Non-stationary analysis of the frequency and intensity of heavy precipitation over Canada and their relations to large-scale climate patterns

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1. Introduction

- In recent decades, Canada have experienced several extreme flood events. For instance, the total damage of the June, 2013 flood of southern Alberta is estimated at $5–6 billion, making it the costliest natural disaster in Canadian history.
- Changes to Canadian extreme and heavy precipitation under the global warming impact can increase the risk of flooding.
- Compared to the block maxima approach that models extreme events using a generalized extreme value (GEV) distribution, the (peaks-over-threshold) POT approach fits all events exceeding a specified threshold to a generalized Pareto (GP) distribution and the occurrence of an exceedance to a Poisson process.
- To avoid possible confusion about definitions regarding extremes, samples of maximum events for the block maxima method will be referred to as extreme events while events for the POT approach as heavy events.
- As the probability of occurrences of climate extremes can be strongly affected by large-scale climate patterns, considerable progress has been made in deriving possible relationships between such climate patterns and extreme climate variables by modeling the latter with non-stationary GEV and GP distributions using climate indices as time-varying covariates.

2. Research procedure

- Daily precipitation measurements were obtained from the second generation, adjusted historical Canadian climate data (AHCCD) database (463 stations).
- Block maxima of extreme precipitation events (annual maximum daily precipitation (AMP)) were fitted with both stationary and non-stationary GEV distributions.
- The number of heavy precipitation events was fitted with a non-stationary Poisson distribution.
- Exceedances of precipitation events over a threshold defined as the 95th percentile of non-zero precipitation were fitted to a non-stationary GP distribution with time-varying parameters.
- We used composite methods to assess the impact of extreme phases of ENSO, PDO, NAO and NP on Canadian heavy precipitation.

3. Extreme value distribution of Canadian Precipitation

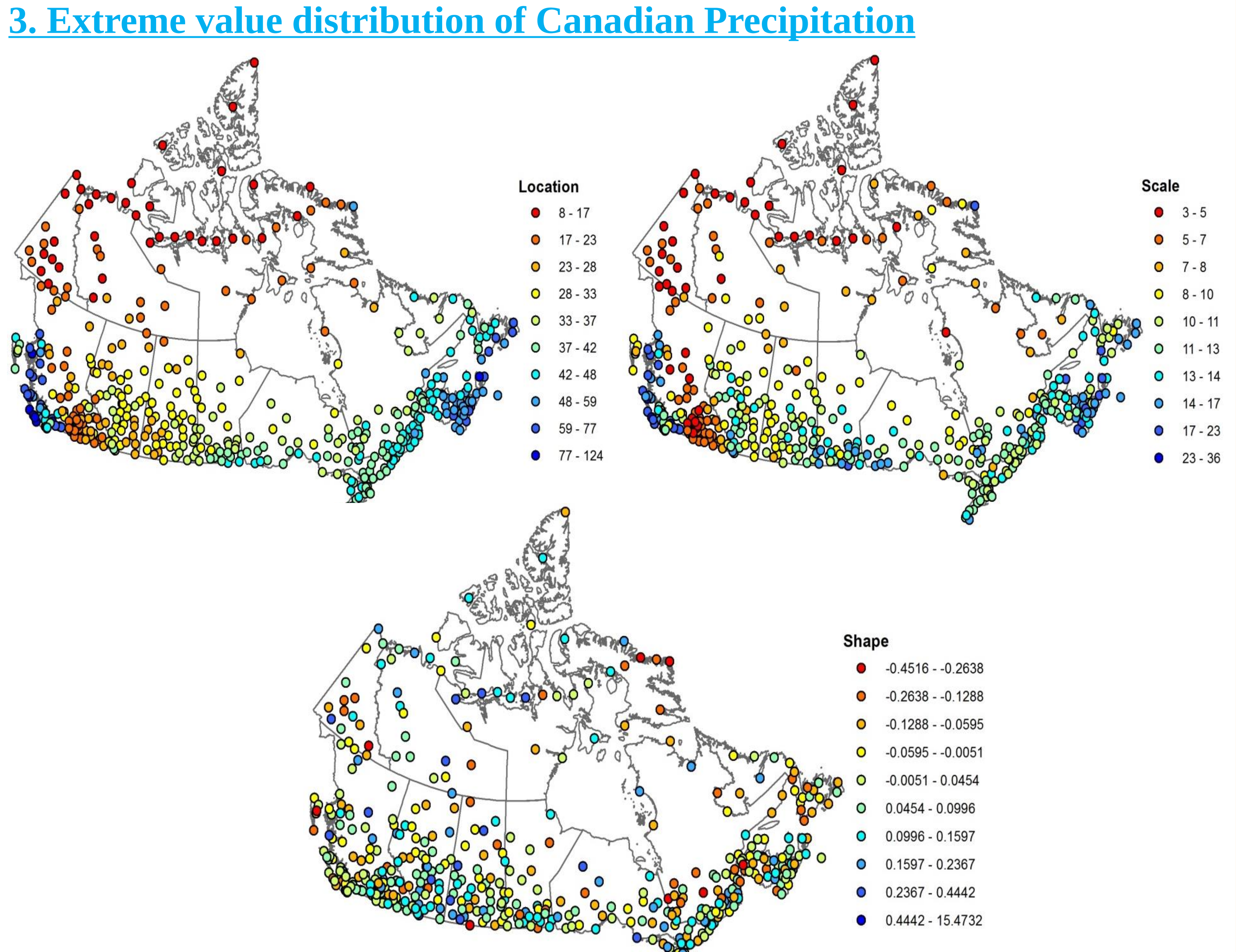

Fig. 1 Maps of location, scale and shape parameters of the GEV distribution for AMP time series derived from the stationary analysis

- Overall, the location and scale parameters increase from north to south and from inland to coastal regions of Canada, with highest location and scale parameters located in southwestern and southeastern coastal regions of Canada. However, there is no clear spatial pattern for the shape parameters.

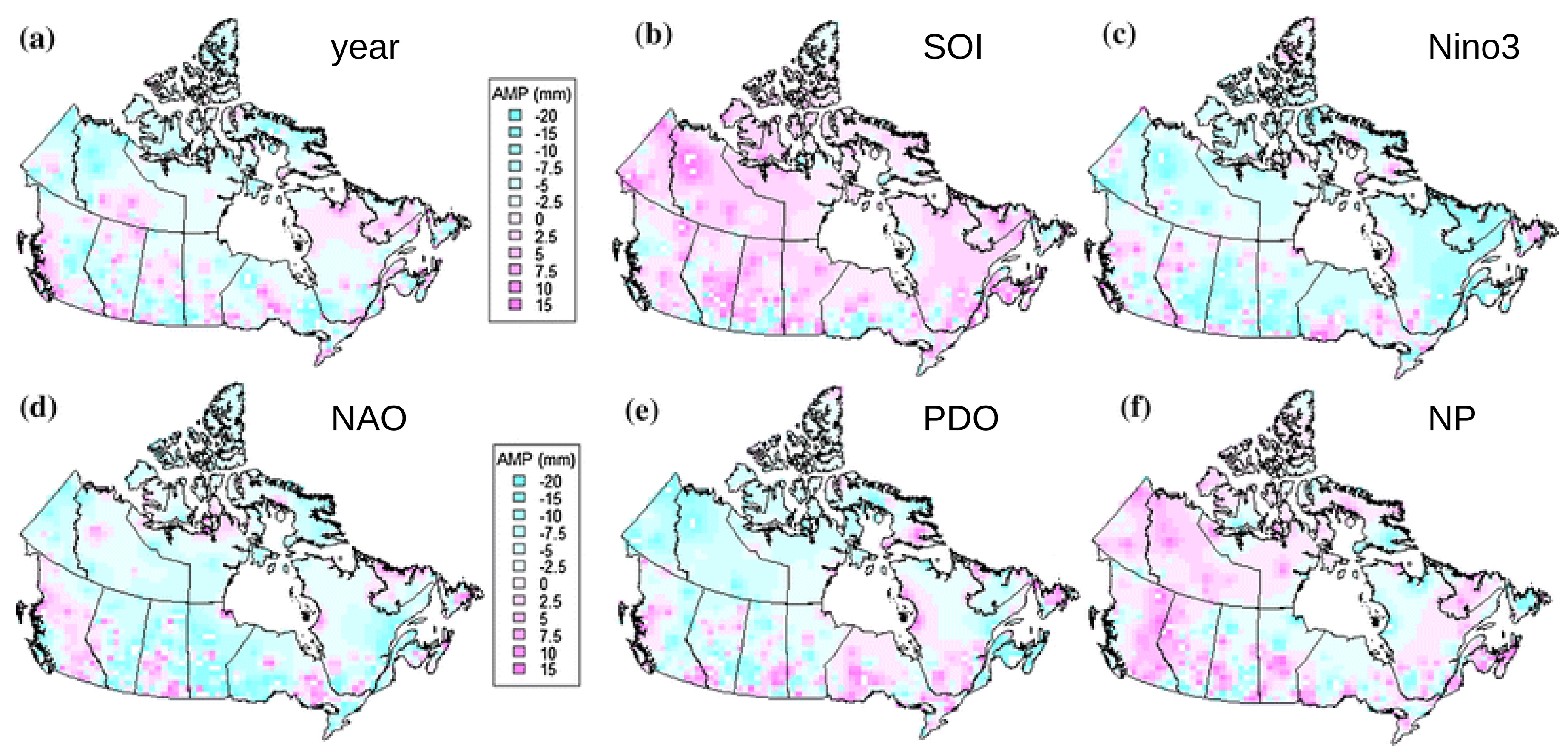

Fig.2 The spatial distributions of differences in AMP of 20-year return period predicted by GEV distributions based on parameters estimated from the maximum and the minimum historical values of a given covariate. The respective covariate used was the year for (a), SOI for (b), Nino3 for (c), NAO for (d), PDO for (e), and NP for (f). The red (blue) grids means that the difference in AMP estimated from the GEV derived from the maximum covariate values are higher (lower) than that derived from the minimum historical values of the covariate.

- In Fig. 2c, areas colored pink (light green) are areas where a high NINO3 index means a wetter (drier) climate than a low NINO3 index, and vice versa. Therefore, a high NINO3 index (when El Niño is active) means that Canada will tend to be dry.

4. Modeling heavy precipitation clusters with Poisson regression

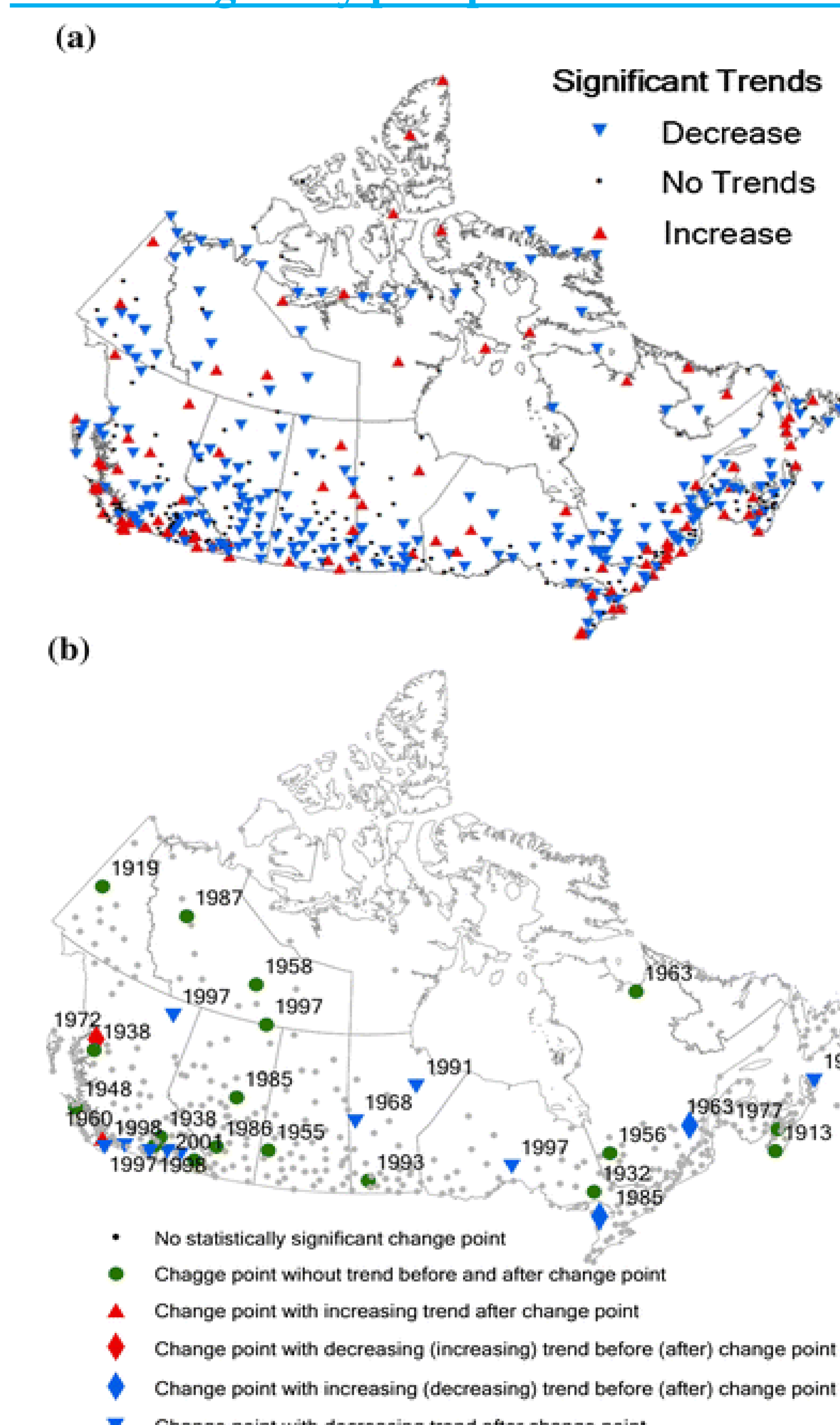

Fig.3 Results of the fitting of the counts of heavy precipitation with a Poisson regression model with rate of occurrence that depends linearly on time without (a) and with (b) a change point detected using the segmented regression.

- In Fig. 3a, Most stations showing increasing trends are located in the southwestern, east coast, northern Arctic and northeastern CP, while decreasing trends are widespread in the CP, eastern and northern Canada.
- Out of 463 stations (Fig. 3b), only 32 stations show statistically significant change points in the occurrences of heavy precipitation. The years the change point occurred are not spatially consistent.

5. GP distribution

- Spatially, precipitation return levels increase in the north–south direction, and as expected, peaked in the southwestern and southeastern coastal regions of Canada, which is consistent with the location and scale parameters of GEV as shown in Fig. 1. For the three return periods (2-, 20- and 100-year return periods), overall GEV estimates precipitation return levels that are smaller than that of GP by about 8.0, 1.4 and 3.7 %, respectively.

6. Composite circulation patterns

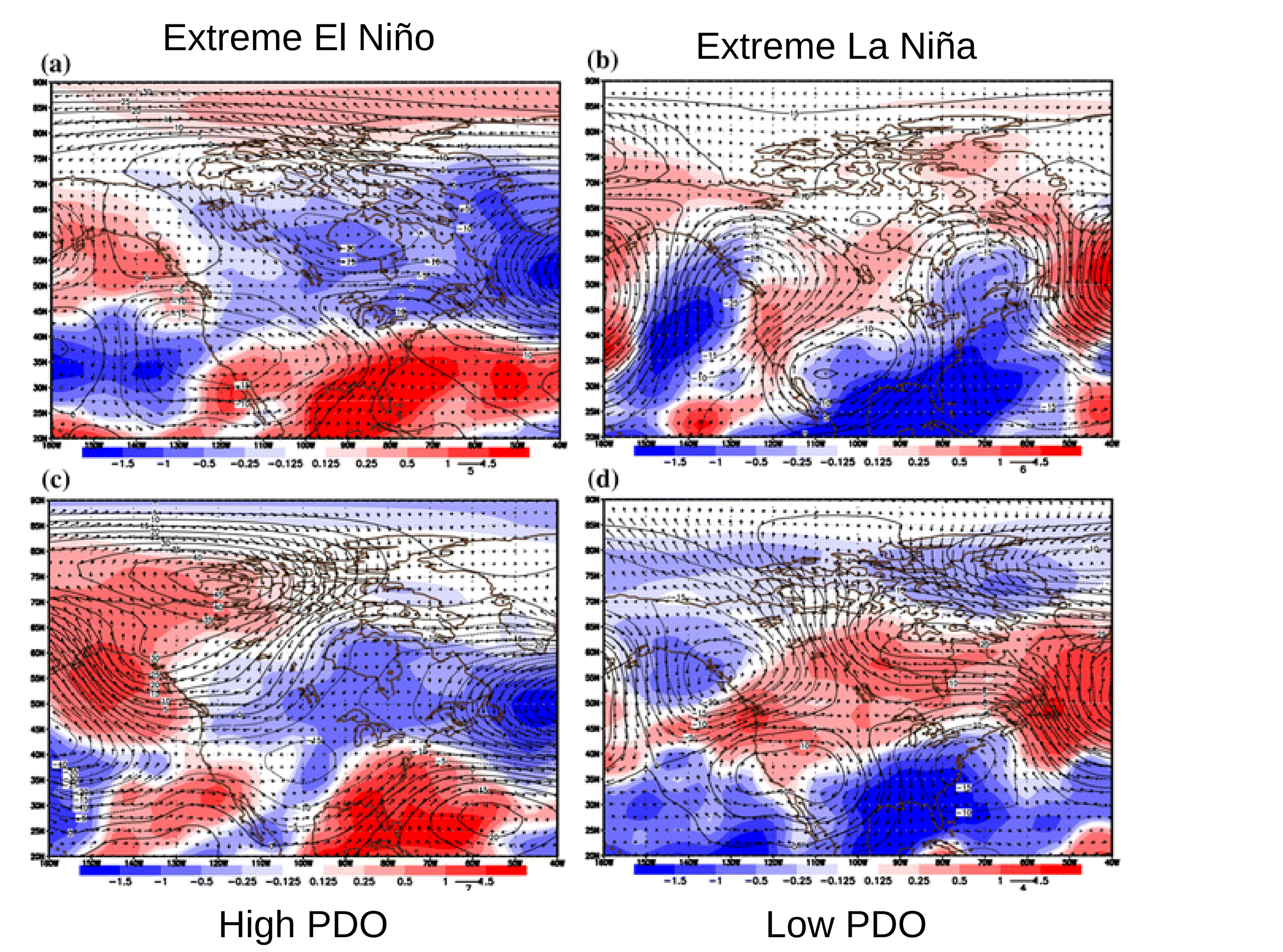

Fig.4 Composite winter 500-hPa geopotential height (m; contour with numbers), 500-hPa wind filed (m/s; vectors) and vertically integrated precipitable-water-content (mm/day; shaded) anomaly patterns for western Canada in winter days.

- Wetter (drier)southern Canada in La Niña (El Niño) winters is also consistent with the positive (negative) PWC anomalies associated with La Niña (El Niño) (Fig. 4a, b).
- Active PDO leads to low pressure zones occurring over the North Pacific Ocean with enhanced anticlockwise winds, resulting in dry conditions in western Canada (Fig. 4c).

7. Conclusions

(1) Most stations had a non-zero shape parameter, which implies that most Canadian AMP series can be modeled by GEV Type II or Type III distributions with heavy tail behavior. About 1/3 of the AMP time series shows non-stationary characteristics.

(2) In general, GEVdistributions tend to under-estimate AMP of western and eastern coastal regions more than other regions of Canada.

(3) By using time-varying, climate indices as covariates in Poisson regression distributions, the results show that clusters of heavy precipitation events in Canada are related to large-scale climate patterns.

(4) By modeling AMP time series with non-stationary GEV and heavy precipitation with non-stationary GP distributions, it is evident that AMP and heavy precipitation of Canada show strong non-stationarities which are likely related to the influence of large-scale climate patterns.

6. References

Tan, X., & Gan, T. Y. (2016). Non-stationary analysis of the frequency and intensity of heavy precipitation over Canada and their relations to large-scale climate patterns. Climate Dynamics, 1-19.

Shabbar, A., Bonsal, B., & Khandekar, M. (1997). Canadian precipitation patterns associated with the Southern Oscillation. Journal of Climate, 10(12), 3016-3027.