Flood frequency analysis and forecasting under non-stationary scenarios

Jianxun (Jennifer) He, PhD, PEng.

Civil Engineering
Schulich School of Engineering
University of Calgary
Email: jianhe@ucalgary.ca

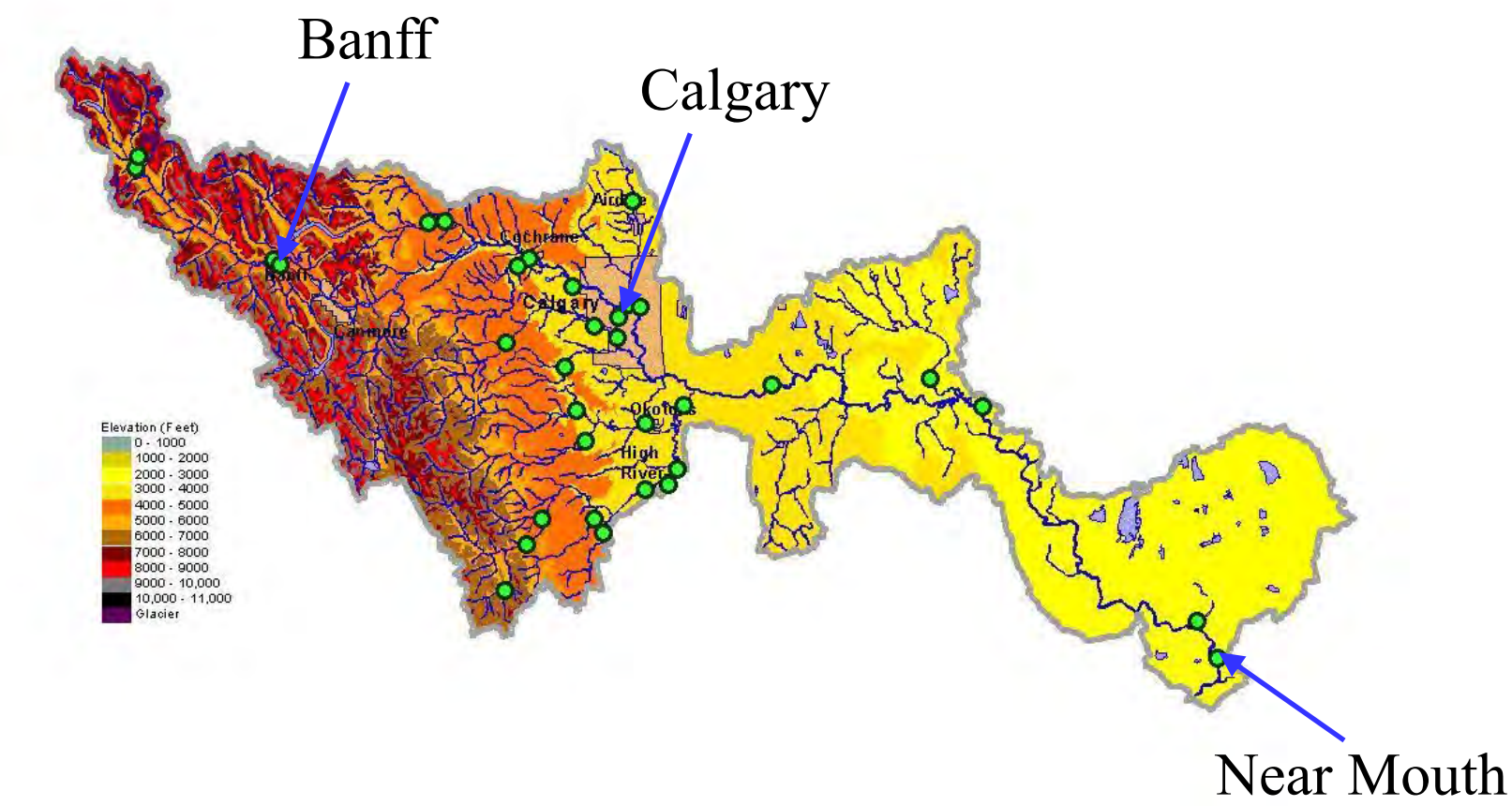
Questions

- Are floods preventable?
- Are floods predictable?
- Are the recent flood events attributed to a changing climate?
- Are the extreme events getting more intense and frequent?
- What can we do (using both structural and non-structural measures) to reduce flood damage?

Presentation Outlines

1. Flood generation mechanisms
2. Climate change impacts
3. Flood frequency analysis
4. Flood modeling and forecasting

Bow River Watershed

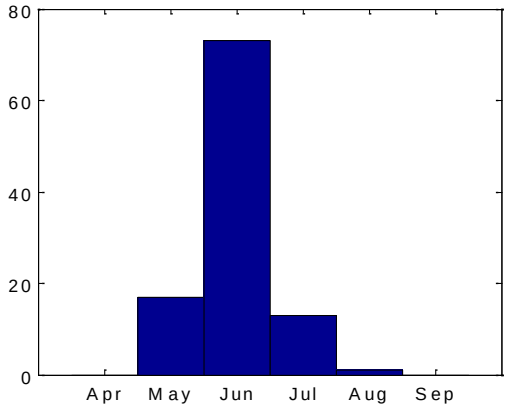


Source: http://www.environment.alberta.ca/apps/basins/

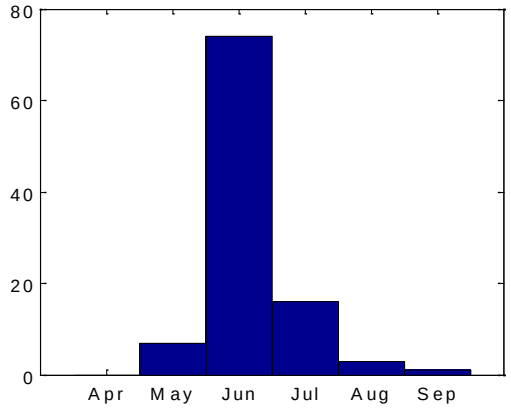
1. Flood Generation Mechanisms

- ✓ **Intensive rainfall**
- ✓ **Snow-melt**
- ✓ **Rain + snow-melt**
- ✓ **Ice jam**
- ✓ **Others**

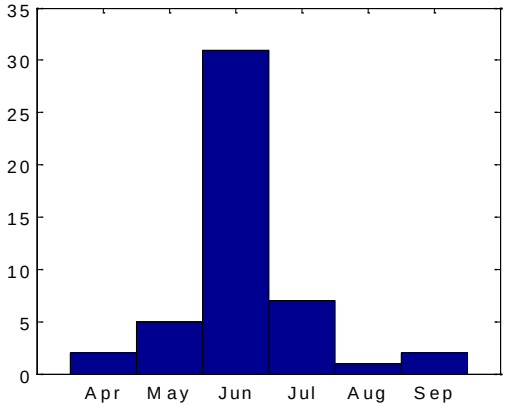
Annual peak flow



(a) Banff (1909 ~ 2013)



(b) Calgary (1911 ~ 2013)



(c) Near Mouth (1966 ~ 2013)

1. Flood Generation Mechanisms

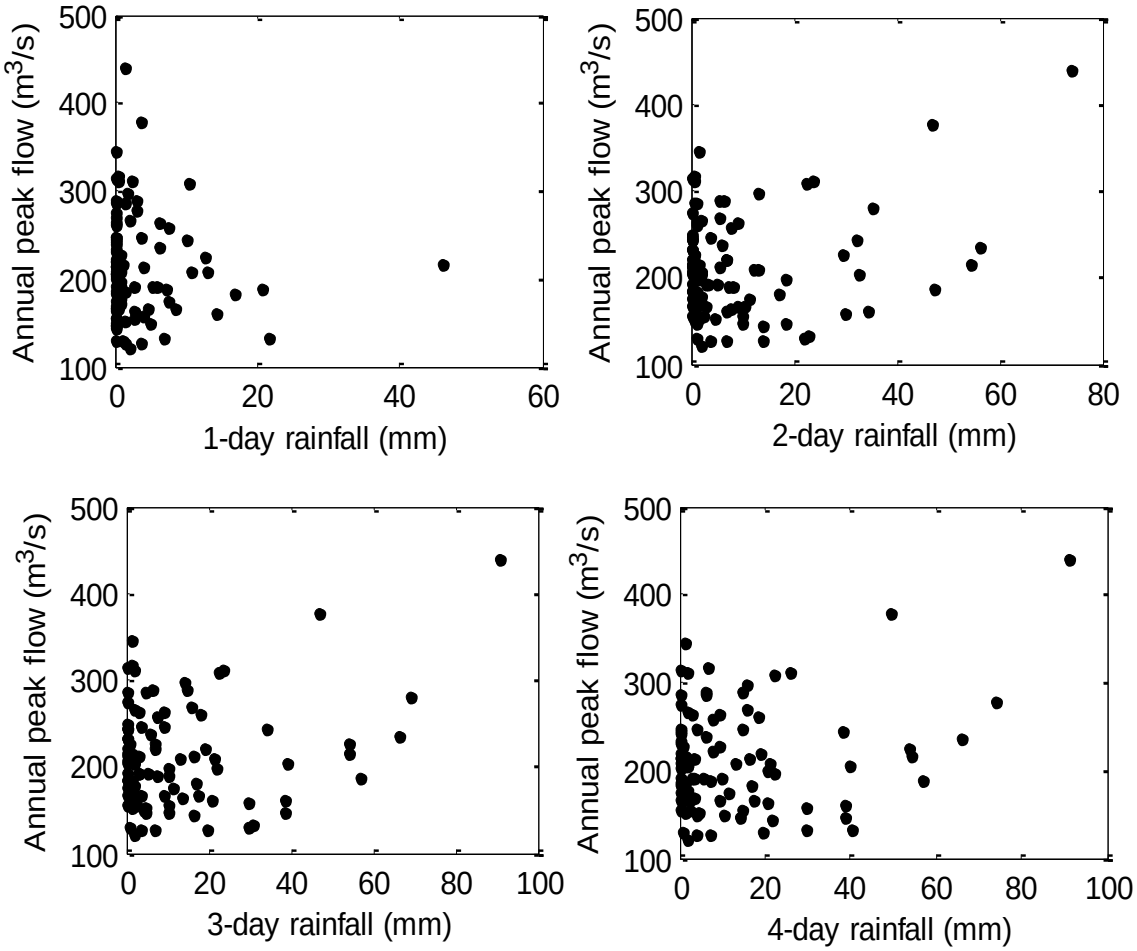


Fig. Relationship between peak flow and multi-day rainfall at Banff

1. Flood Generation Mechanisms

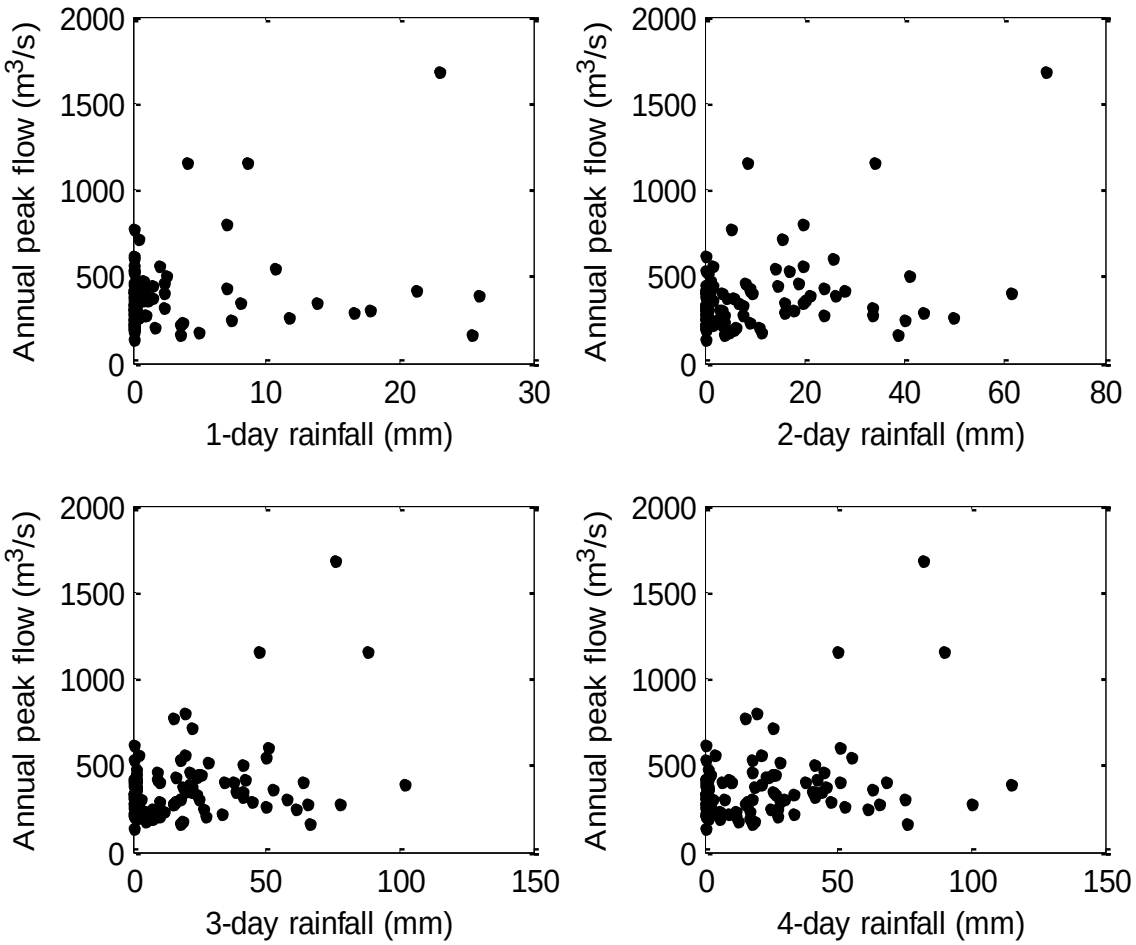
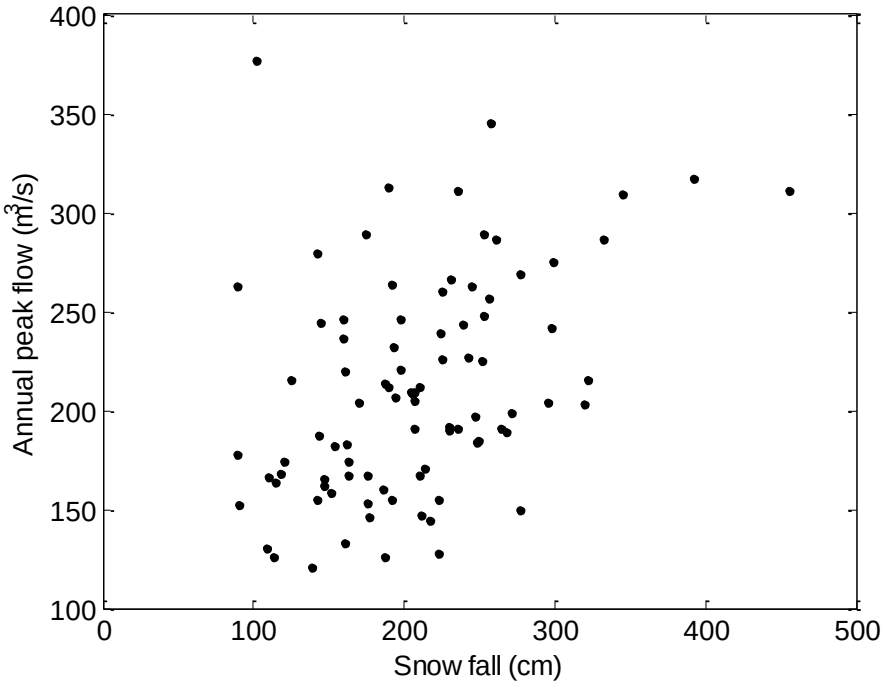
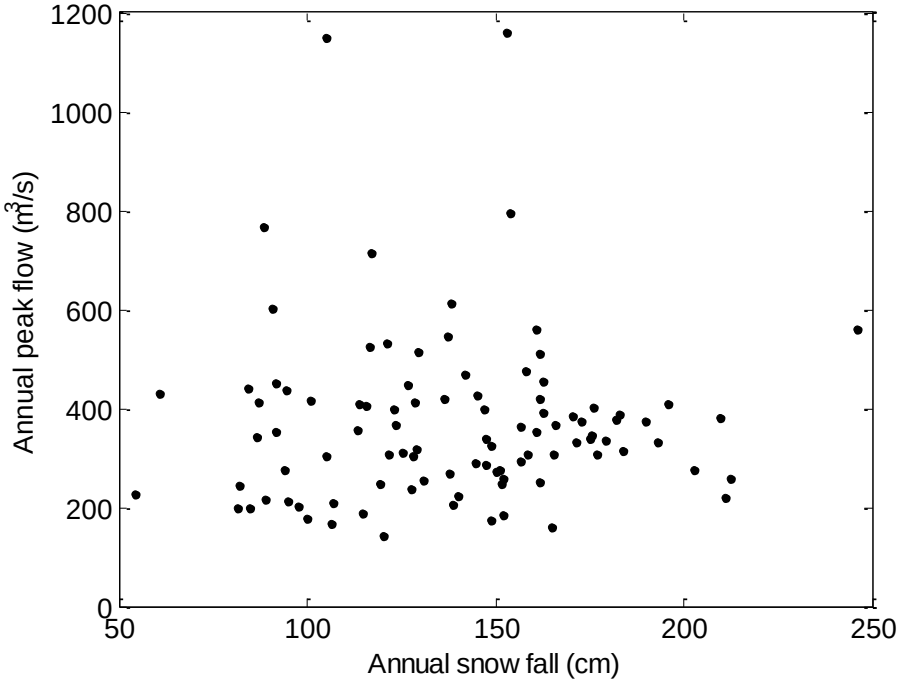


Fig. Relationship between peak flow and multi-day rainfall at Calgary

1. Flood Generation Mechanisms



(a) Banff



(b) Calgary

Fig. Relationship between annual snow fall and annual peak flow

1. Flood Generation Mechanisms

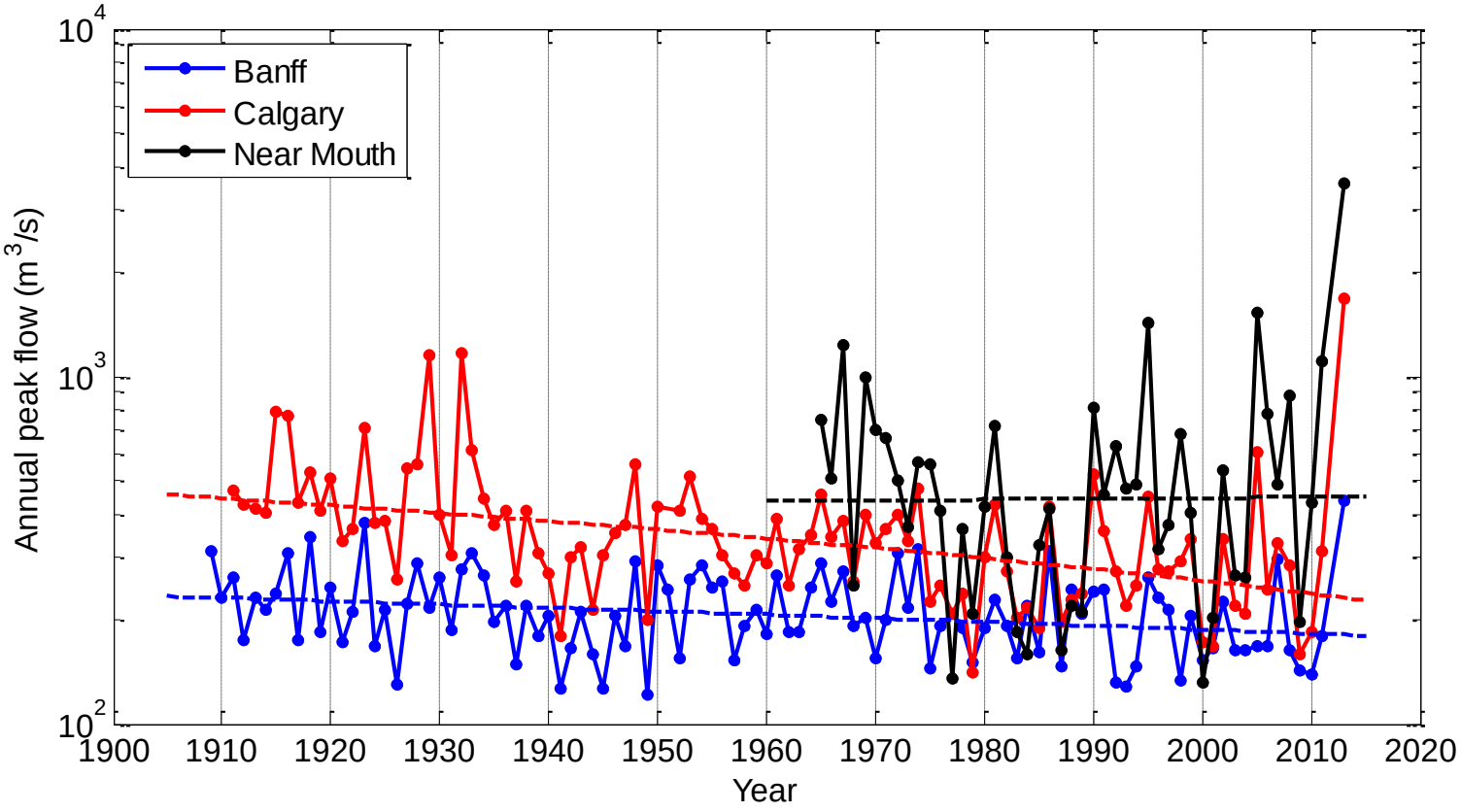
Results:

-Rainfall + snowmelt dominate.

-Peak flows are likely closely related to snowfall in headwater river reach.

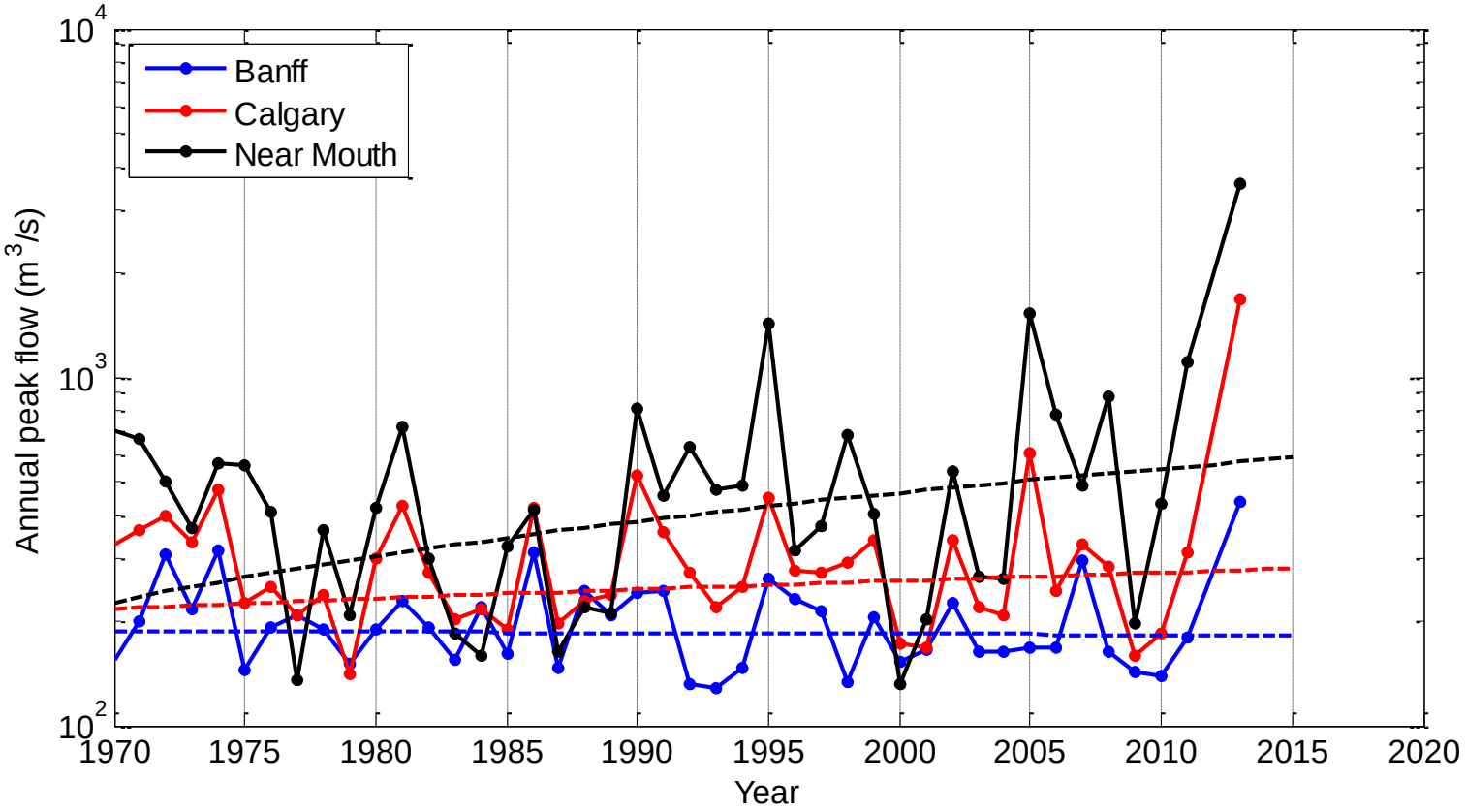
-Mechanisms governing peak flows in Calgary reach are likely more complicated.

Annual peak flow



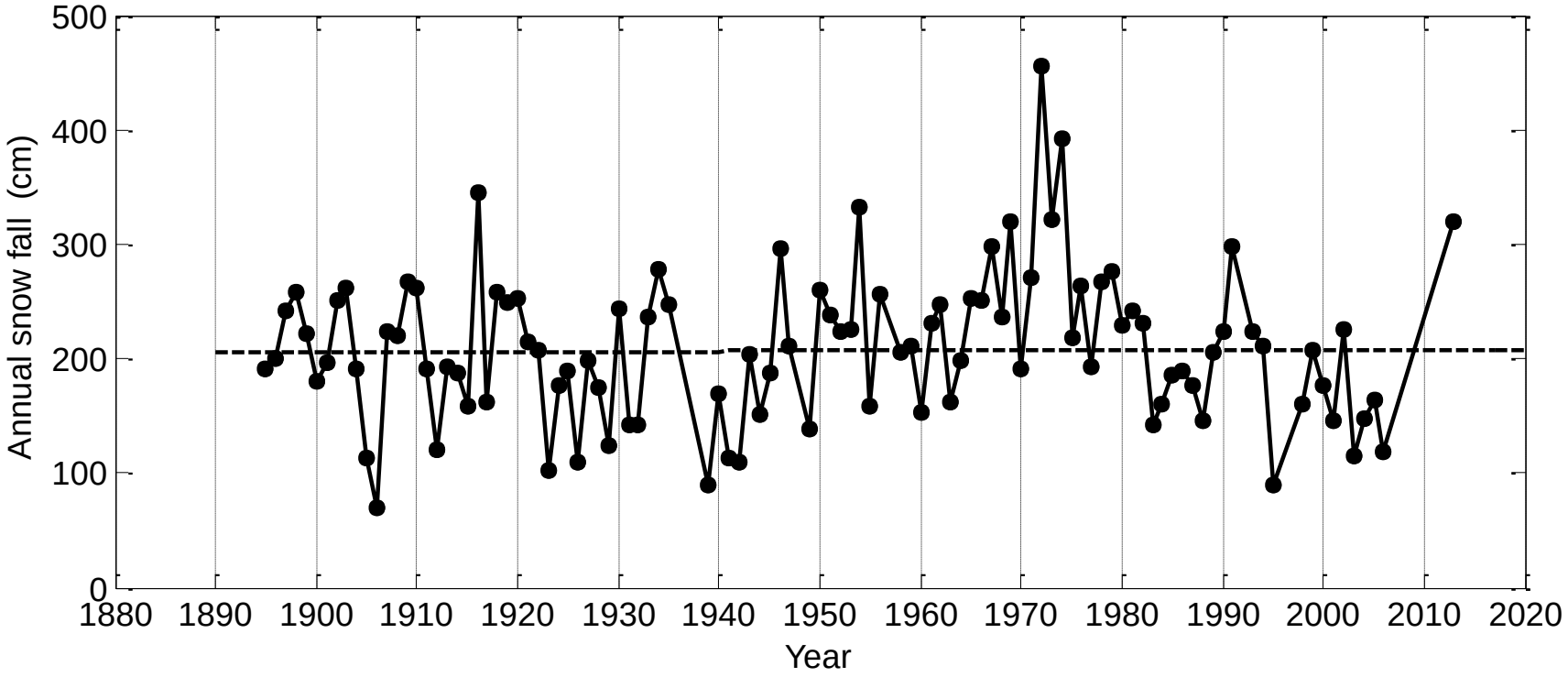
✓ MK trend analysis (all available data): significant downward trend at Banff and Calgary; while insignificant upward trend at Near Mouth.

Annual peak flow



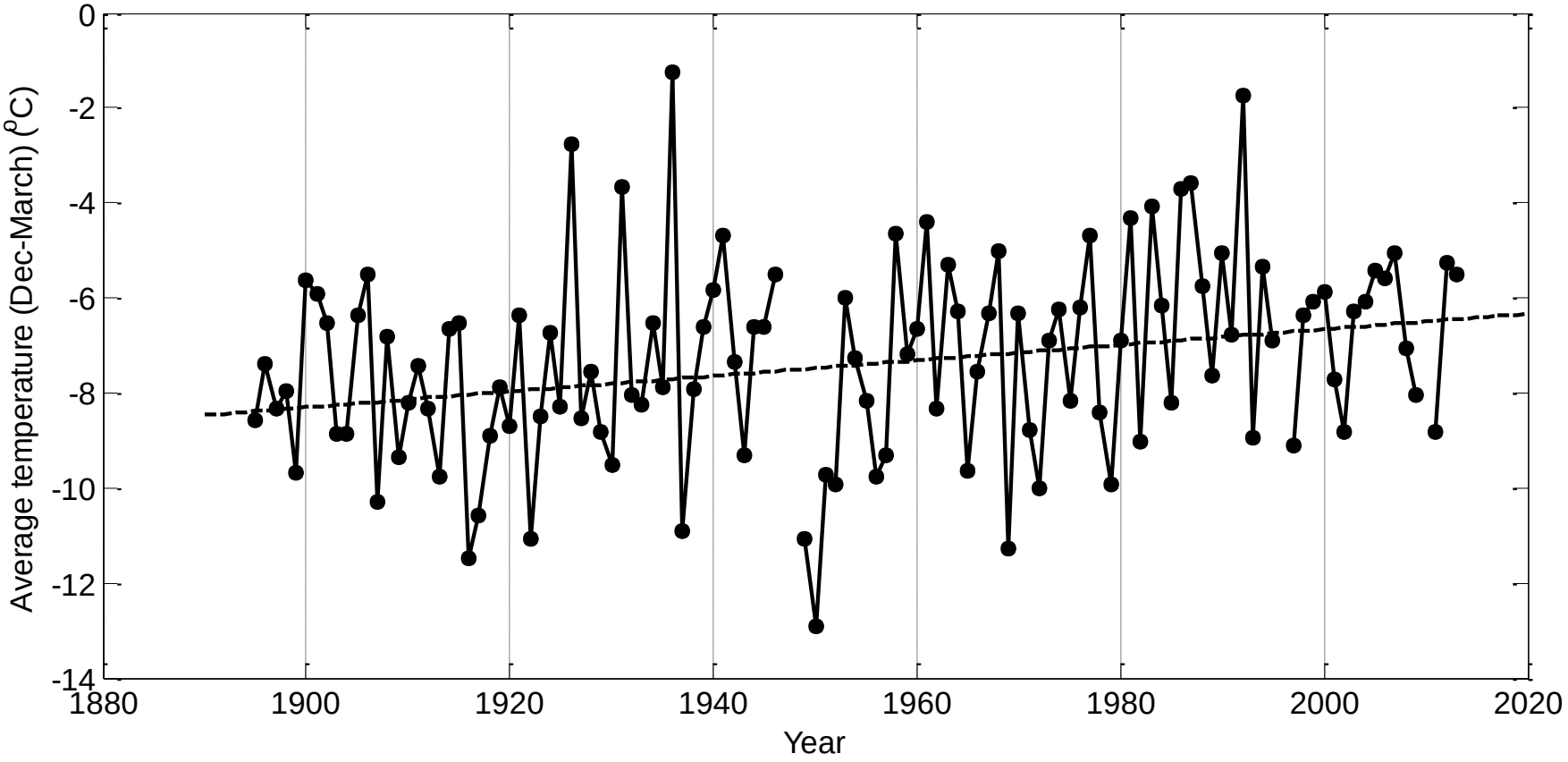
✓ MK trend analysis (after 1970): insignificant downward trend at Banff; insignificant upward trend at Calgary; significant upward trend at Near Mouth.

Annual snowfall at Banff (previous July – June)



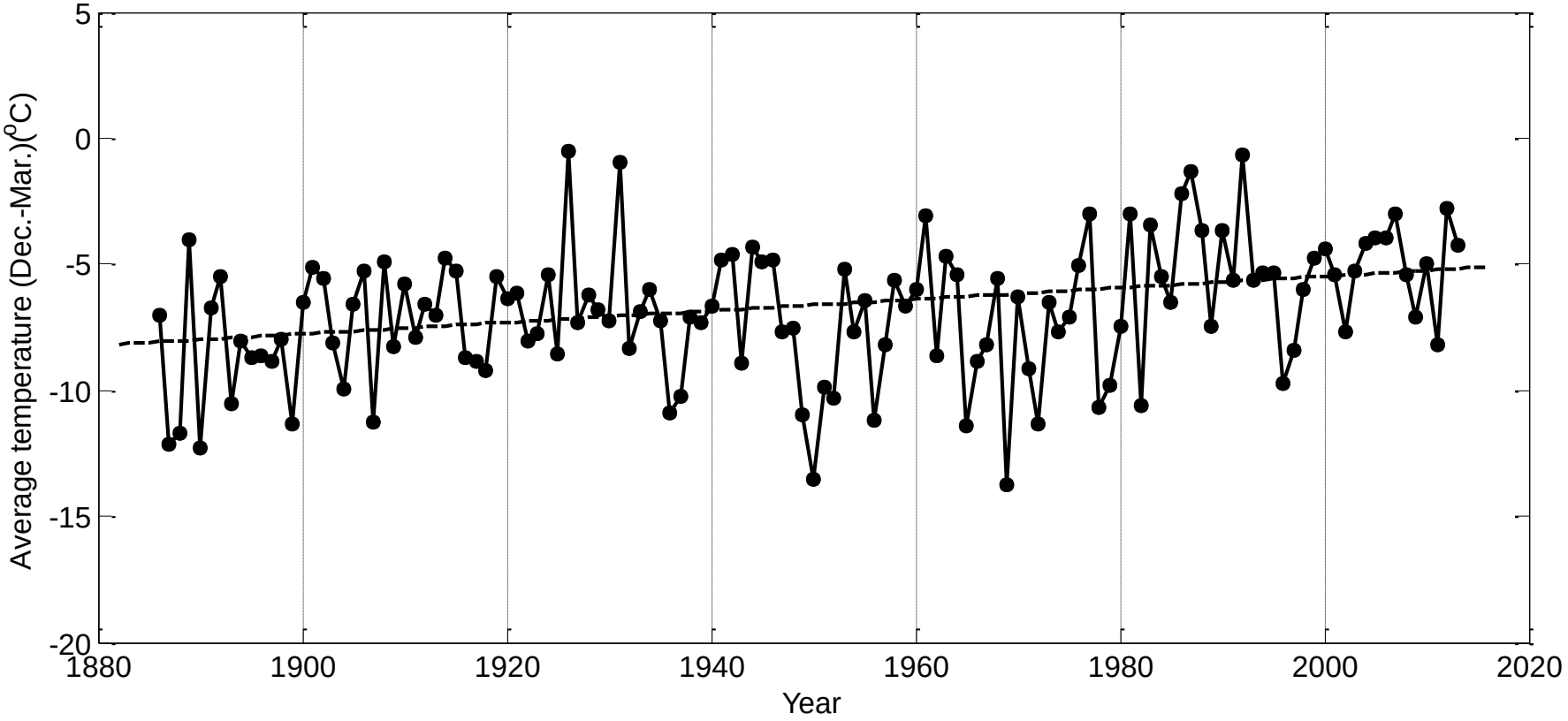
✓ MK trend analysis: insignificant upward trend.

Average air temperature at Banff (previous Dec. – March)



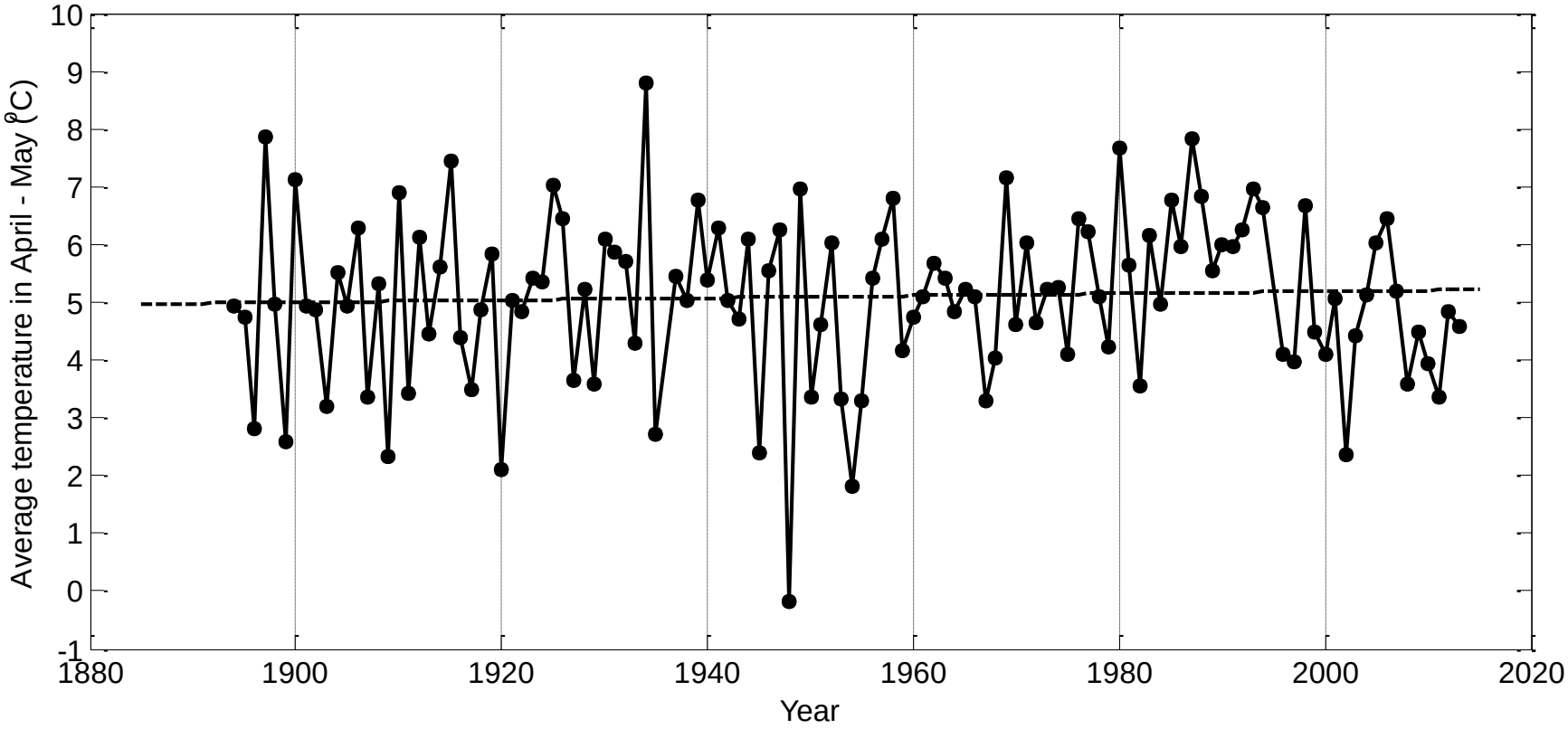
✓ MK trend analysis: significant upward trend.

Average air temperature at Calgary (previous Dec. – March)



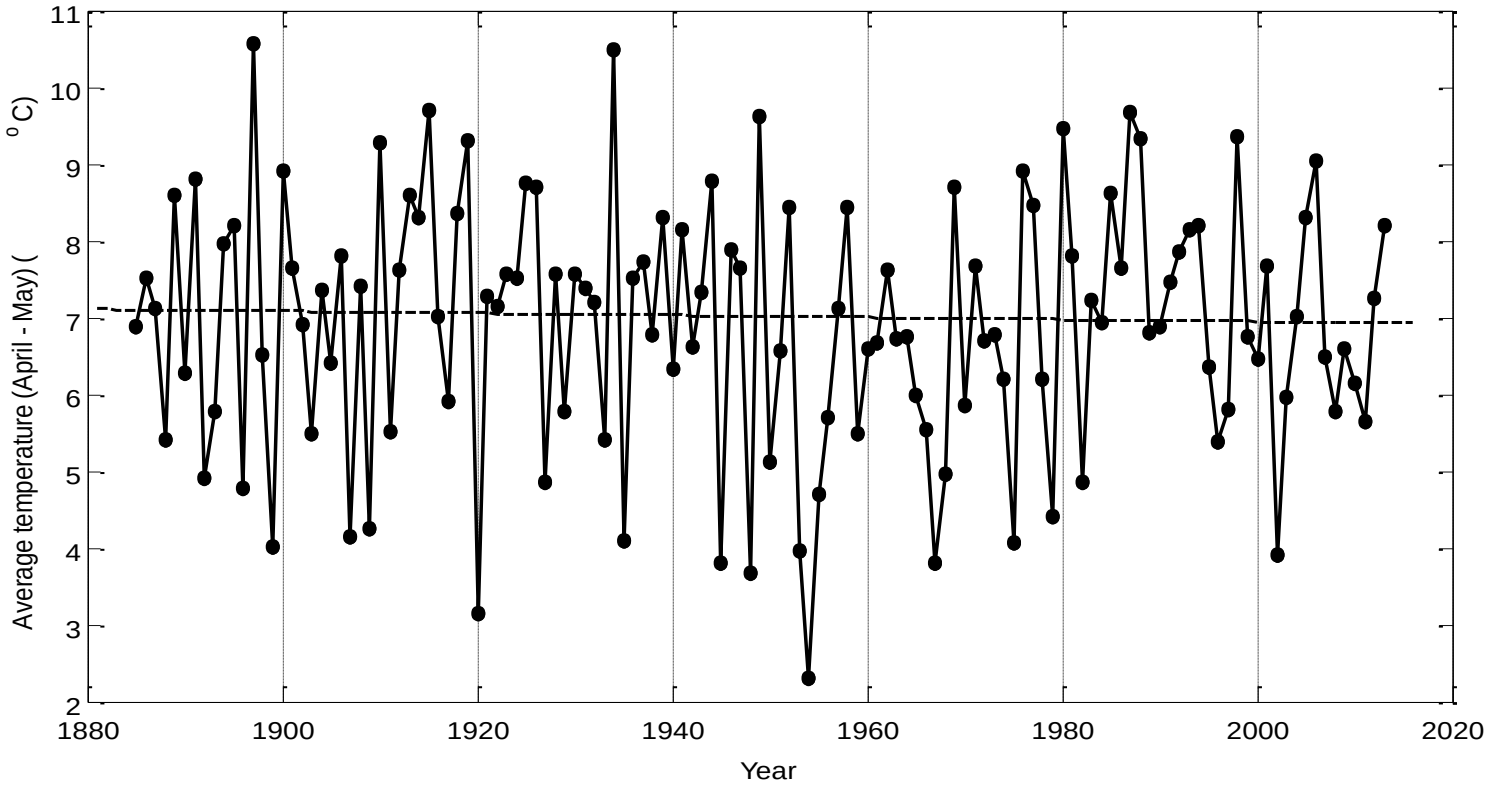
✓ MK trend analysis: significant upward trend.

Average air temperature at Banff (April – May)



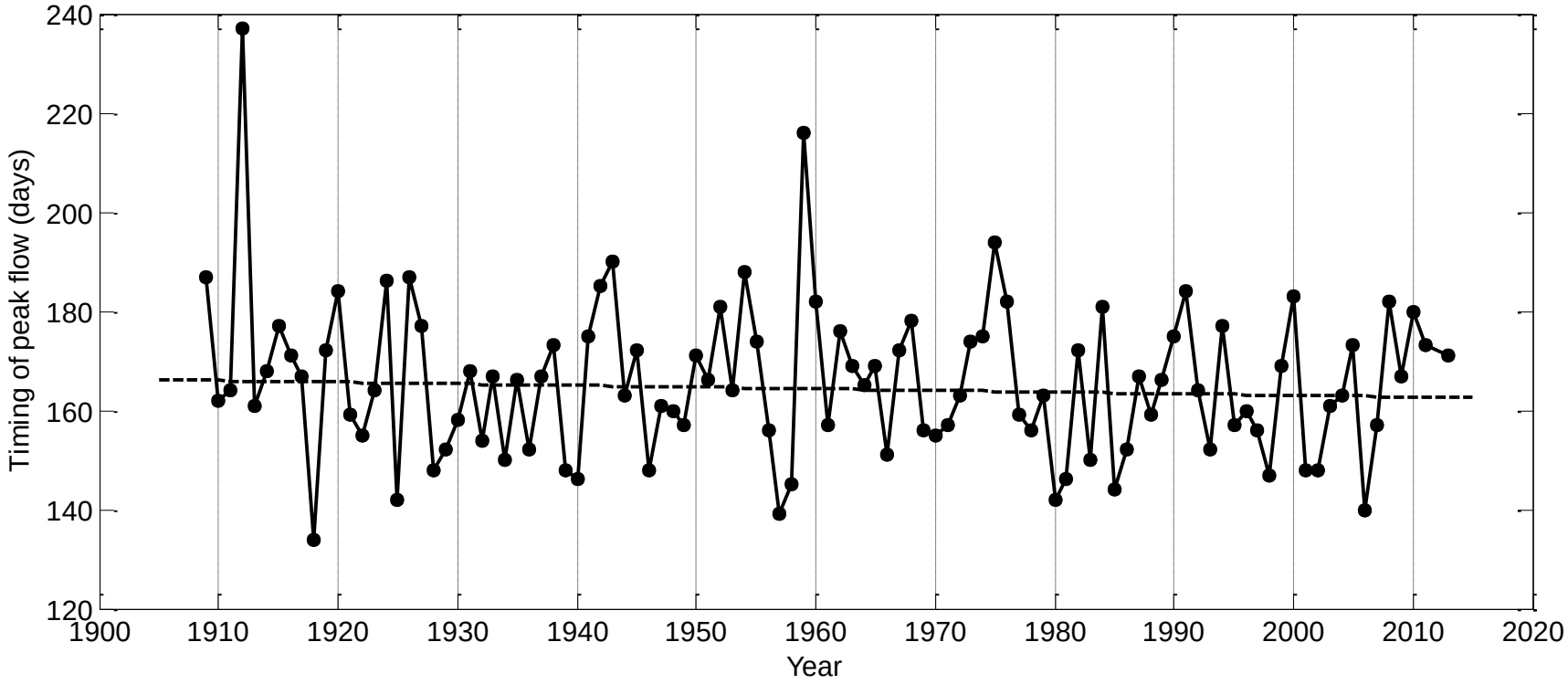
✓ MK trend analysis: insignificant upward trend.

Average air temperature at Calgary (April – May)



✓ MK trend analysis: insignificant downward trend.

Timing (from Jan. 1) of annual peak flow at Banff



✓ MK trend analysis: insignificant downward trend.

2. Climate Change Impacts

Results:

-It appears that change points exist in data series.

-Trends in climatological variables have been identified.

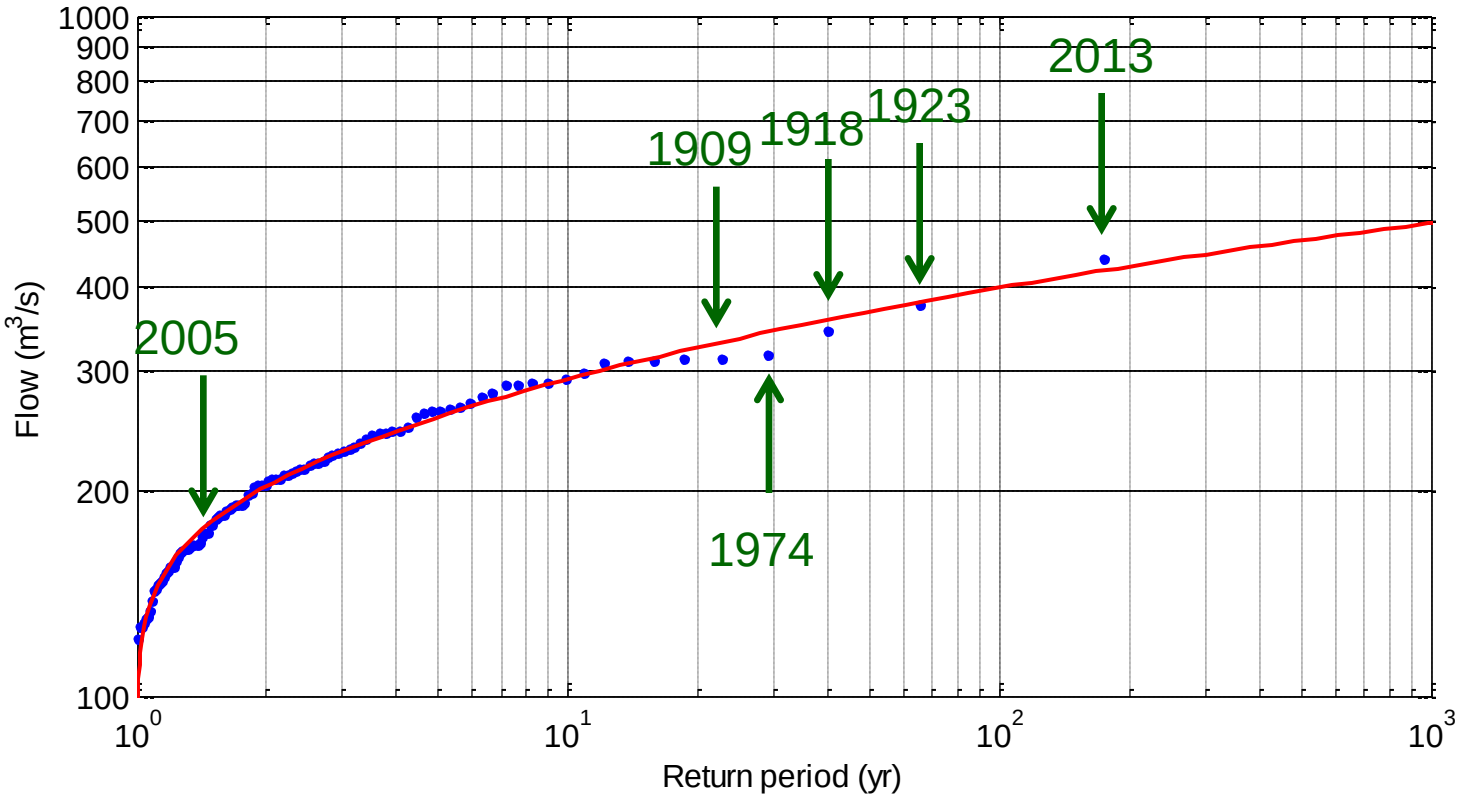
- Significant increases in average air temperature during Dec.-Mar.

-The impacts of climate change might be highly complicated. Comprehensive analysis approach is needed to assess climate change impacts.

Future works:

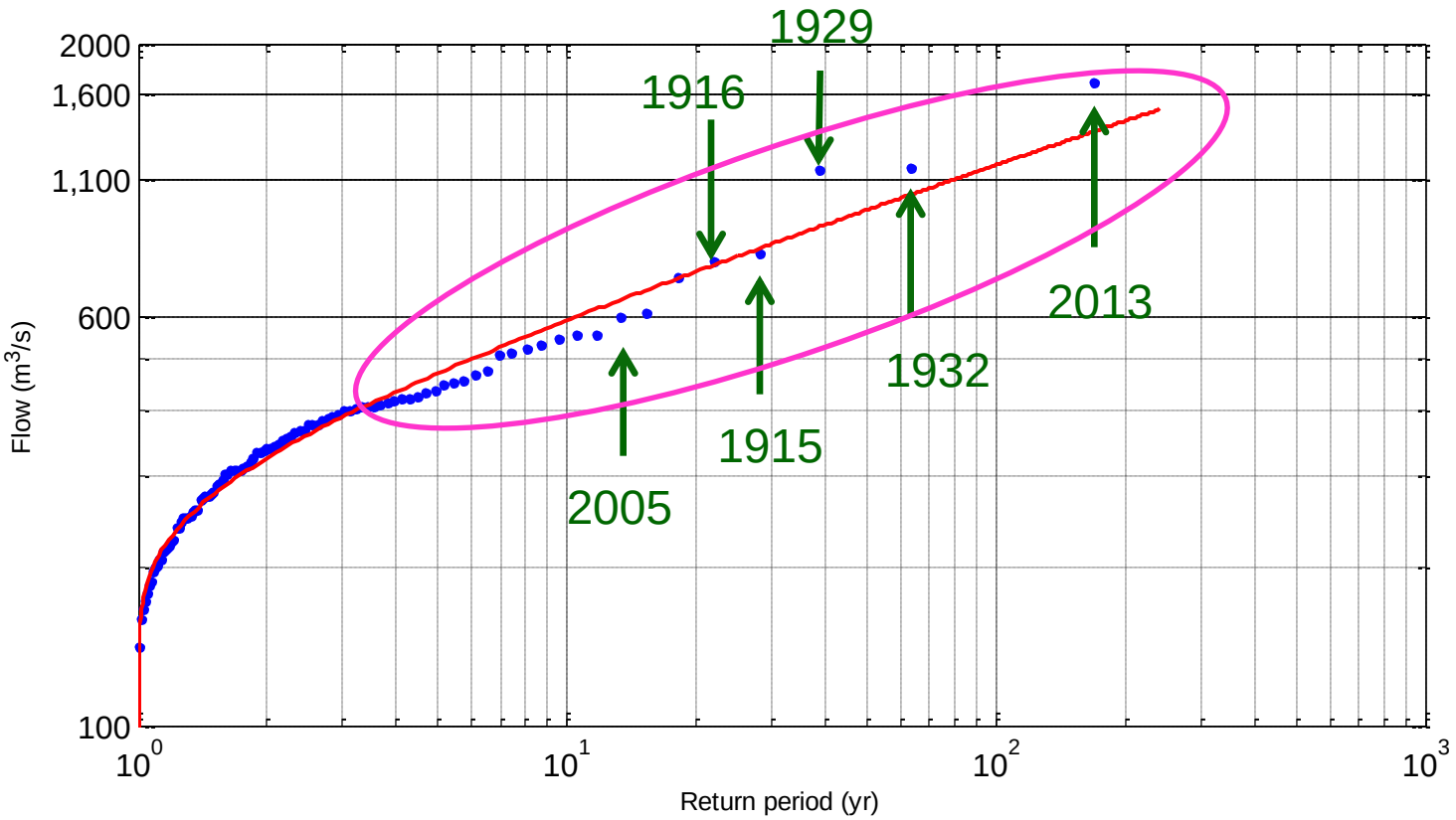
- Climate change impacts on the Bow.
- More rigorous approach needed.

3. Flood Frequency Analysis



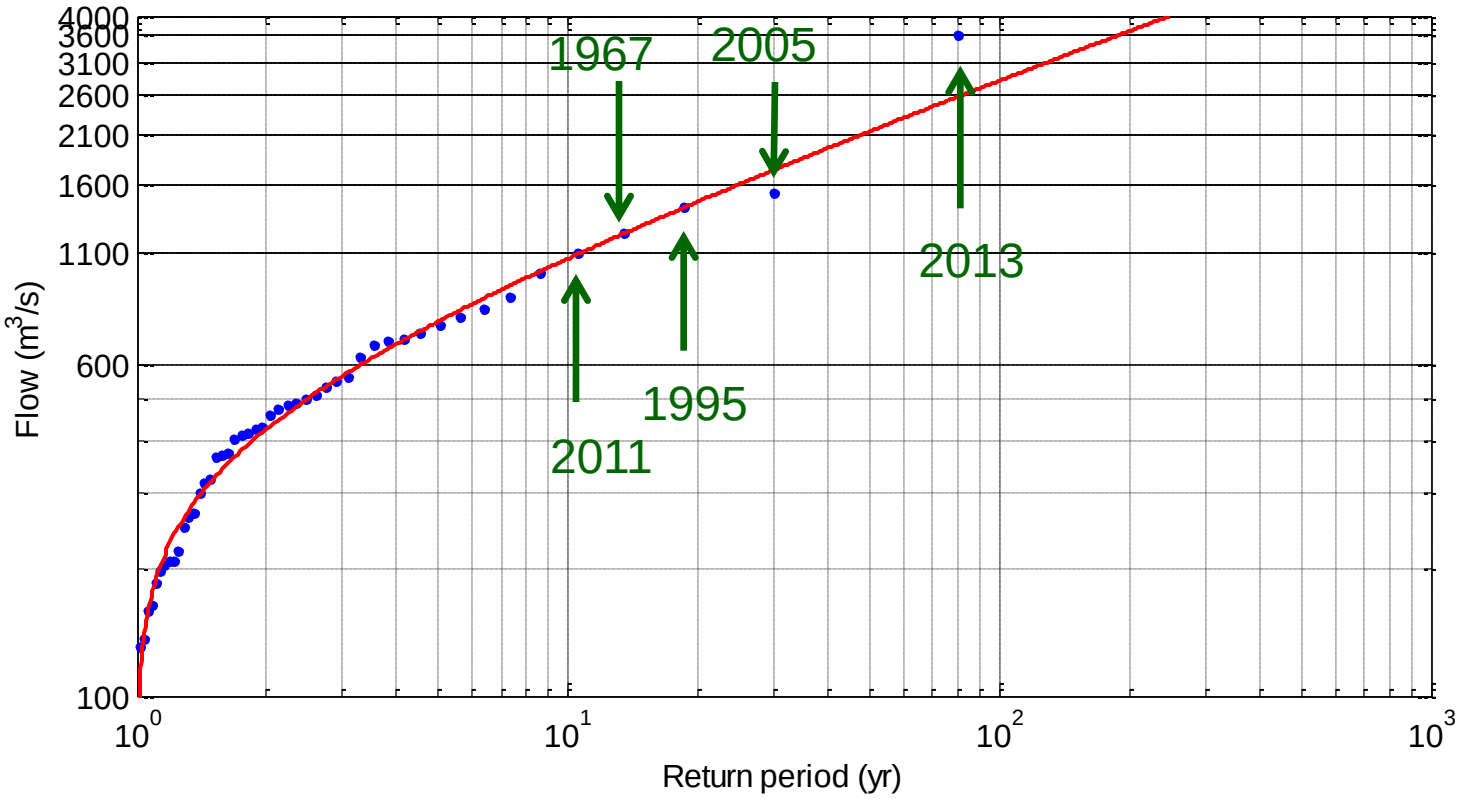
At Banff (1909 – 2013)

3. Flood Frequency Analysis



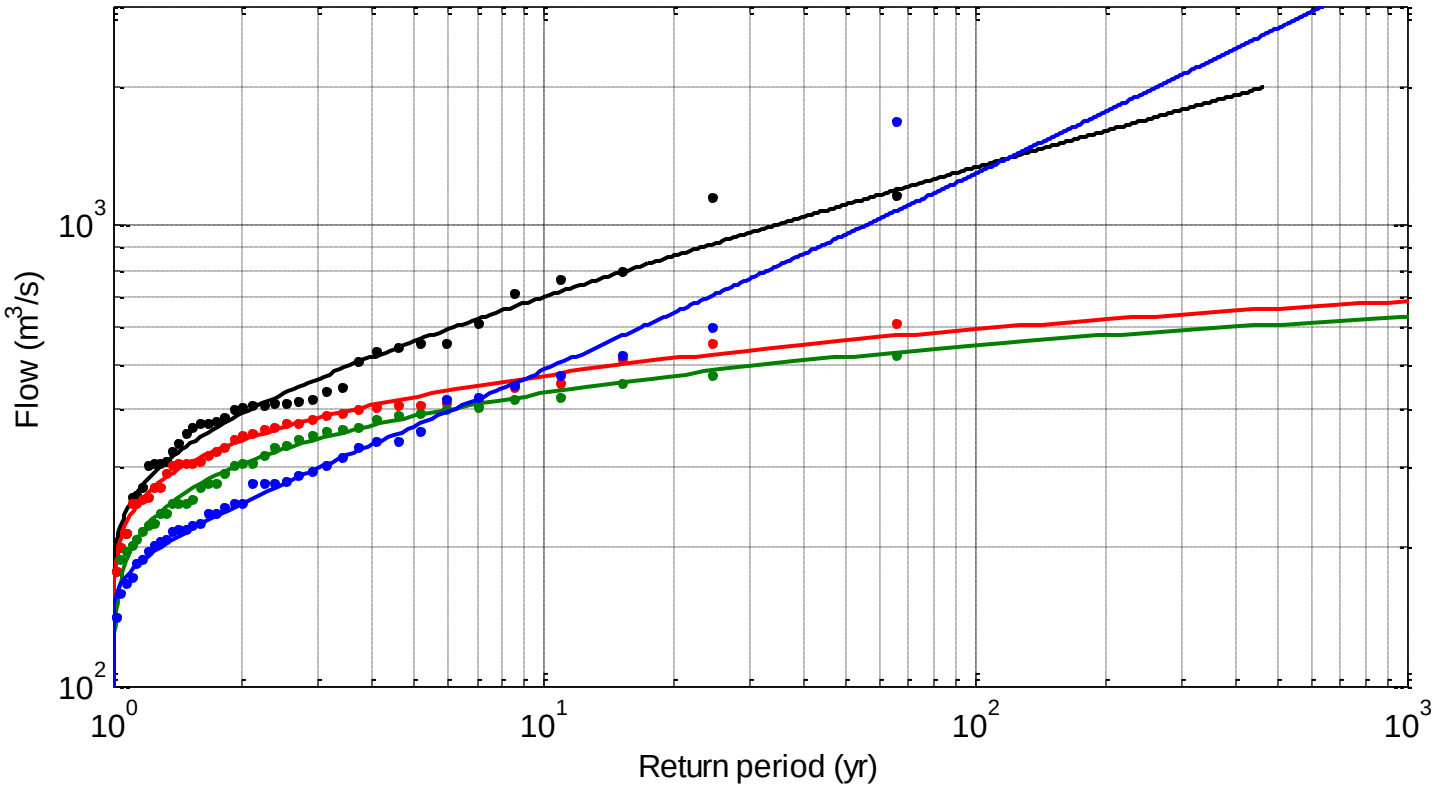
At Calgary (1911 – 2013)

3. Flood Frequency Analysis



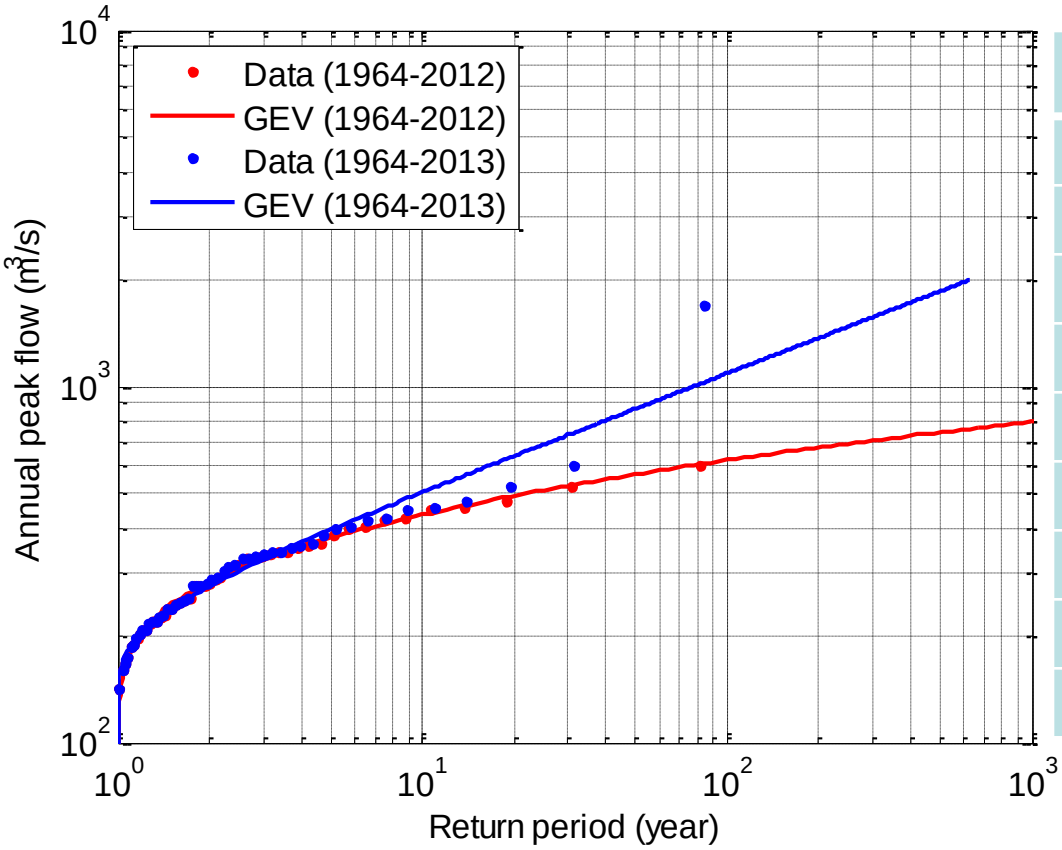
At Near Mouth (1965 - 2013)

3. Flood Frequency Analysis



At Calgary (black:1913 – 1952; red: 1933 – 1972; green: 1953 – 1992; blue: 1973 - 2013)

3. Flood Frequency Analysis



Results	Including 2013	Excluding 2013	Ratio
ξ	244.4747	252.6273	--
α	77.8943	82.6049	--
κ	-0.3312	0.0139	--
Q_2	274.8288	282.8258	0.97
Q_{10}	504.8425	435.6335	1.16
Q_{50}	865.6013	566.3384	1.53
Q_{100}	1088.4	620.6961	1.75
Q_{200}	1367.9	674.3319	2.03
Q_{500}	1850.5	744.3031	2.49

Calgary (1964 - 2013)

3. Flood Frequency Analysis

Results:

-Frequency analysis is sensitive to “unusual” data points.

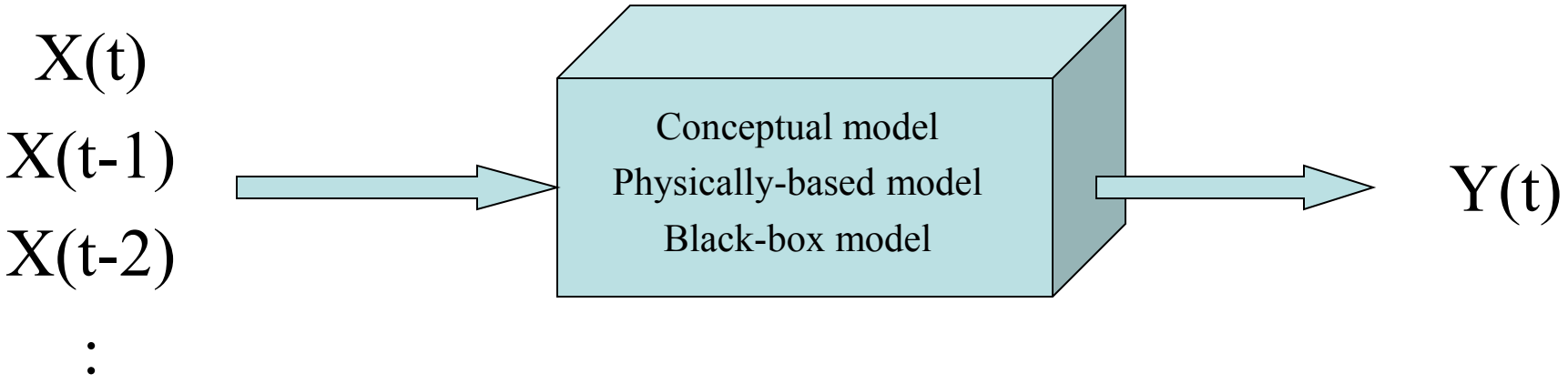
-Uncertainty can be very big, which may hinder its applications.

Future works:

-Mixture model

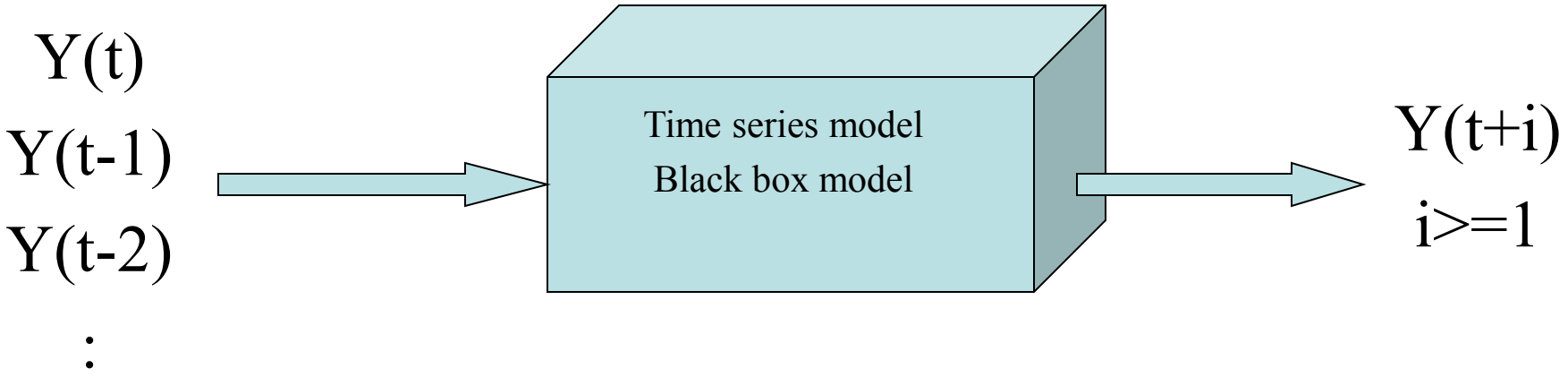
-Multivariate frequency analysis

❖ Modeling



- Multiple flood generation mechanisms
- Model re-calibration if non-stationary

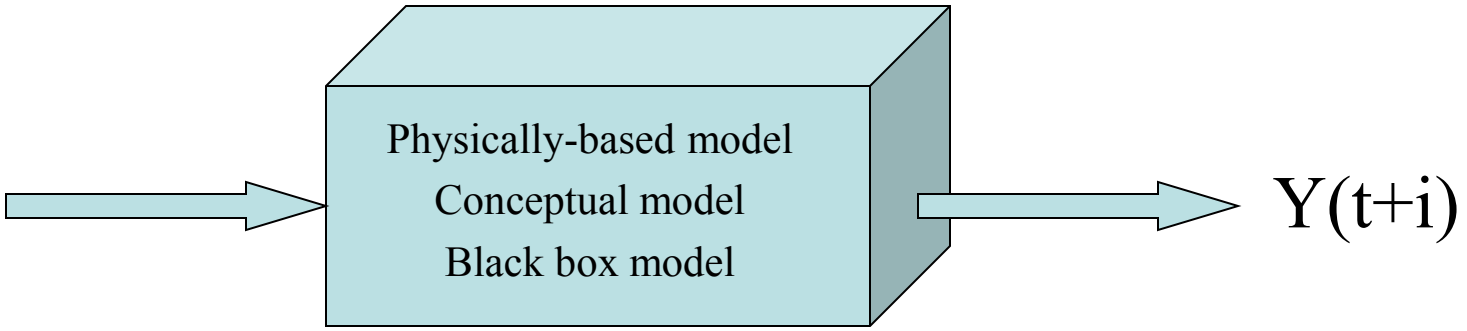
❖ Forecasting



- Short lead time

❖ Weather prediction + flood modeling

X(t+i)
X(t+i-1)
X(t+i-2)
:
i>=1



- Numerical weather prediction
- Medium range forecasting

4. Flood Modeling and Forecasting

Future works:

- Approach for model calibration and verification especially for modeling multiple mechanisms.
- Assessing Kalman filter technique for flood modeling and forecasting taking the advantage of its capability to model process based on process states.
- More reliable short and long lead time forecasting.

Thank you!