An Assessment of Summer Hydro-Climatic Extremes on the Canadian Prairies

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Introduction

- Since human activities and ecosystem health are dependent on adequate, reliable water supplies, hydro-climatic variability and extremes pose serious threats to society and the environment.
- Prolonged, large-area droughts are among Canada's costliest natural disasters, affecting agriculture, forestry, industry, recreation, human health and society, and aquatic ecosystems.
- Impacts from excessive wet periods include threats to public safety, damage to infrastructure, over-topping of reservoirs, and agricultural crop losses.
- The Canadian Prairies are particularly susceptible due to their high natural hydro-climatic variability, including periodic droughts and excessive moisture conditions.

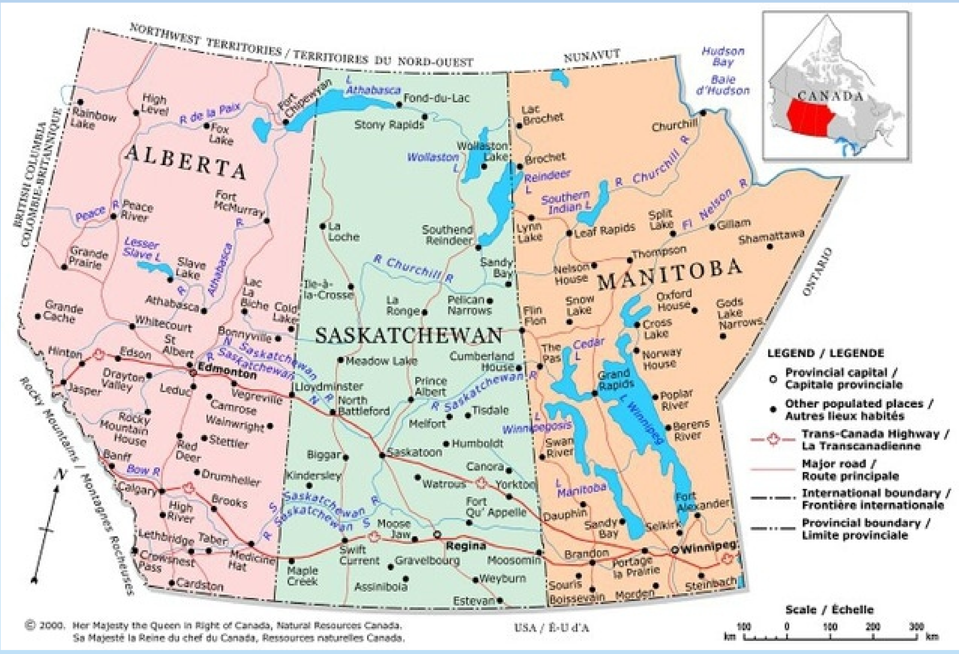


Fig. 1: The Canadian Prairie Provinces

- Extremes are caused by distinct mid-tropospheric circulations that disrupt expected precipitation & temperature patterns.

Objectives

- Although previous studies examined the occurrence and atmospheric causes of Canadian Prairie droughts, none have focused on the spatial characteristics of both extreme dry and wet periods.
- Using the SPI as a hydro-climatic extreme indicator and an atmospheric synoptic typing procedure, this investigation evaluates the dominant mid-tropospheric atmospheric circulation patterns associated with the spatial characteristics of extreme dry and excessive wet conditions over the southern Canadian Prairies from 1950 to 2011.

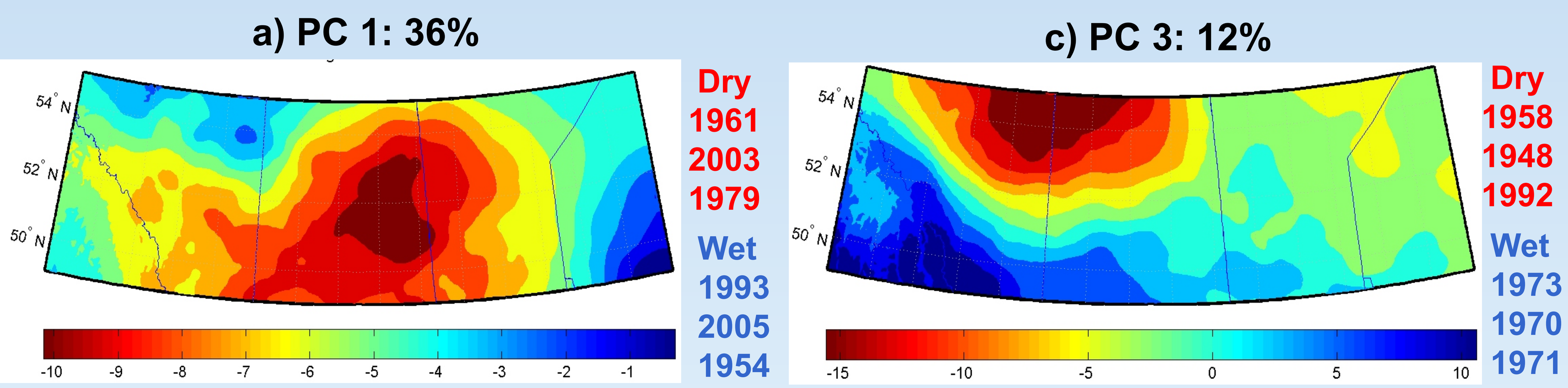
Data & Methodology

- The study area (Fig. 1) includes the southern half of the three Prairie Provinces of Alberta, Saskatchewan, & Manitoba.
- Three-month summer (Jun-Jul-Aug) SPI values are evaluated over the period 1950 to 2011. Monthly temperature and precipitation input are obtained from the Canadian CANGRD data set.
- Principal component (PC) analysis determines dominant spatial SPI patterns, which are assessed for trends and variability. Extremes are also identified and related to the dominant mid-tropospheric circulation patterns.
- An atmospheric synoptic typing procedure based on k-means clustering (Cuell and Bonsal, 2009) incorporates daily 500 hPa geopotential heights for the period 1950 to 2011 over the region 40°N to 60°N and 130°W to 100°W (see Fig. 3). The daily heights are classified into 12 dominant types.
- Dominant atmospheric circulation patterns associated with spatial characteristics in hydro-climatic extremes are evaluated by determining the relative frequency of each synoptic type during identified extreme summers. These dominant patterns are then assessed for trends and variability during the study period.

Results

Spatial Characteristics of Extreme Hydro-Climatic Events:

- Figs. 2a to c show the spatial distribution and variance explained by the first three SPI PCs. The three highest and lowest summers corresponding to each PC are also provided.
- PC1 (36%): Same-sign values over most of the southern Prairies; Represents positive or negative SPI over the entire study area. Extreme negative SPI: 1961, 1967, & 1979; Extreme positive SPI: 1993, 2005, & 1954.
- PC2 (14%): Distinct west-east pattern. Extremes include 1985, 1975, & 1977 (dry in west; wet in east); Extreme opposite patterns in 1954, 1961, & 1956.
- PC3 (12%): North-south pattern. Most extreme in 1958, 1948, & 1992 (dry north; wet south); Opposite extremes in 1973, 1970, & 1971.



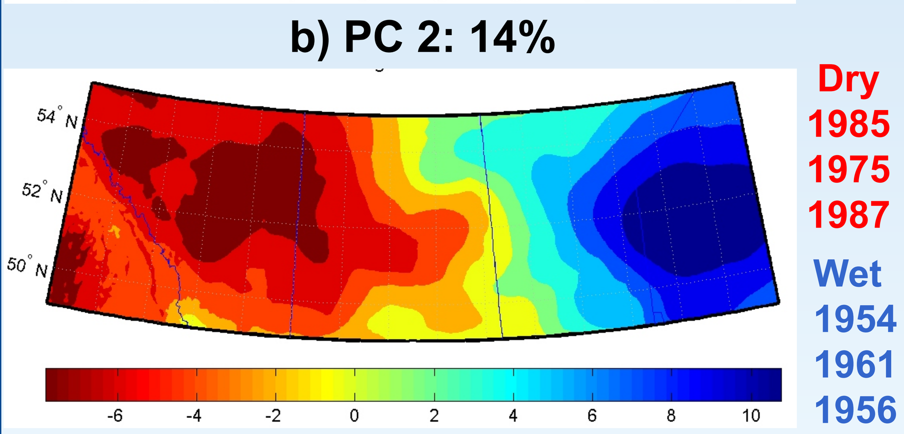
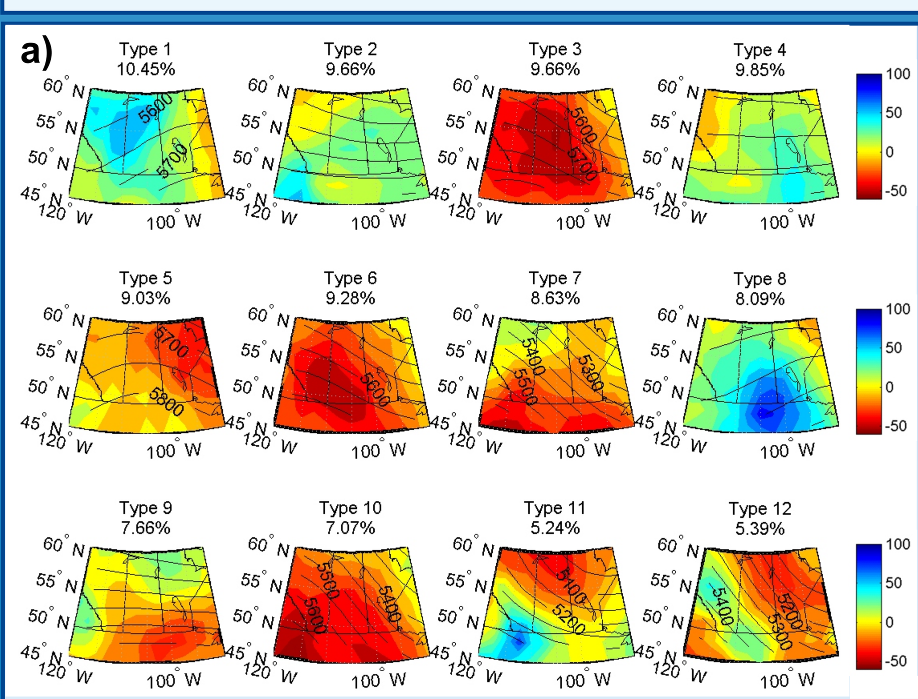


Fig. 2: First three principal components (PCs) of summer SPI over the southern Canadian Prairies for the period 1950 to 2011; a) PC1, b) PC2, and c) PC3. The three highest and lowest extreme summers are identified.



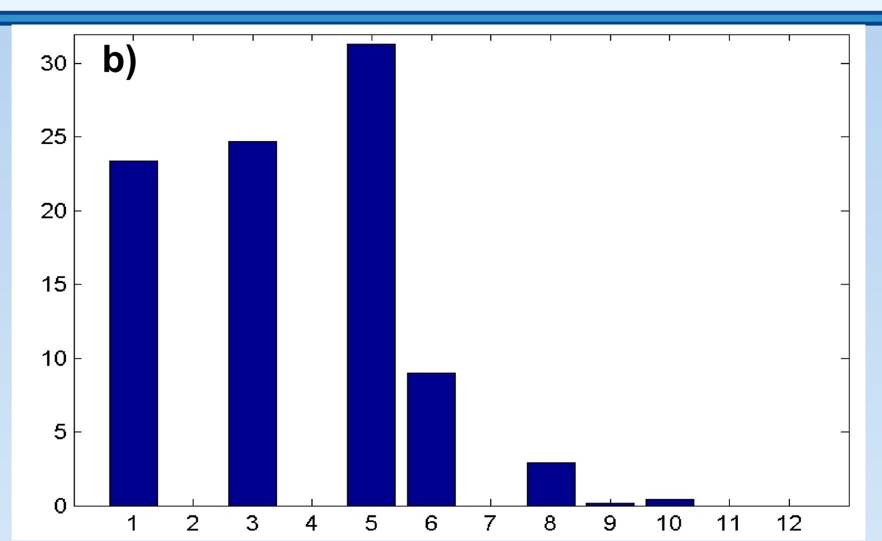


Fig. 3: a) The 12 atmospheric synoptic types over the southern Canadian Prairies from 1950-2011. Frequency of occurrence and precipitation departures from normal are provided; b) Average frequency of each synoptic type during the summer.

Mid-Tropospheric Circulation Patterns

- Fig. 3a displays the 12 synoptic types (ordered by frequency) along with corresponding precipitation departures
- Fig. 3b shows five dominant summer circulation types; Types 5, 3, & 8 associated with ridging or north-westerly flow and resultant drier than normal conditions; Types 1 & 6 have south-westerly flow and wetter than normal conditions.

Relationships between Mid-Tropospheric Circulation and Hydro-Climatic Extremes:

- Figs. 4a and b show relative frequencies of synoptic types during the two highest (negative SPI over the entire study region) and two lowest (positive SPI) summer PC1 values. The associated summer SPI pattern is provided.
- Dry PC1 (1961, 2003): Increase in Type 5 (large-scale ridging centred over the region; prohibits precipitation); Decrease in Type 1 (south-westerly flow; conducive to moisture advection from the Pacific).
- Wet PC1: Results not as consistent compared to dry extremes; however, increases in Type 1 and decrease in Type 5 are observed.

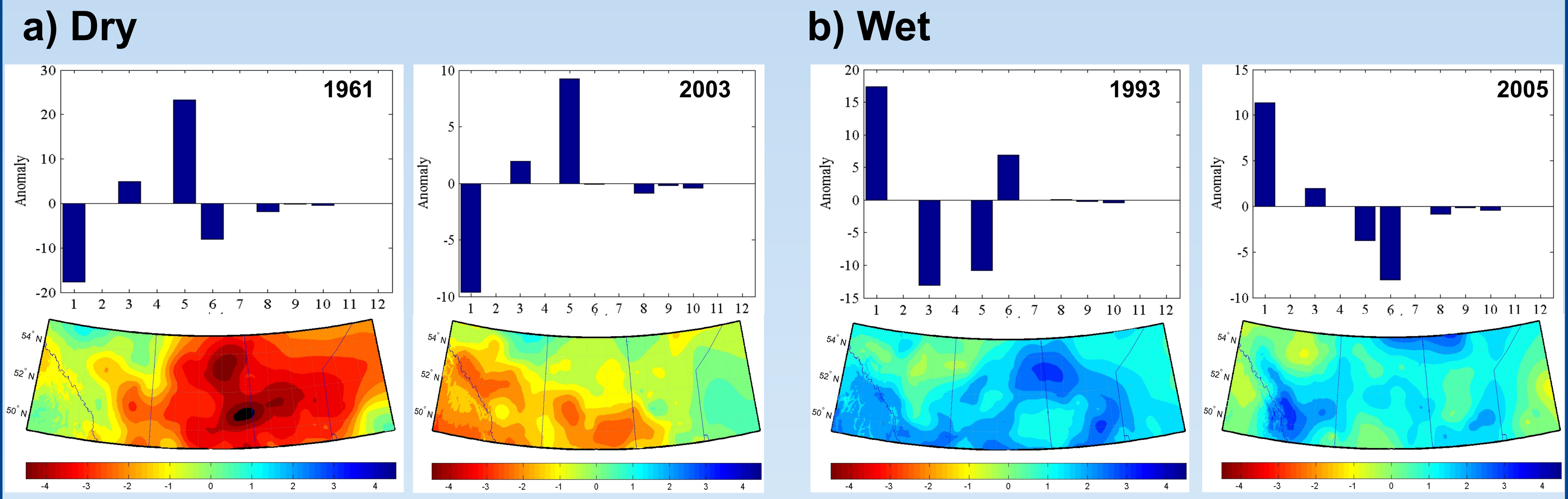


Fig. 4: Relative frequencies of the 12 synoptic types (expressed as the % of normal occurrence based on the 1950 to 2011 mean) during a) the two highest (corresponding to negative SPI (dry) over the study region) and b) the two lowest (corresponding to positive SPI (wet) summer PC1 values). The associated summer SPI pattern is also provided.

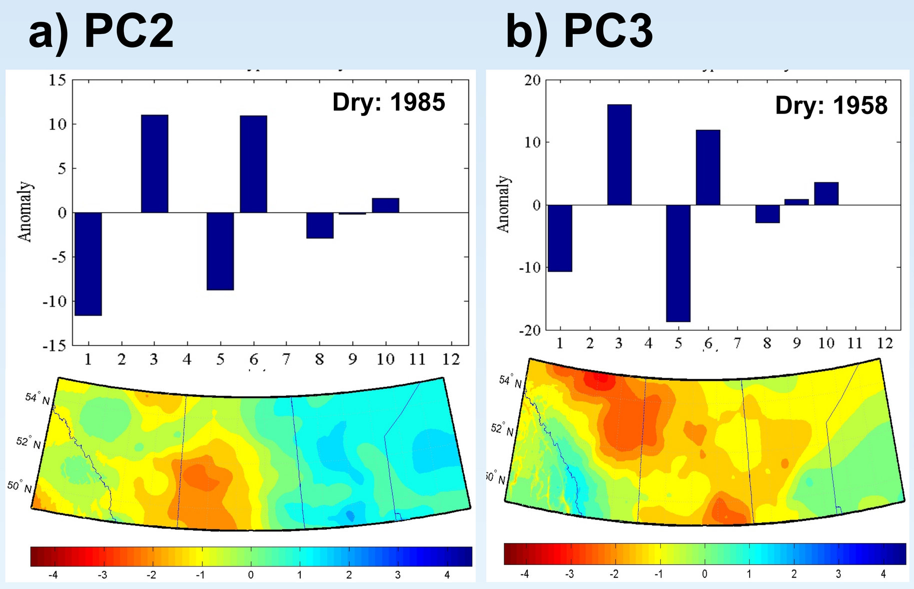


Fig. 5: Same as Fig. 4 except for highest summer PC2 & PC3 values. The highest PC2 (PC3) correspond to negative SPI in the west (north) and positive SPI in the east (south).

- Fig. 5a and b show extremes in PC2 and PC3 with opposing SPI patterns in an east-west (5a) and north-south (5b) direction.
- Both summers associated with a decrease in Type 1 (south-westerly flow; wet conditions) and a decrease in Type 5 (ridging over central Prairies).
- Increases in Types 3 and 6; Both indicative of ridging in the west and northwesterly-flow. Explains regional SPI differences.
- Opposite SPI patterns (not shown) reveal an increase in synoptic types with ridging in the eastern study area.

Trends in Relevant Types:

- Time series of relevant synoptic patterns (Type 5: major ridging; Type 1: southwesterly flow) are provided in Fig. 6.
- Type 5: Considerable inter-annual & inter-decadal variability; Significant increasing trend.
- Type 1: Considerable inter-annual & inter-decadal variability; Non-significant increasing trend.
- Suggests that atmospheric circulation patterns associated with hydro-climatic extremes have increased, especially those related to drought.

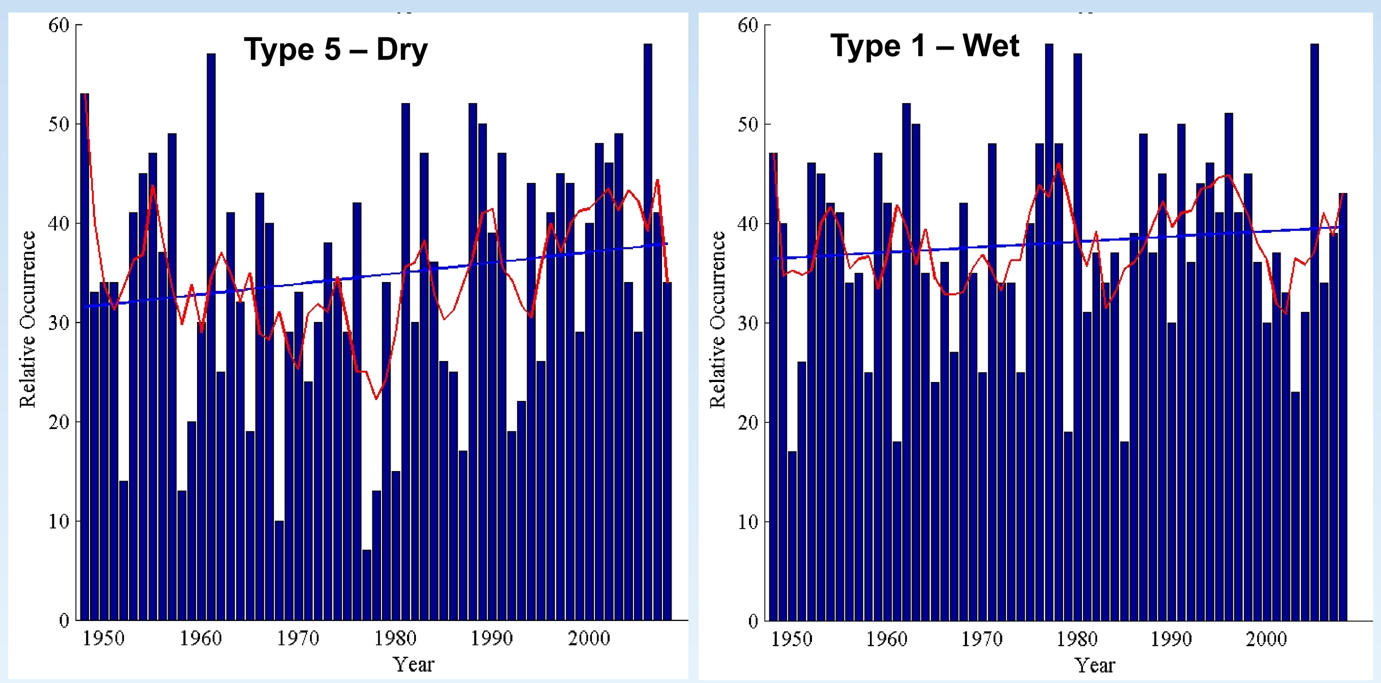


Fig. 6: Time series of the frequency occurrence for *the two key* synoptic types for the period 1950 to 2011. Linear trends and 11-year running mean values are also provided.

Summary

- Atmospheric synoptic typing procedure identifies characteristics circulation patterns (ridge, trough, zonal) over the Prairies.
- Good separation between summer and winter types.
- Prairie summer hydro-climate: Distinct spatial characteristics as identified by the first three PCs.
- Occurrence of key synoptic types associated with extreme low and to a lesser extent extreme high SPI summers associated with various PCs.
- Trends and variability in key synoptic types reveal some interesting trends and variations.

Future Directions

- Incorporation of other hydro-climatic indicators that include temperature (e.g., SPEI).
- Analysis of other seasons.
- Continued quantitative analyses and further assessment of key atmospheric circulation patterns associated with past dry and wet extremes (trends and variability).
- Relationships between synoptic types and large-scale teleconnections.
- Assessment of future changes to hydro-climate (RCM/GCM output).
- Assessment of changes to future "key" atmospheric circulation patterns and implications for the occurrence of future extremes.

References

- **Cuell, C. & Bonsal, B.R., 2009.** An assessment of climatological synoptic typing by principal component analysis and kmeans clustering. *Theoretical and Applied Climatology*, **98:** 361-373.