P1.23 DOWNSCALING AND PROJECTION OF THE WINTERTIME EXTREME DAILY PRECIPITATION OVER NORTH AMERICA BY LARGE-SCALE ATMOSPHERIC CIRCULATION

Jiafeng Wang
Climate Research Branch, Meteorological Service of Canada, Downsview, Ontario, Canada, and
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
Xuebin Zhang[*]
Climate Research Branch, Meteorological Service of Canada, Downsview, Ontario, Canada
Elaine Barrow
Atmospheric and Hydrologic Science Division, Environment Canada, Regina, Saskatchewan, Canada

Abstract

The influence of large scale circulation, represented by the first three rotated EOFs and their associated PCs of wintertime mean sea level pressure, on winter maximum daily precipitation over the North America during 1948-1998 has been investigated. The observed relationship between the circulation and the extreme precipitation is then used to derive projected changes in extreme precipitation in the future due to circulation change caused by the increase of greenhouse gases as simulated by CGCM2 conducted at CCCma forced by IPCC “IS92a” forcing scenario. It appears that impact of human induced circulation change on winter maximum daily precipitation in 2050-2099 is comparable to the observed response of extremes precipitation to the occurrence of El Nino in the second half of the 20th century.

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[*] *Corresponding author address:* Dr. Xuebin Zhang, Climate Research Branch, Meteorological Service of Canada, 4905 Dufferin Street, Downsview, Ontario, Canada, M3H 5T4; E-mail: Xuebin.Zhang@ec.gc.ca

1. INTRODUCTION

Extreme weather and climate events can cause great damage to society. The occurrence of those events has increased in some areas of the world (Easterling et al. 2000). The spatial scale of those events is usually much smaller than the resolution of GCM, downscaling is typically considered to derive at information about possible future changes in these events usable by the impact research community. Downscaling falls into two categories: statistical or dynamical. Statistical downscaling is performed by first identifying the connection between the local or regional surface climate variables and the large-scale fields in observational data, and then applying such relationship to GCM simulated future large-scale fields to derive at the projections of the variables of interest for the future, assuming the relationship valid in the future. Dynamical downscaling involves the use of a regional dynamical model with finer spatial and temporal scales forced by boundary conditions simulated by a GCM. A hybrid method that makes use of both statistical and dynamical approaches has also been explored recently for downscaling the precipitation statistics (Gershunov et al. 2000).

The projected changes in the future extremes have been derived from GCM simulations (e.g., Zwiers and Kharin 1998, Kharin and Zwiers 2000). These studies provide an overall picture of what could happen in the future, but they do not offer information at sufficiently fine spatial scale for impact assessment. It is possible to derive those projections to regional/local scales by producing daily sequences of weather events (e.g. Cavazos 1999). But such approach is usually not tailed for the extremes and the information derived by such approach may be hard to use by impact community. Katz et al. (2002) and Wang et al. (2003) showed that the extreme value modeling approach provides a new way of assessing possible changes in the risk associated with extreme events. Zhang et al. (2003a) also indicate that the large scale climate variability such as El Nino-Southern Oscillation, the Pacific Decadal Oscillation, and the North Atlantic Oscillation have profound influence on winter precipitation over the North America, not only on the seasonal total precipitation, but also on extreme precipitation in the season. It therefore appears that extreme value modelling approach is a plausible way of producing scenarios of extreme precipitation for the future.

In this paper, we model winter time maximum daily precipitation conditional on the state of large scale circulation represented by sea level pressure field. We will show the potential of extreme value modelling approach for the estimation of changes in the probability distribution parameters of extreme precipitation and hence for the production of scenarios of changes in extremes in the future. We briefly discuss the method and data in section 2. Connections between winter mean SLP and maxima daily precipitation amounts are illustrated in section 3. The projected changes of wintertime extreme precipitation over North America during the latter half of 21th century are shown in section 4. Conclusions and discussion are offered in section 5.

2. DATA AND METHODS

2.1 Method

The winter season maximum daily precipitation over the North America may be modelled with a generalized extreme value distribution (GEV, Zhang et al. 2003a), with a cumulative distribution function given by

$$F(x,m,s,g)=\begin{cases}\exp\left\{-\left[1+g\left(x-m\right)/s\right]^{-1/g}\right\}, & 1+g(x-m)/s>0, g\neq 0\\ \exp\{-\exp[-(x-m)/s]\} & g=0\end{cases} \qquad (1)$$

F is the cumulative probability for maximum daily precipitation less than x; m, s and g are the location, scale and shape parameters, respectively.

Zhang et al. (2003b) showed that the use of more than one largest daily precipitation for a season makes more efficient use of available daily data and may significantly improve model fitting. This is termed as r largest method. Following Zhang et al (2003a), we also use the 3 largest values per season.

The connections between circulation and extreme precipitation can be identified by introducing co-variates (or predictors in regression analysis) into the parameters of the GEV distribution. We consider the location parameter being a linear function of the co-variates. In order to ensure scale parameter a positive value, we take the logged scale parameter as a linear function of the co-variates. To avoid complexity, the shape parameter is treated as a constant. We use the first three rotated principal components (as will be described below in the data subsection) as the covariates. To reveal the influence of a particular circulation pattern represented by a REOF on extreme precipitation, we use the associated PC as the co-variate in model fitting with the following equations:

$$\begin{cases}m=m_0+ay\\ \ln s=s_0+by,\\ g=g_0\end{cases} \qquad (2)$$

where y is an individual PC.

To identify the connections between large-scale circulation and for the estimate of projected changes in extreme precipitation, we bring all three RPCs as co-variates:

$$\begin{cases}m=m_0+\sum_{i=1}^{3}a_i y_i\\ \ln s=s_0+\sum_{i=1}^{3}b_i y_i,\\ g=g_0\end{cases} \qquad (3)$$

where y_i ($i=1,2,3$) are the three leading PCs. The model parameters in (2) or (3) can be estimated using the method of maximum likelihood (Zhang et al. 2003a). This involves the solving of a non-linear optimization problem. Coles (2001) provides easy to use S functions for the estimation. But this study uses our own implementation of the optimization.

The projected changes in extreme precipitation are assessed by estimating return period of the current 20-year return values of extreme precipitation in year 2050-2099. In doing so, we use the projected changes in the circulation (PCs) as detailed below to obtain the projected parameters of the GEV distribution using (3). The difference between 20 years and projected return period is considered as projected change in return period for the assessment of changes in the probability of extreme precipitation.

2.2 Data

Daily precipitation data for three North American countries, Canada, the United States, and Mexico, have been extracted from the enhanced version of the Global Daily Climatology Network (V1.0). Stations with at least 30-years observations are selected. The locations of stations used in this study are displayed in Figure 1b. We consider winter season (December-March) maximum daily precipitation. For a better model fitting, we use the r largest method with r=3. That is, the 3 largest daily precipitation amounts that do not cluster together are employed (the events have to be separated by at least 5 days).

Global warming will ultimately increase troposphere temperature and hence result in higher geopotential heights. As a result, geopotential heights may not be a good indicator for future changes in circulation (Zorita and von Stroch 1999). We therefore use the sea level pressure (SLP) to represent large-scale circulation. The SLP data from NCEP/NCAR reanalysis (Kalnay et al. 1996) have been used in this study. The original 2.5° x2.5° grids are first converted into 5° x5° grids. Owning to the strong influence of circulation over the North Pacific on North America climate, we use a domain covering 180?-50?W, 15?-70?N. The anomalies of seasonal mean SLP are computed and then subject to principal component analysis. We selected first three principal components that explain 74.5% variance of SLP field. We then apply varmatrix rotation (Barnston and Livezey 1987). The rotated PCs are used as co-variates in extreme value modeling.

The projected SLP changes were computed from the mean of CGCM2 three ensemble runs conducted at the Canadian Centre for Climate Modelling and Analysis (CCCma) forced by the IPCC "IS92a" forcing scenario (IPCC 1992). The data were obtained from CCCma web site (www.cccma.bc.ec.gc.ca). The difference in the two 50-year mean of model simulated SLP fields computed from 2050-2099 and 1950-1999 are taken as the projected changes in circulation. The projected changes in SLP are then projected onto the three rotated EOFs to obtain projected changes in PCs for the estimate of changes in extreme precipitation in the future

3. EXTREME PRECIPITATION AND CIRCULATION

To illustrate how the seasonal mean circulation may impact seasonal maximum daily precipitation, we display in Fig. 1 the first rotated EOF as well as the response in the 20-year return period of maximum precipitation when the value of first rotated PC is one-standard-deviation greater than the mean.

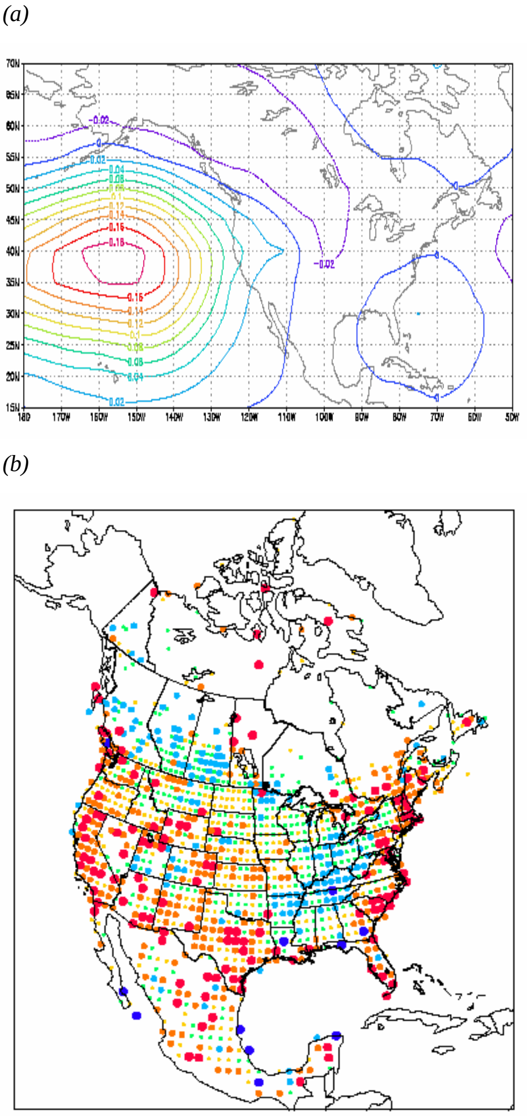

Fig. 1. a) REOF1 of SLP; b) The change of return period of the 20-year return value when the associated PC is one-standard-deviation greater than the mean (red: >12.5 years; orange: 5~12.5 years; light blue: -12.5~ -5 years; blue: <-12.5 years)

The circulation represented by the first REOF is characterized by a strong positive pressure anomalies centred in the east of North Pacific. Under the influence of such circulation, extreme precipitation is much reduced over the North America, except over the northwest, and the Mississippi-Ohio river valleys where extreme precipitation is enhanced. The responses of extreme precipitation to other two circulation patterns (REOF2 and REOF3) are also strong. They are not discussed in detail here.

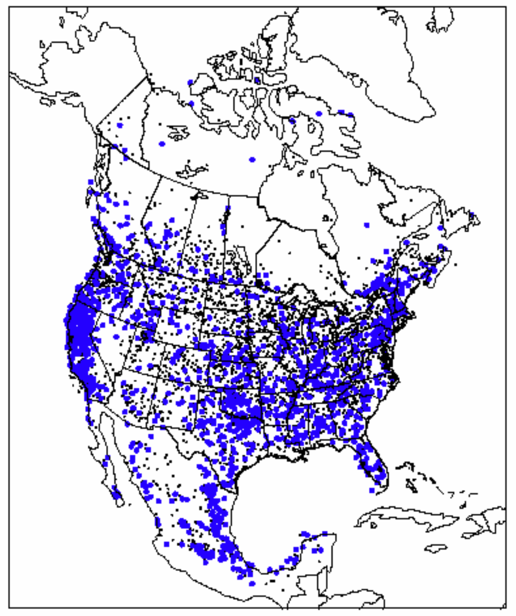

Fig. 2. Locations of stations whose winter extreme precipitation are significantly influenced by large scale circulation. Blue dots show stations with statistical significance at the 5% level..

Figure 2 shows the locations of stations whose winter extreme precipitation is significantly influence by the large-scale circulation represented by the first three rotated EOFs and their associated PCs over the eastern North Pacific and North America. The influence of large-scale circulation is statistically significant at the 5% level at more than 30% of all stations analysed. The circulation influence is particularly strong over the west cost, especially over the California, and eastern part of the continent. The connection is relatively weaker in the middle west of the United States.

4. PROJECTED CHANGES IN EXTREME PRECIPITATION

The projected changes in the return period of current 20-year return extreme precipitation are computed for every station. For an easy display, we average the projected return period changes for all stations within a 1°x1° grids. Those are plotted in Fig. 3.

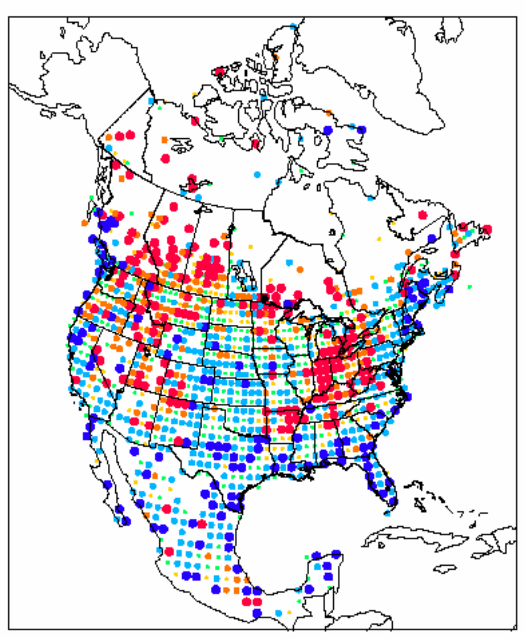

Fig. 3. Projected changes in the return period of current 20-year return extreme precipitation during 2050-2099 (the scale is the same as that in Fig. 1b) due to circulation change.

It appears that the circulation change alone could cause a substantial changes in the risks associated with extreme precipitation. Extreme daily precipitation will increase over much of the North America except the lee side of Rockies in US and Canadian Prairies, and Mississippi-Ohio river valleys where extreme precipitation would decrease. The spatial pattern of projected changes in the return period is very similar to that of extreme precipitation responses to El Nino (Zhang et a. 2003a). This is reasonable since the CGCM2 simulated SLP changes for the year 2050-2099 are also very similar to SLP anomalies during EL Nino years (Fig. 4).

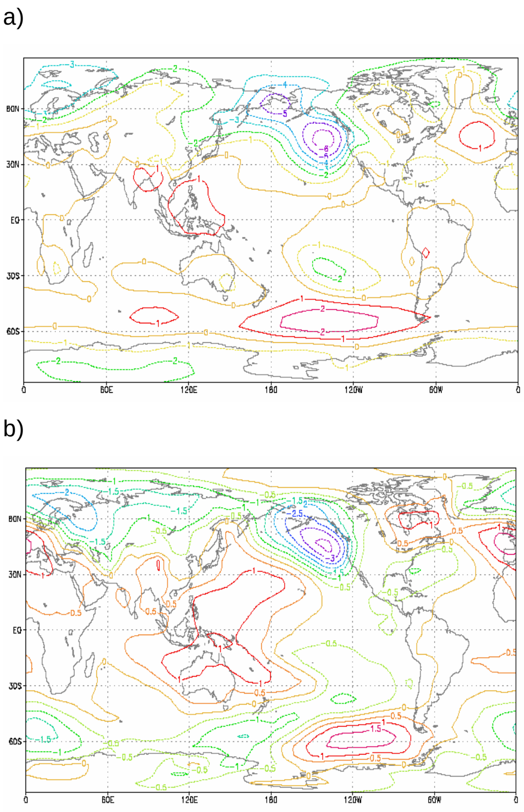

Fig. 4. a) The CGCM2 simulated SLP changes for the year 2050-2099 compared to 1950-1999; b) Composite of sea level pressure anomaly during El Nino winters during 1950-1999.

5. CONCLUSION AND DISCUSSIONS

We have investigated the influence of large-scale circulation on winter time maximum daily precipitation over North America, by modelling the extreme values with circulation indices being co-variates. We found that large-scale circulation anomalies exert strong influence not only to the seasonal total precipitation as reported before (any reference), but also to extreme precipitation. We provided a framework of statistical downscaling approach with which future changes in the probability of extreme precipitation at local and regional scales may be derived from GCM simulations. It was revealed that changes in circulation alone could cause substantial changes in extreme precipitation in the future. We note that the projected changes in extreme precipitation presented here are somewhat different from those in Meehl et al. (2000), in Zwiers and Kharin (1998) and Kharin and Zwiers (2000). This is not unexpected since our study dealt with extreme precipitation in winter, while the other studies were more interested in annual extremes. In addition, we only considered the changes caused by circulation change. Thus the projected changes in extreme precipitation we presented here should not be considered as a scenario of future extremes, since many other factors (some of them may be more important than SLP) have not been taken into account. For example, we did not consider the influence of atmospheric moisture. But the increase in the tropospheric temperature and hence the increase of moisture holding capacity of the atmosphere may likely result in an increase in extreme precipitation. Nevertheless, this study clearly demonstrates that it is possible to assess the changes in the risks of extremes in the future, with a proper use of statistical tools.

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