Characterization of Droughts in Canada Using the ERA5 Data

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Introduction

Droughts could adversely impact all life, the environment, water security, and the sustainability of water resources. Monitoring and characterization of droughts would provide insights on the factors that play a role in determining a drought's nature and improve our skill to assess and predict the drought-related risks (e.g. insufficient water supply and wildfires). Due to the effects of climate change on the water cycle behavior, droughts are expected to occur more frequently and severely in Canada, especially in western Canada [1]. A drought is typically characterized by a series of variations in meteorological conditions (e.g., precipitation, temperature, atmospheric circulations), surface features (e.g., vegetation cover and health, snow cover), and surface/sub-surface water resources (soil moisture, streamflow, lakes and rivers, groundwater level, etc.) [2]. The drought indices can be used to quantitatively characterize the drought events. The Climate Moisture Index (CMI), defined as the difference between annual precipitation (P) and annual potential evapotranspiration (PET), is one of the most widely used drought indices. In this project, the CMI values derived from a state-of-the-art atmospheric reanalysis product will be used to characterize droughts in Canada.

Methodology

The Climate Moisture Index (CMI) & Climate Data

- CMI (cm) = annual P (cm) – annual PET (cm)
- Positive CMI values denote wet or moist conditions, while negative CMI values indicate dry conditions.
- CMI is calculated using the precipitation and PET fields derived from ERA5, the fifth generation of ECMWF atmospheric reanalysis. The ERA5 data were downloaded from ECMWF's Copernicus Climate Data Store.
- ERA5 is used since the ERA5 precipitation data are generally more accurate than other precipitation products [3].
- PET is estimated using the fields of surface air temperature, dewpoint temperature, surface wind, surface pressure, surface net radiation from ERA5 based on the FAO-56 Penman-Monteith equation [4].
- The CMI values are calculated for the years of 1979 to 2019 and the geographical area covering the entirety of Canada.

Results: Long-term CMI changes over the Canadian Prairies

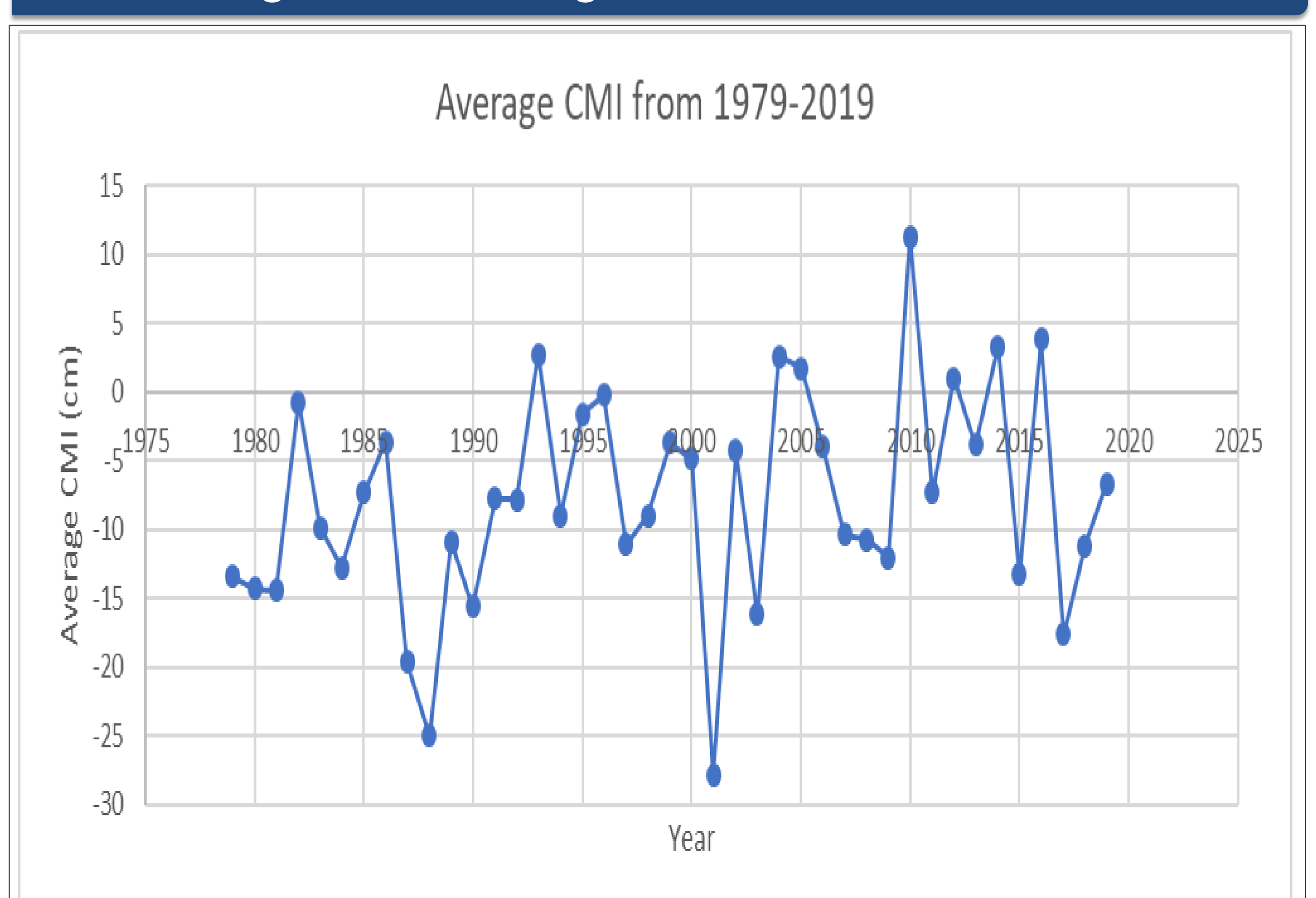

Figure 1. Changes in the average CMI over the Canadian Prairies for the years of 1979-2019.

Results: CMI values across Canada for the selected years

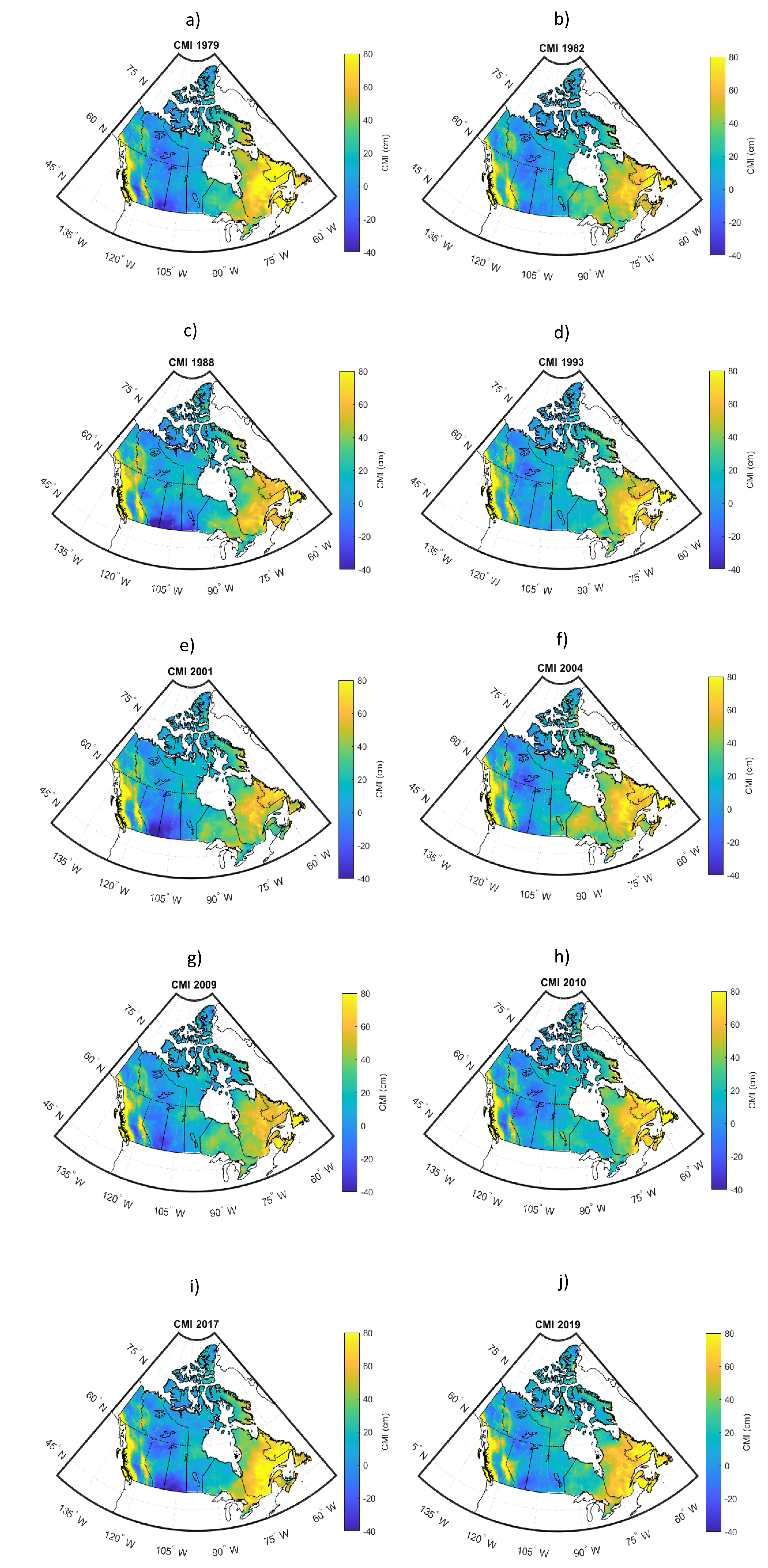

Figure 2. CMI values across Canada for (a) 1979, (b) 1982, (c) 1988, (d) 1993, (e) 2001, (f) 2004, (g) 2009, (h) 2010, (i) 2017, and (j) 2019, respectively.

Results & Discussion

Figure 1 shows the average CMI values in the Canadian Prairies for 1979 to 2019. The Canadian Prairies experienced dry conditions (negative CMI) for most of the 41 years. The substantial droughts (substantial negative CMI) occurred mainly in the years 1979-81, 1987-88, 2001, 2003, 2015 and 2017, with the lowest CMI value (close to -30 cm) for 2001. In contrast, over the past 41 years, the Canadian Prairies experienced the moistest conditions in 2010 with the CMI reaching as high as 11 cm (Fig. 1).

Table 1 Averaged precipitation, PET, and CMI values in the Canadian Prairies for the substantial drought years

Year	Precipitation (cm)	PET (cm)	CMI (cm)
1979	39.5198	52.8948	-13.3749
1980	43.5117	57.7678	-14.2561
1981	45.3779	59.7786	-14.4007
1987	39.8172	59.4422	-19.625
1988	39.2334	64.2408	-25.0074
2001	32.2897	60.1261	-27.8363
2003	42.1197	58.2319	-16.1123
2015	46.5997	59.8535	-13.2539
2017	41.5584	59.1391	-17.5806

In the substantial drought years, the annual precipitation was significantly lower than the 'normal' level (about 50-55 cm) in the Canadian Prairies region with the year 2001 receiving the lowest precipitation (only about 32 cm) (Table 1). Meanwhile, the PET values were relatively high in this region (generally > 50-55 cm, which is the 'normal' PET range for this region) with the year 1988 presenting the highest PET (close to 65 cm) (Table 1). This also reflects a realistic balance mechanism between precipitation and radiation. A decrease in clouds and precipitation could typically increase the surface net solar radiation, which would then lead to an increased PET.

Figure 2 presents the spatial pattern of CMI over Canada for the selected years. The results are similar to the analysis based upon the Canadian Forest Service climate data [2]. Unsurprisingly, in terms of the spatial pattern, the CMI values were typically very high in the Pacific coast and eastern Canada but were relatively low in west-central Canada. The droughts mainly occurred in the Canadian Prairies, but with a clear interannual variation. The significant Canadian Prairies droughts (as indicated by a piece of the extremely low CMI values) were typically located near the U.S. and west-central Canada border (e.g. Figures 2a, 2c, 2e, and 2i).

Conclusion & Future Plan

- The Canadian droughts mainly occurred in the Prairies, especially near the U.S. and west-central Canada border, but with an interannual variation.
- Using the ERA5-based CMI values over the past four decades, several substantial drought years or periods (e.g. 2001, 1987-1988, 2017) have been identified for the Canadian Prairies region. The droughts are typically characterized by low precipitation and relatively high PET.
- In this project, the CMI values were calculated for the time period 1979 to 2019, which is the current temporal coverage of ERA5. In the future, the ERA5 product will be available for a longer time period (from 1950 onwards), which would provide more opportunities for addressing the long-term CMI changes in the Canadian Prairies. In addition, the ERA5-based CMI values will be compared to those derived from other climate data sets (e.g. MERRA-2, JRA55) in the future.

Acknowledgements

ERA5 was downloaded from ECMWF's Climate Data Store; ROP at UTM.

References

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