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Tree-ring chronologies are a rich source of information of past climate-driven non-stationarities in hydrologic variables. They are typically directly related to available water in respective years, thereby providing a basis for paleo-hydrology reconstruction. This study investigates the time series of tree-ring chronologies, with the objective of identifying the spatiotemporal patterns and extents of non-stationarities, which are essentially representations of past "climate changes". This study also generates ensembles of moving-average streamflow time series for the centuries prior to the period of observational record. The major headwater tributaries of the Saskatchewan River basin (SaskRB), the main source of surface water in the Canadian Prairie Provinces, are used as the case study. This extended abstract gives a brief summary of the methodology and some examples of the results. The analyses and results show how the reconstruction of paleo-hydrology broadens the understanding of hydrologic characteristics of a basin beyond the limited observational records, and therefore, provides a basis for more reliable assessment and management of available water resources.

INTRODUCTION

The design and management of water resources infrastructure have been generally based on the information available in the periods of observational record with the central, default assumption of stationarity [1]. In practice, observational records of hydrologic variables have been commonly assumed to be a realization of a stationary stochastic process whose statistical characteristics are contained in the records. This assumption is not true in general and diverges from reality with the length of the period considered [2]. Natural proxy records of hydroclimatic behaviour over the past several centuries or millennia have introduced opportunities to go beyond the limited periods of observational records. Among all, tree-ring data and their induced reconstructions of streamflows are very promising [3]. Tree-ring data, through the science of dendrohydrology, provide a platform for the reconstruction of paleo-hydrology as a vehicle for

better understanding and addressing the non-stationarities in climatic and hydrologic variables. This study follows two main objectives: (1) The identification of the timing and extent of non-stationarities in statistical properties of paleo-data time series, and (2) The reconstruction of streamflow time series for the pre-observational period.

METHOD AND CASE STUDY

Under the assumption that the growth rate of trees, represented by standard index chronologies, is a reliable proxy for hydrology, we directly investigate the stationarities/non-stationarities in the statistical properties of the time series of index chronologies. The "standard index chronology" refers to the average of the detrended growth rates (tree-ring widths) of several sampled trees located within a "chronology site". We attempt to evaluate how well the available data in the period of observational record is representative of the longer-term behaviour of the system. To this end, for each chronology site, the statistical properties of the segment of the time series that overlaps with the period of observational record are compared with the statistical properties of the full-length time series.

Unlike the conventional approach that reconstructs annual flows, in this work, we directly reconstruct the five-year moving average flows. Multiple linear regression models are used for mapping and reconstruction. Note that the timing and extent of dry and wet periods in the past can be effectively identified by the reconstructed moving average time series of paleo-streamflows. An emphasis is also put to quantify the uncertainty in reconstruction due to the choice of predictors. To this end, all possible combinations of chronology sites are tested as potential sets of predictors and the sets producing the minimum values for Akaike Information Criterion (AIC) are used for reconstruction.

The headwater tributaries of SaskRB originating from the Rocky Mountains in Alberta, Canada, are used as the case study. These tributaries are the main source of surface water in the Canadian Prairie Provinces [4]. The effective management of water resources is of high priority in the region to minimize vulnerability to climate change and drought. The analyses conducted in this study are aimed at providing a better understanding and evaluation of the available surface water resources across SaskRB, a prerequisite building block for effective management of water resources. The analysis of proxy records and the reconstruction of paleo-hydrology in the major tributaries of SaskRB, North Saskatchewan, Red Deer, Bow, and Oldman Rivers, are of interest in this study. There is a relatively rich source of tree-ring data available in the area, grouped in 33 tree-ring chronologies (http://www.parc.ca/urtreelab/).

RESULTS

Comparing the mean of the standard index chronologies (growth rates) in the historical period against the same property calculated over the full available records indicates that the mean growth in the North Saskatchewan River Basin over the historical period is an over-estimation of the long-term mean growth in this basin. In contrast, in the Oldman River Basin, the mean growth over the historical period is an under-estimation of the long-term mean growth in the basin.

Figure 1 shows the time series of reconstructed five-year moving average flows in Oldman River for the period of 1600 to 2001. The envelope created by the set of time series represents the uncertainty due to the choice of predictors. This uncertainty is variable with time, and for certain periods, it is larger than that of other periods. E.g., the reconstructions for the period of

1875-1910 demonstrate relatively large uncertainties, whereas, for the period of 1760-1785, the uncertainties seem to be minimal. The accuracy of the predicted flows in the observational period through cross-validation is an indication of the accuracy of the paleo-reconstructions.

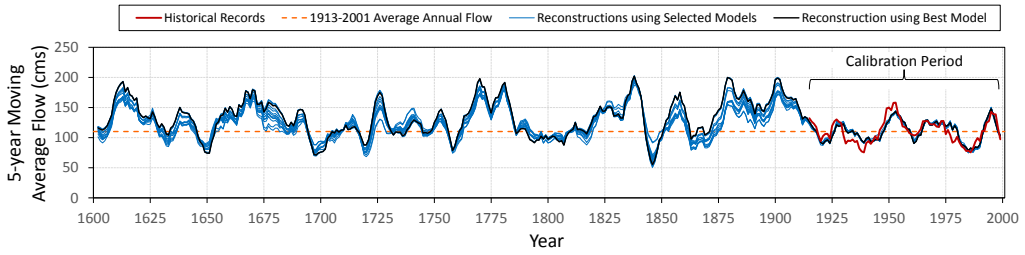

Figure 1. Time series of reconstructed five-year moving average flows in Oldman River. The best model is the model with minimum Akaike information criterion. The shown reconstructed flows for the calibration period are the results of leave-one-out cross validation.

CONCLUSION

The results of this study confirm that stationarity might have never existed in hydrology as exemplified in this study in the Saskatchewan River Basin. The statistical properties of annual paleo-hydrologic time series across the basin, i.e., the mean and autocorrelation structure (not reported in this extended abstract), have consistently undergone significant changes (non-stationarities) at different points in the history of the region. The resulting ensembles of moving-average paleo-streamflows pinpoint the timing and extent of past dry and wet periods in the SaskRB tributaries, and also, provide a range of uncertainty in reconstruction of streamflows. The improved understanding of statistical properties of streamflows is of significance in SaskRB for the evaluation of reliably available water resources and optimal planning and management of existing water resource systems.

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