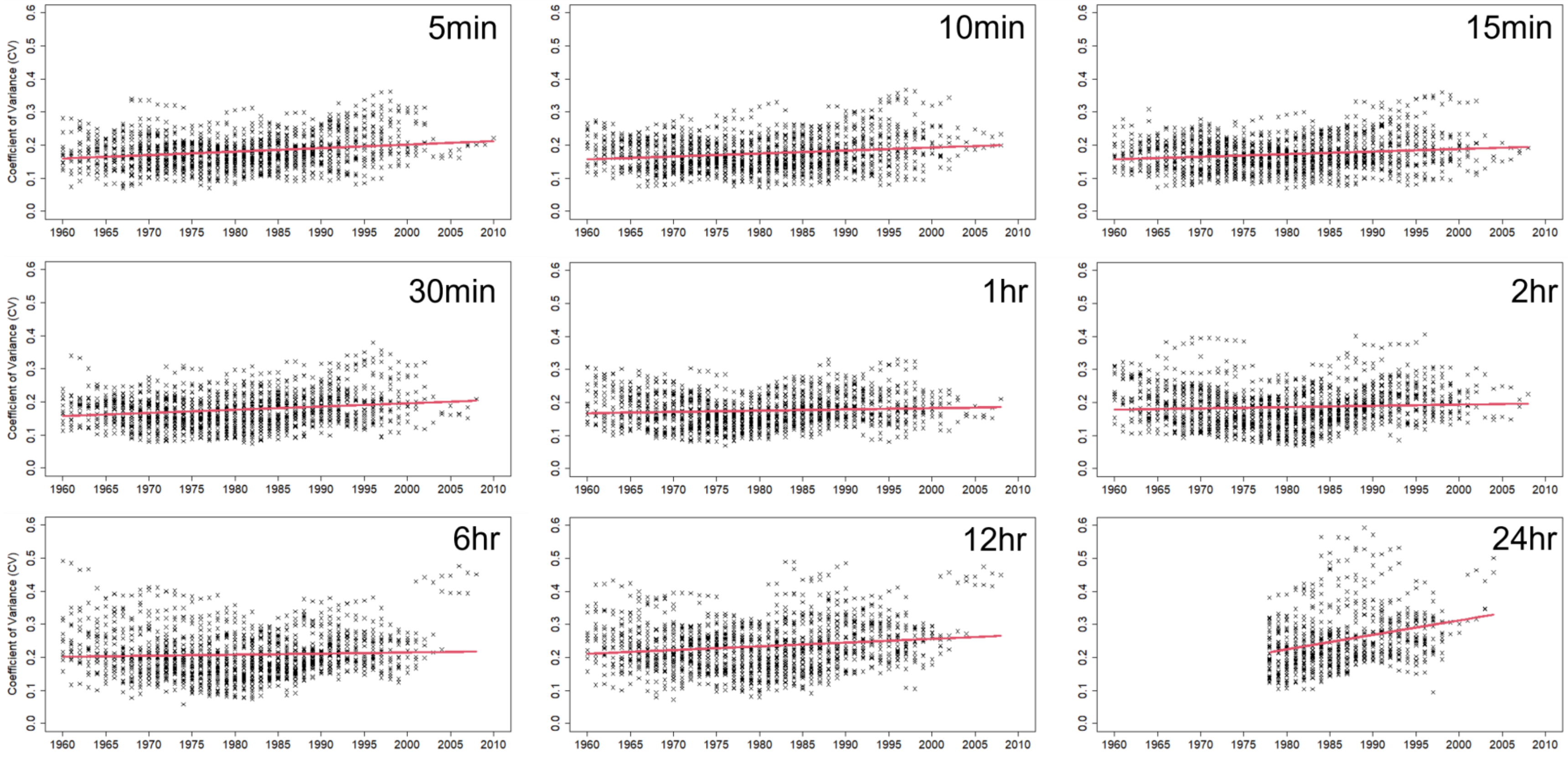
From previous:

- Mean is decreasing
- Variance is increasing

$CV = \frac{\sigma}{\bar{x}}$

- It is expected to see CV will increase
- Increased CV means:
  - Increased variability in AMS occurrence time
  - High fluctuations in AMS occurrence time

Results – trend of the coefficient of variation (CV)

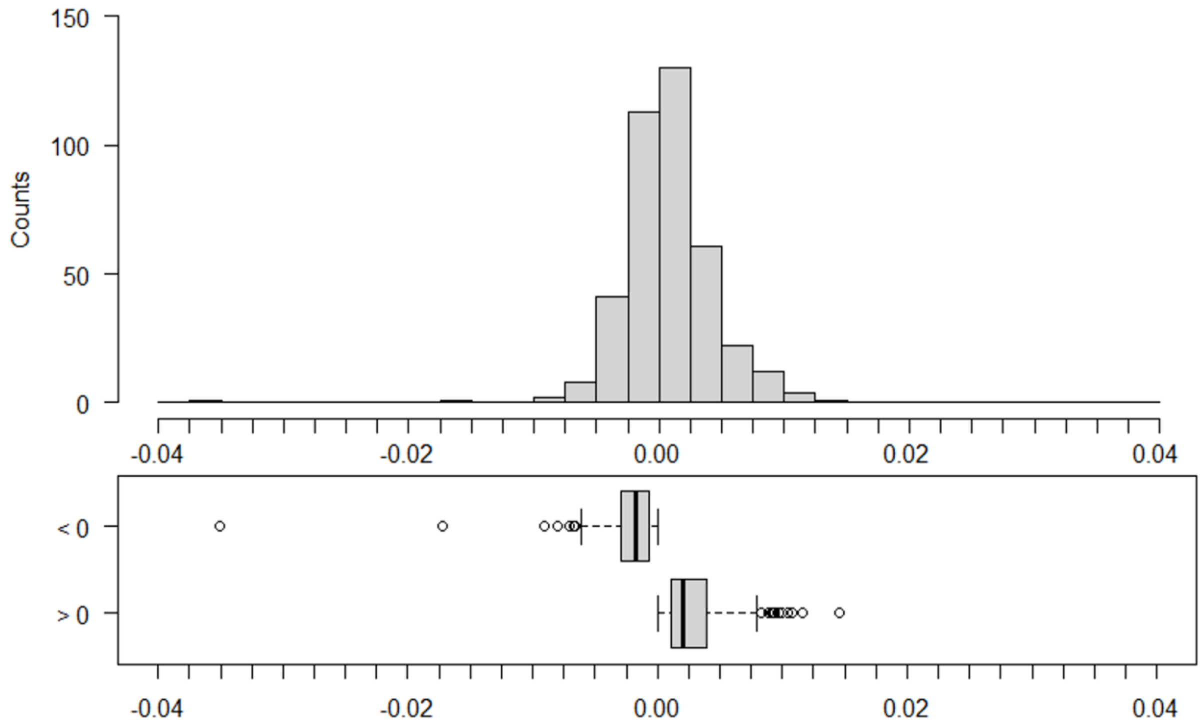


Results – trend of the coefficient of variation (CV)

Trend analysis of CV (all stations)

- Measured Sen's slope
- Slightly right skewed (more positive slopes)
  - 230 positive slopes (near 0.0020)
  - 166 negative slopes (near -0.0018)

- Climate change impact various locations differently
- Location variations exist
- Overall trend is increasing
- This result is the first of this kind



Conclusions

- Provided a method/direction to quantify and qualify the impact of climate change on rainfall occurrence time and its variability
- Long duration rainfall events (6 and 12hr) have more changes in rainfall occurrence time
- Heavy rainfall events are occurring at an altered time and time window of the year
  - Average change in the mean: shifted 44 days forward (~1.5 months)
  - Variance of rainfall occurrence time has changed
  - Increased coefficient of variance – increased variability of heavy rainfall occurrence time
- Provides a new angle on looking at climate change impact on heavy rainfall events
  - Improve the comprehensive research framework
  - Knowing magnitude and frequency are changing
  - Adding a new parameter: the time/timing

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