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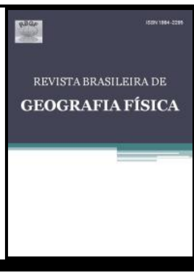

Trends in Indices for Extremes in Daily Precipitation over Idaho - USA

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A B S T R A C T

The objective of this study was to analyze the trends in seven annual extreme indices of precipitation for Idaho, USA. The analyses were conducted for 35 meteorological stations, during the period from 1970 to 2006, a high quality and a fairly long-term dataset. The analyses of precipitation indices presented large spatial variability and few statistically significant trends. Thus it is not possible to conclude that significant changes in precipitation have occurred in this region during the past few decades.

Keywords: Climate change, global warming, environmental impact

Tendências nos Índices Extremos de Precipitação Diária sobre Idaho - USA

R E S U M O

O objetivo deste estudo foi analisar as tendências em sete índices anuais extremos de precipitação para Idaho, EUA. As análises foram conduzidas para 35 estações meteorológicas, durante o período de 1970 a 2006, com dados de alta qualidade e longo prazo. As análises dos índices de precipitação apresentaram alta variabilidade espacial e poucas tendências estatisticamente significativas. Logo, não é possível concluir que ocorreram mudanças significativas na precipitação nesta região durante as últimas décadas.

Palavras - chave: Mudanças climáticas, aquecimento global, impacto ambiental

1. Introduction

The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) indicated with high confidence that there is growing indicate that the global changes in extremes of climatic variables observed in recent decades can only be accounted when anthropogenic and natural factors are considered, and that the industrialization have caused the planet to warm by about 1 □C (Subash et al. 2011). Future climate change is likely to affect agriculture, increasing the risk of misery and water scarcity around the world. Folland et al. (2001) showed that in some regions both temperature and precipitation extremes have already shown amplified responses to changes in mean values. Extreme climatic events, such

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as heat waves, floods and droughts, can have strong impact on society and ecosystems and are thus important to study (Toreti and Desiato, 2008; Choi et al., 2009; Santos et al., 2011). It is widely conceived that with the increase of air temperature, the water cycling process will be accelerated, resulting in an increase of precipitation amount and intensity.

Extreme events should be by definition rare, and depending on their severity, the recovery of the regional or local climate system could even take several years (Kioutsioukis et al., 2010), affecting the ecological system, as well as, the economic and social sectors. The assessment of extreme events and their predictability is one of the major challenges of the climate change community; because to understand a region's climate, it is necessary to observe how often extreme events occur (Llano and Penalba, 2011). In the recent decades, changes in climate variability, extreme events of weather and climatic extreme events are the subject of increasing attention.

The mountain ranges over the western United States have a marked influence on the climate of Idaho. Also, the climate features of Idaho are determined by its distance from the Equator, elevation above sea level, and distance from the Pacific Ocean. The economy of Idaho relies heavily on the water supply, of which the majority comes from winter precipitation (Harshburger et al., 2002). Most of Idaho's winter precipitation is stored as snow at high elevations and contributes to streamflow during the spring season. Harshburger et al. (2002) affirm that the winter precipitation and consequent spring streamflow have experienced large interannual and decadal variations.

The Expert Team on climate change detection, monitoring and indices, sponsored by WMO (World Meteorological Organization) Commission for Climatology (CCI) and the Climate Variability and Predictability project (CLIVAR) has developed a set of indices (Peterson et al., 2001) that represents a common guideline for regional analysis of climate. This study attempts to provide new information on trends, on a regional scale, using records of daily precipitation over Idaho, USA, through the analysis of different indices based on observational data from multiple stations in the region.

2. Material e Methods

2.1 Data and Quality Control

Daily precipitation data were taken from 35 meteorological weather stations across Idaho, USA, between 41 - 49º N latitude and 109 - 118º W longitude for the period between 1970 – 2006. This period has been chosen because it characterizes a fairly long-term dataset for each station. The map of station locations and elevation is shown in Figure 1; the numbers indicating the stations with their names and coordinates shown in Table 1. The dataset was provided by National Climatic Data Center.

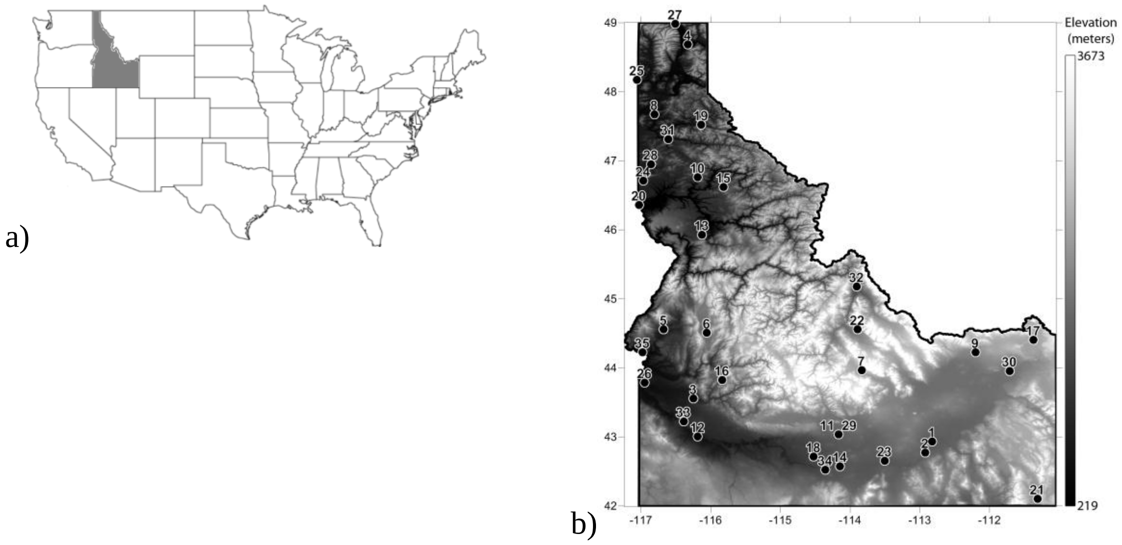

Figure 1. (a) Map of the USA with the state of Idaho highlighted; and (b) map of elevation of Idaho with the locations of the stations used in this study. The numbers relate to the name, latitude, longitude and elevation of the selected stations presented in Table 1. The time series used in this study is from 1970 to 2006.

Table 1. Meteorological stations used for the analysis of daily precipitation in Idaho, USA for the period from 1970 to 2006

ID	STATION	LAT	LON	ELEVATION (m)
1	Aberdeem	42.95	-112.82	1342
2	American Falls	42.79	-112.92	1318
3	Boise	43.57	-116.24	871.1
4	Bonners Ferry	48.69	-116.32	563
5	Cambridge	44.57	-116.67	808
6	Cascade	44.52	-116.05	1485
7	Chilly Barton Flat	43.98	-113.83	1908
8	Couer Dalene	47.68	-116.80	658
9	Dubois	44.24	-112.20	1665
10	Elk River	46.77	-116.18	887
11	Grace	43.05	-114.16	1315
12	Grand View	43.02	-116.18	720
13	Grangeville	45.94	-116.12	1021
14	Hazelton	42.59	-114.14	1238
15	Headquarters	46.63	-115.81	958
16	Idaho City	43.84	-115.83	1202
17	Island Park	44.42	-111.37	1922
18	Jerome	42.73	-114.52	1140
19	Kellogg	47.53	-116.13	703
20	Lewiston	46.37	-117.02	433
21	Lifton Pumping	42.12	-111.31	1809
22	May	44.57	-113.89	1546
23	Minidoka Dam	42.67	-113.50	1269
24	Moscow	46.72	-116.96	802
25	Newport	48.18	-117.05	653
26	Parma	43.80	-116.94	698

continuation

27	Porthill	48.99	-116.50	541
28	Potlatch	46.96	-116.85	778
29	Richfield	43.05	-114.16	1305
30	Saint Anthony	43.97	-111.71	1516
31	Saint Maries	47.32	-116.60	653
32	Salmon - KSRA	45.19	-113.90	1211
33	Swan Falls	43.24	-116.38	708
34	Twin Falls	42.54	-114.35	1207
35	Weiser	44.24	-116.97	644

An exhaustive data quality control was conducted because indices of extremes are sensitive to changes in station location, exposure, equipment, and observer practice (Haylock et al., 2006). Data Quality Control (QC) is a prerequisite for determining climatic indices. The quality control module of the RClimdex software performs the following procedures: 1) Replaces all missing values (currently coded as -99.9) into an internal format that the software recognizes, and 2) Replaces all unreasonable values. Those values include daily maximum temperature less than daily minimum temperature. In addition, the QC also identifies outliers in daily maximum and minimum temperature. The outliers are daily values outside a range defined by the user. Currently, this range is defined as *4* times standard deviation (*sdt*) of the value for the day, that is, (mean – *4* x *std*, mean + *4* x *std*), where *std* for the day and *4* is the input from the user (Zhang and Yang, 2004; Vincent et al. 2005). Initially, data from 60 meteorological stations were available, and after the QC, only stations with less than 10% of missing data for a period of at least 30 years were considered, resulting in the 35 weather stations used in the analyses (Table 1).

2.2 Methodology

The RClimdex software developed by Xuebin Zhang and Feng Yang from Canadian Meteorological Service (Zhang and Yang, 2004) was used in this study to obtain the climatic extremes indices, following methodologies of Zhang et al. (2005) and Haylock et al. (2006). In order to run the RClimdex software, the format of the input data file has several requirements: 1) ASCII text file; 2) Column sequence: Year, Month, Day, TMAX, and TMIN. (NOTE: Temperature units = degrees Celsius); 3) the format as described above was space delimited (e.g. each element was separated by one or more spaces); 4) for data records, missing data were coded as -99.9 and data records were in calendar date order (Zhang and Yang, 2004). RClimdex provided 7 extreme precipitation indices, which were chosen for discussion here (Table 2), because they better explain the precipitation behavior of Idaho. The resulting series were analyzed through trends. The slopes of the annual trends of the climate indices were calculated based on a least square linear fitting. Trends were obtained for each index at the 35 locations and the statistical significance of the trends were assessed through the Student's t-test and the number of degrees of freedom was obtained based on the length of the data set, i.e., 37 for the 1970-2006 (Haylock et al., 2006; Dufek and Ambrizzi, 2008).

Table 2. Definition of extreme precipitation indices used in this study

Indices	Name	Definition	Units
Rx1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5days	Max 5-days precipitation amount	Monthly maximum consecutive 5-days precipitation	mm
SDII	Simple daily intensity index	Annual mean precipitation when PRCP>=1.0mm	mm
R20mm	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	mm

Linear trend analyses were performed for all precipitation indices used in the study. The slopes of the linear trends are calculated by least squares fitting. Since a normal frequency distribution may not necessarily fit very well to indices data, a non-parametric Mann-Kendall test is used to identify whether or not trends are significant. The method is simple and robust, and it also has the advantage of being able to deal with missing values.

The null hypothesis (H_0) states that the deseasonalized data (x_1, x_2,…, x_n) is a sample of n independent and identically distributed random variables. The null hypothesis that standard normal variable (Z_c) is not statistically significant or has no significant trend is accepted if $-Z_{1-p/2} \leq Z_c \leq Z_{1-p/2}$, where $Z_{1-p/2}$ is the standard normal deviate and p is the significance level for the test. Or, Z_c is statistically significant if $Z_c < -Z_{1-p/2}$ or if $Z_c > Z_{1-p/2}$ (Partal and Kahya, 2006). Kendall's statistic (S) is computed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k)$$

The variance of S is given by

$$\operatorname{var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} e_i(e_i-1)(2e_i+5)}{18}$$

where, x_j , x_k are sequential data values; n is the length of the dataset; m is the number of tied groups; and e_i is the size of the ith tied group. Z_c is obtained as follows:

$$Z_c = \frac{S-1}{\sqrt{\operatorname{var}(S)}} \quad (S > 0)$$

$$Z_c = 0 \quad (S = 0)$$

$$Z_c = \frac{S+1}{\sqrt{\operatorname{var}(S)}} \quad (S < 0)$$

Positive values of Z_c indicate increasing trends while negative Z_c shows decreasing trends. When testing either increasing or decreasing monotonic trends at a significance level *p*, the null hypothesis was rejected for absolute value of Z_c greater than $Z_{1-p/2}$ (Partal and Kahya, 2006). In this study, significance level *p* of 0.05 is applied.

3. Results and Discussion

Table 3 presents the annual trends of the extreme indices of precipitation obtained for 35 locations in Idaho. The bold and highlighted values represent significant level of 5% ($p<0.05$). Only the trends of precipitation indices that are significant at 5% level are discussed. As the precipitation indices have a large variation, the number of trends with statistical significance is few. The Rx1day index, which means the maximum one day precipitation amount, showed two stations with positive trends and one station with negative trend presenting statistical significance. The spatial distribution of this index is displayed in Figure 2a. The index Rx5day, i.e. the maximum five days precipitation amount, showed only two stations with positive trends statistically significant, but these stations are different of those shown in the Rx1day index (Figure 2b). Alexander et al. (2006) also found increases in the precipitation over this area of the United States.

The ratio between the daily precipitation amount on wet days and the number of wet days, called Simple Daily Intensity Index (SDII) shows four stations with positive trends and its spatial distribution is shown in Figure 2c. The number of very heavy precipitation days (R20mm) index presented only one station with negative trend and three stations with positive trends, as shown in Figure 2d. The maximum number of consecutive days with daily precipitation less than 1 mm, called CDD index, presented one station with negative trend and two stations with positive trends (Figure 2e). Consecutive wet days (CWD) index have shown only negative trends (10 stations) (Figure 2f), showing a predominant decrease of the maximum number of consecutive days with daily precipitation equal or higher than 1 mm. The last analyzed index is the annual total wet-day precipitation (PRCPTOT) that presented only negative (4 stations), which suggests a decreasing tendency in total annual precipitation in the studied area, as presented in Figure 2g. Thus, how the trends of the ratio between the daily precipitation amount on wet days and the number of wet days (SDII) is increasing, and the total annual precipitation is decreasing as well, is possible to conjecture that the annual number of wet days (days with precipitation equal or higher than 1mm) is decreasing faster in the last decades over the studied area. Therefore, the agreement between these indices shows that the wet conditions in this region are decreasing as shown by the CWD index.

Table 3. Annual trends of the extreme indices of precipitation for Idaho, USA. The bold and highlighted values represent significance at 5% level (p<0.05)

STATION	Rx1day (mm)	Rx5day (mm)	SDII (mm)	R20mm (days)	CDD (days)	CWD (days)	PRCPTOT (mm)
Aberdeem	-0.112	-0.201	0.006	-0.005	0.061	-0.018	-0.605
American Falls	**-0.302**	-0.271	-0.017	**-0.032**	0.227	-0.051	-2.276
Boise	-0.145	-0.101	-0.010	0.002	0.458	-0.032	-1.342
Bonners Ferry	0.160	-0.350	-0.009	-0.057	-0.110	**-0.082**	**-5.178**
Cambridge	0.113	**0.508**	**0.028**	0.015	**-0.663**	-0.049	1.458
Cascade	0.022	0.117	0.014	0.038	-0.122	**-0.107**	0.423
Chilly Barton Flat	-0.115	-0.135	0.003	0.000	0.694	**-0.089**	-2.336
Couer Dalene	0.166	-0.123	-0.003	-0.037	-0.078	-0.086	-1.529
Dubois	-0.160	-0.013	-0.016	-0.019	-0.109	0.026	-0.004
Elk River	0.199	-0.196	0.043	-0.035	-0.118	**-0.200**	-2.078
Grace	0.095	0.117	-0.011	0.002	-0.157	-0.030	-1.654
Grand View	-0.149	-0.245	-0.017	-0.014	0.571	-0.023	**-1.528**
Grangeville	0.063	0.115	0.016	0.045	0.077	-0.003	-0.257
Hazelton	0.158	0.122	0.014	0.008	0.331	-0.017	0.257
Headquarters	0.195	0.334	-0.009	-0.014	-0.027	-0.005	-0.892
Idaho City	-0.220	-0.302	-0.017	-0.066	0.184	**-0.205**	**-5.320**
Island Park	0.028	-0.398	0.012	-0.028	0.014	**-0.216**	-5.641
Jerome	0.115	0.193	0.005	0.026	0.445	-0.032	-0.272
Kellogg	-0.044	**1.046**	**0.041**	0.044	-0.098	0.016	5.095
Lewiston	0.106	0.107	-0.011	0.003	-0.102	0.006	-0.041
Lifton Pumping	-0.188	-0.036	0.001	0.007	-0.321	-0.023	-1.024
May	**0.340**	0.260	0.020	**0.055**	-0.210	-0.007	0.938
Minidoka Dam	0.096	0.069	0.006	0.006	0.553	-0.023	-0.714
Moscow	0.109	-0.044	0.006	-0.003	0.056	-0.049	-0.124
Newport	0.281	-0.258	**0.048**	0.040	0.013	**-0.128**	-2.153
Parma	-0.077	-0.268	-0.008	-0.021	-0.144	**-0.114**	**-2.795**
Porthill	0.125	0.251	0.016	0.022	0.041	-0.002	0.522
Potlatch	0.362	0.066	**0.095**	**0.154**	-0.048	**-0.102**	1.405
Richfield	**0.181**	0.402	0.007	**0.035**	**0.940**	-0.037	-2.089
Saint Anthony	0.060	0.248	0.018	0.040	-0.120	0.007	1.137
Saint Maries	0.128	0.062	-0.004	0.026	-0.250	-0.040	0.318
Salmon - KSRA	-0.083	-0.028	0.015	-0.004	-0.006	-0.006	-1.053
Swan Falls	-0.182	-0.333	-0.016	-0.020	**0.850**	-0.023	-1.256
Twin Falls	-0.020	0.029	0.002	-0.005	0.480	**-0.043**	-0.020
Weiser	-0.196	0.137	-0.016	-0.015	-0.135	0.026	0.933

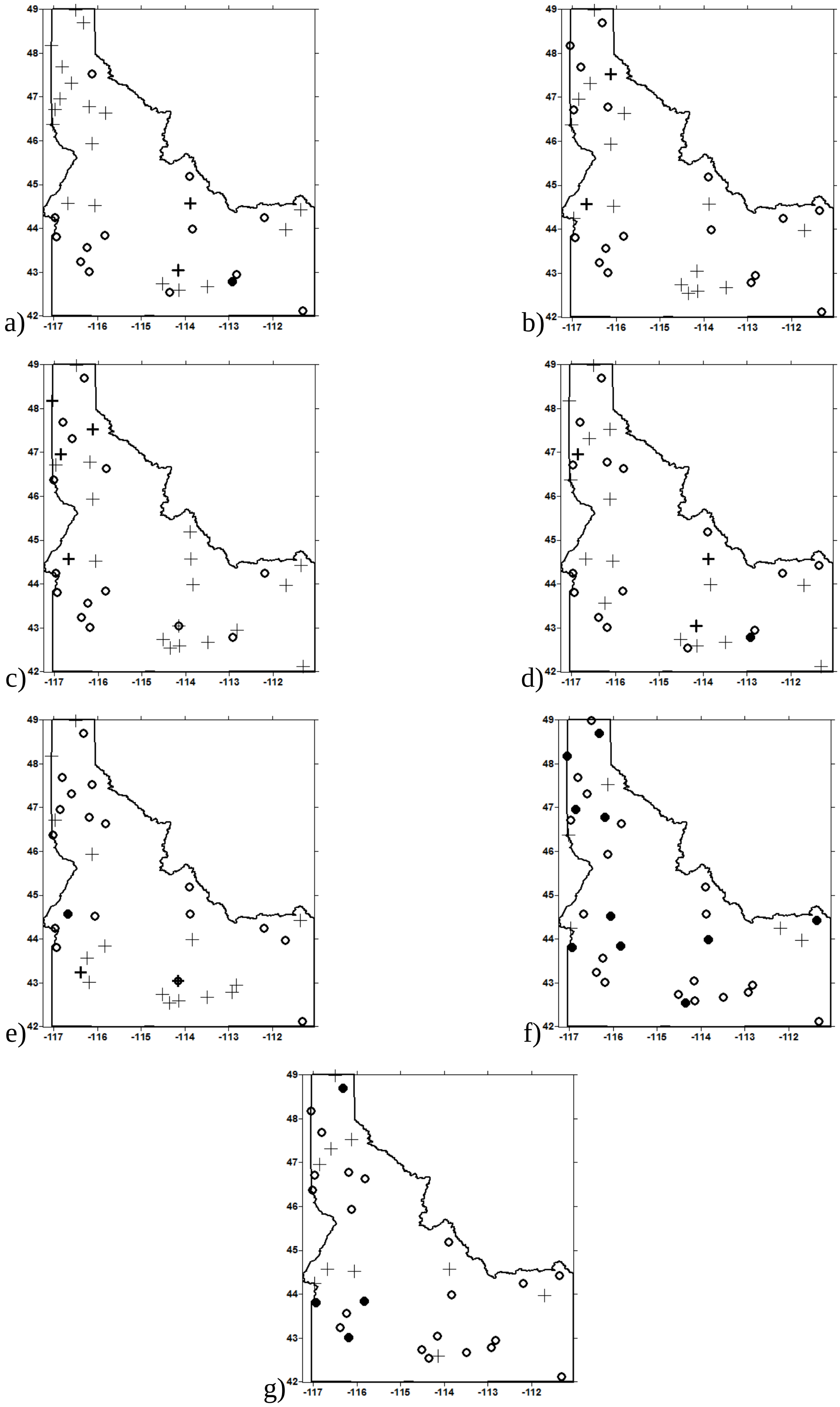

Figure 2. Spatial distribution of precipitation extreme trends for Idaho, USA. The symbol (✚) means positive trends, and (●) means negative trends, statistically significant at 5% level ($p<0.05$), while the symbols (+) means positive trends, and (O) means negative trends statistically non-significant. (a) Rx1day index, (b) Rx5days index, (c) SDII index, (d) R20mm index, (e) CDD index, (f) CWD index and (g) PRCPTOT index.

Table 4 helps the interpretation of the figures that show the analyses of extreme precipitation indices. The percentages of locations with statistically significant and insignificant trends at the 5% level are shown. It can be seen that 5.7% of the stations show an increase in RX1day and RX5day, 11.4% in SDII, 8.6% and 5.7% to R20mm and CDD, respectively. These results an increase in the maximum 1 and 5 days precipitation amount, and in the number of very heavy precipitation days, as well as, a little increase in the maximum number of consecutive days with daily precipitation less than 1 mm. There is a decrease of 28.6% in CWD, and 11.4% in PRCPTOT. These results indicate the agreement in behavior between different precipitation indices, and that the precipitation events have become more intense and isolated in Idaho.

Table 4. The percentage of stations showing significant and not significant trends at the 5% level for the temperature and precipitation indices for Idaho, USA

INDICE	Positive significant trend (%)	Positive not significant trend (%)	Negative significant trend (%)	Negative not significant trend (%)
RX1day	5.7	54.4	2.8	37.1
RX5day	5.7	45.7	0.0	48.6
SDII	11.4	48.6	0.0	40.0
R20mm	8.6	45.7	2.8	42.9
CDD	5.7	42.8	2.8	48.7
CWD	0.0	14.3	28.6	57.1
PRCPTOT	0.0	28.6	11.4	60.0

4. Discussion and Conclusions

Studies have shown that one of the most important questions regarding extreme events is if their occurrence is increasing or decreasing over time, characterized by the frequency of these events and if they are changing significantly. This study presents analyses of the trends in seven annual extreme precipitation indices of precipitation for Idaho, USA. The analyses were conducted using long-term and high quality data sets for 35 meteorological stations for a period between 1970 and 2006.

Extreme events of precipitation are a random signal in the climate record and a time series of 35 years is important for a recent trend analysis. Some of the indices in this study can be good indicators for climate extremes in Idaho. The precipitation indices showed a large variation for the studied time series and, in general, with few statistically significant trends. The most important findings related to the precipitation indices are that the consecutive wet days and total annual precipitation have decreased, and that the precipitation events have become more intense and isolated in Idaho. Due to the large number of stations without statistical significance it is difficult to conclude definitely about the precipitation behavior over Idaho.

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