

TRENDS OF TEMPERATURE EXTREMES IN IDAHO - USA

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ABSTRACT

The main objective of this study was to analyze the trends in nine annual extreme indices of temperature for Idaho, USA. The analyses were conducted for 35 meteorological stations, during the period from 1970 to 2006, characterized by a long-term and high quality data set. The software used to process the data was the Rclimindex 1.0. The analyses of extreme temperature indices have identified an increase in the maximum and minimum air temperature in Idaho. Predominantly, the minimum air temperature is increasing in the studied region. Most of part of Idaho has shown a decrease in the diurnal temperature range, which indicates that the minimum temperature is increasing faster than the maximum temperature.

Keywords: climate change, Rclimindex, climatology, global warming, quality control, environmental impact, agriculture.

TENDÊNCIAS DE TEMPERATURAS EXTREMAS EM IDAHO - USA

RESUMO

O principal objetivo desse estudo foi analisar as tendências anuais em nove índices extremos de temperatura para Idaho, EUA. As análises foram feitas para 35 estações meteorológicas para o período de 1970 a 2006, caracterizado por uma série longa e confiável. O software utilizado no processamento dos dados foi o Rclimindex 1.0. As análises dos índices extremos de temperatura identificaram aumento nas temperaturas do ar máximas e mínimas em Idaho. A temperatura mínima teve um aumento predominante sobre a região estudada. A maior parte de Idaho apresentou diminuição na amplitude térmica diária, o que indica que a temperatura mínima está aumentando mais rápido que a máxima.

Palavras-Chaves: mudanças climáticas, Rclimindex, climatologia, aquecimento global, controle de qualidade, impacto ambiental, agricultura.

INTRODUÇÃO

The fourth assessment report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) indicated with high confidence that there is growing evidence 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 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), as well as, can affects the ecological system, economic and social sector. 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 last decades, changes in climate variability, extreme events of weather and climatic extreme events are the subject of increasing attention.

For a variety of reasons, many of the empirical studies on observed climate change have focused on mid to high-latitude locations where some of the most comprehensive datasets are available and where numerical models of climate predict the largest changes to occur given the buildup of greenhouse gases. Literally hundreds of studies from these locations revealed that over the past century, the average temperature has increased, the rate of increase accelerated in the most recent decades, the minimum daily temperature increased more quickly than the maximum temperatures, and therefore, the diurnal temperature range generally decreased (Peralta-Hernandez et al., 2009).

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) affirms that the winter precipitation and consequent spring streamflow have experienced large interannual and decadal variations. Abatzoglou (2011) shows that the climate variability across the Western US is dominated by a set of spatially fixed, recurrent perturbations to the large-scale flow field spanning decadal (Pacific Decadal Oscillation, PDO), interannual (El Niño-Southern Oscillation, ENSO) and intramonthly (Pacific-North American pattern, PNA) timescales. In order to gain an understanding of Idaho climate, a study using weather station data to analyze the local climate variability of air temperature is warranted, in order to establish which areas of this region are being more affected by the possible global warming.

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, in regional scale, using records of daily air temperature over Idaho, USA, through the analysis of different indices based on observational data from multiple stations in the region. This analysis is important for Idaho since any change in climate can have large impacts on the daily life of the population and environment dependent on scarce water resources for agricultural and municipal use.

MATERIAL AND METHODS

Data and Quality Control

Daily maximum and minimum surface air temperatures data were taken from 35 meteorological weather stations across Idaho, USA, between 41 - 49° N latitude and 109 - 118° W longitude for the period between 1970 – 2006. This period has been chosen because it characterizes a 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 for these stations was from 1970 to 2006.

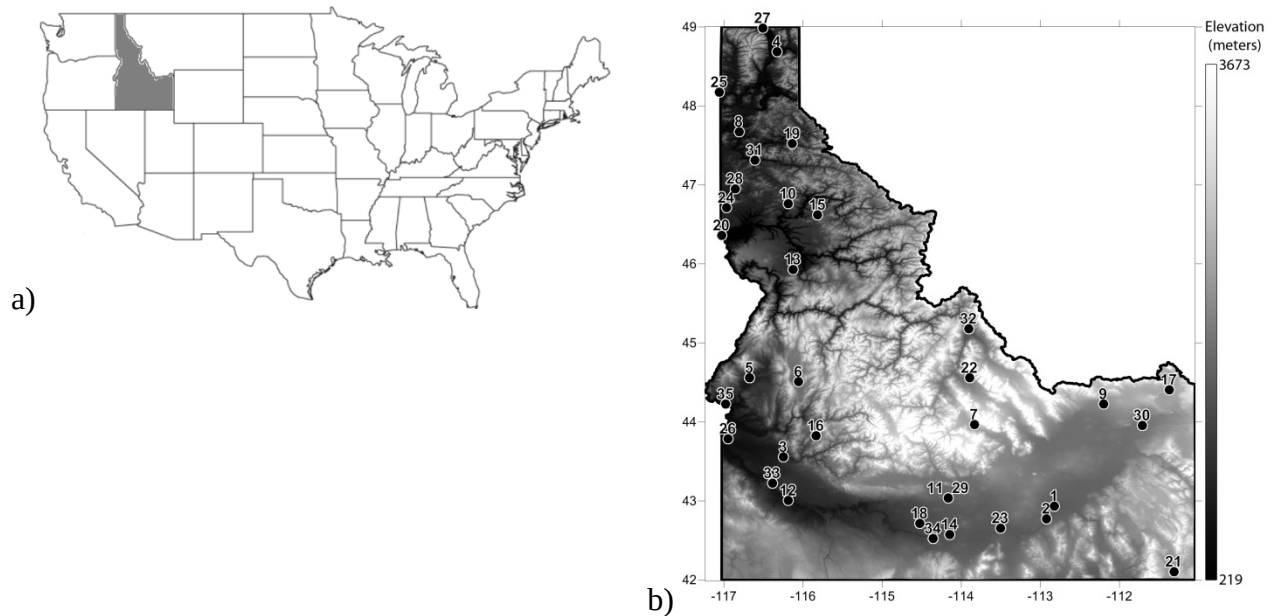


Table 1 - Meteorological stations used for the analysis of maximum and minimum daily air temperature, and daily precipitation in Idaho, USA

ID	STATION	LAT	LON	ELEVATION (m)	START	END
1	Aberdeen	42.95	-112.82	1342	1970	2006
2	American Falls	42.79	-112.92	1318	1970	2006
3	Boise	43.57	-116.24	871.1	1970	2006
4	Bonniers Ferry	48.69	-116.32	563	1970	2006
5	Cambridge	44.57	-116.67	808	1970	2006
6	Cascade	44.52	-116.05	1485	1970	2006
7	Chilly Barton Flat	43.98	-113.83	1908	1970	2006
8	Couer Dalene	47.68	-116.80	658.4	1970	2006
9	Dubois	44.24	-112.20	1665.1	1970	2006
10	Elk River	46.77	-116.18	887.9	1970	2006
11	Grace	43.05	-114.16	1315	1970	2006
12	Grand View	43.02	-116.18	720	1970	2006
13	Grangeville	45.94	-116.12	1021	1970	2006
14	Hazelton	42.59	-114.14	1238	1970	2006
15	Headquarters	46.63	-115.81	958	1970	2006
16	Idaho City	43.84	-115.83	1202	1970	2006
17	Island Park	44.42	-111.37	1922.1	1970	2006
18	Jerome	42.73	-114.52	1140	1970	2006
19	Kellogg	47.53	-116.13	703	1970	2006
20	Lewiston	46.37	-117.02	433.1	1970	2006
21	Lifton Pumping	42.12	-111.31	1809	1970	2006

22	May	44.57	-113.89	1546	1970	2006
23	Minidoka Dam	42.67	-113.50	1269.2	1970	2006
24	Moscow	46.72	-116.96	802	1970	2006
25	Newport	48.18	-117.05	653	1970	2006
26	Parma	43.80	-116.94	698	1970	2006
27	Porthill	48.99	-116.50	541	1970	2006
28	Potlatch	46.96	-116.85	778	1970	2006
29	Richfield	43.05	-114.16	1305	1970	2006
30	Saint Anthony	43.97	-111.71	1516	1970	2006
31	Saint Maries	47.32	-116.60	653	1970	2006
32	Salmon - KSRA	45.19	-113.90	1211	1970	2006
33	Swan Falls	43.24	-116.38	708	1970	2006
34	Twin Falls	42.54	-114.35	1207	1970	2006
35	Weiser	44.24	-116.97	644	1970	2006

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 RCLimindex 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 n times standard deviation (std) of the value for the day, that is, $(\text{mean} - n \times std, \text{mean} + n \times std)$, where std for the day and n is an 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).

Methodology

The RCLimindex 1.0 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. (2005b) and Haylock et al. (2006). In order to run the RCLimindex 1.0 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). RCLimindex provided 10 extreme climate indices, which were chosen for discussion here (Table 2), because they better explain the climate 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; Santos and Brito, 2007; Dufek and Ambrizzi, 2008).

Table 2 - Definition of extreme air temperature indices used in this study

Indices	Name	Definition	Units
SU	Summer Days	Annual count when TX(daily maximum)>25°C	Days
ID	Iced Days	Annual count when TX(daily maximum)<0°C	Days
TR	Tropical Nights	Annual count when TN(daily minimum)>20°C	Days
FD	Frost Days	Annual count when TN(daily minimum)<0°C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Min Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
DTR	Diurnal Temperature Range	Monthly mean difference between TX and TN	°C

The spatial distribution of the indices trends was represented using the symbols (⊕) for positive trends, and (●) for negative trends, statistically significant at 95% level, i.e. $p < 0.05$. The representation of the trends which are statistically non-significant at the 95% level used the symbols (+) for positive trends, and (O) for negative trends.

RESULTS

Table 3 shows the annual trends of the extreme indices of air temperature in Idaho, obtained by using the software RCLimindex 1.0, for 35 weather stations. The

bold and highlighted values represent significant level of 5% ($p < 0.05$). The discussions presented in this study are only for those trends that showed significant level of 5%. The index *Summer Days* (SU) showed with positive trend at 8 stations and negative trend at 2, evidencing an overall increase in the annual number of days when the maximum air temperature was higher than 25°C. The spatial distribution trend of this index is shown in Figure 2a. The index *Iced Days* (ID) showed only stations with negative trends, totalizing 3 stations, but the stations with negative trends are predominant, showing that the annual number of days when the

maximum air temperature was less than 0°C is decreasing. These results are consistent with those shown by SU index, especially to the Grace station with presents positive trend to SU and negative trend to ID. Figure 2b shows the spatial distribution trends of ID index; the significant values are well distributed over the studied area. It is possible to identify the homogeneous behavior of the indices presenting, predominantly, negative trends. These results are in agreement with those of Karl et al. (1996).

Tropical Nights (TR) index shows 8 stations with positive trends. These results show that the annual number of days when the minimum air temperature is higher than 20°C is increasing; the spatial distribution is shown in Figure 2c, presenting predominant increase in the southwestern, and decrease trends in the northern areas of Idaho.

The *Frost Days* (FD) index presented 11 stations with negative trends and 2 stations with positive trends showing that the annual number of days when the minimum air temperature is lower than 0°C is decreasing. Only Idaho City and Saint Anthony presented increase in this index, and both the cities are located in the mountain regions which facilitate the freezing of the air. Figure 2d evidences the predominant decrease trends in the northern region of Idaho.

The *Max Tmax* (TXx) index, i.e. monthly maximum value of daily maximum temperature, presented 11 stations with positive trends and 3 stations with negative trends, showing a predominant increase in the monthly maximum value of daily maximum temperature in the southern region of Idaho (Figure 2e).

It is possible to observe in *Min Tmax* (TXn) index a similar behavior, with only positive trends (12 stations), showing that the monthly minimum value of daily maximum temperature is increasing as well. The spatial distribution is shown in Figure 2f, and these results indicate a predominant increase in the temperature in the studied area. The *Max Tmin* (TNx) index, i.e. monthly maximum value of daily minimum air temperature, shows 7 stations with positive trends and 1 station with negative trend (Figure 2g).

The *Min Tmin* (TNn) index presented a similar behavior of the TXn with predominant positive trends (25 stations), indicating that the minimum temperature is also increasing in this region (Figure 2h). These results are very dangerous, because the water to human consumption and agriculture in Idaho is provided by the snow on the mountains and with the air minimum temperature increasing the melting will be accelerated hindering the water management in the State. The increase of the air temperature in the study

area was also previously identified by Karl et al. (1996) and Alexander et al. (2006).

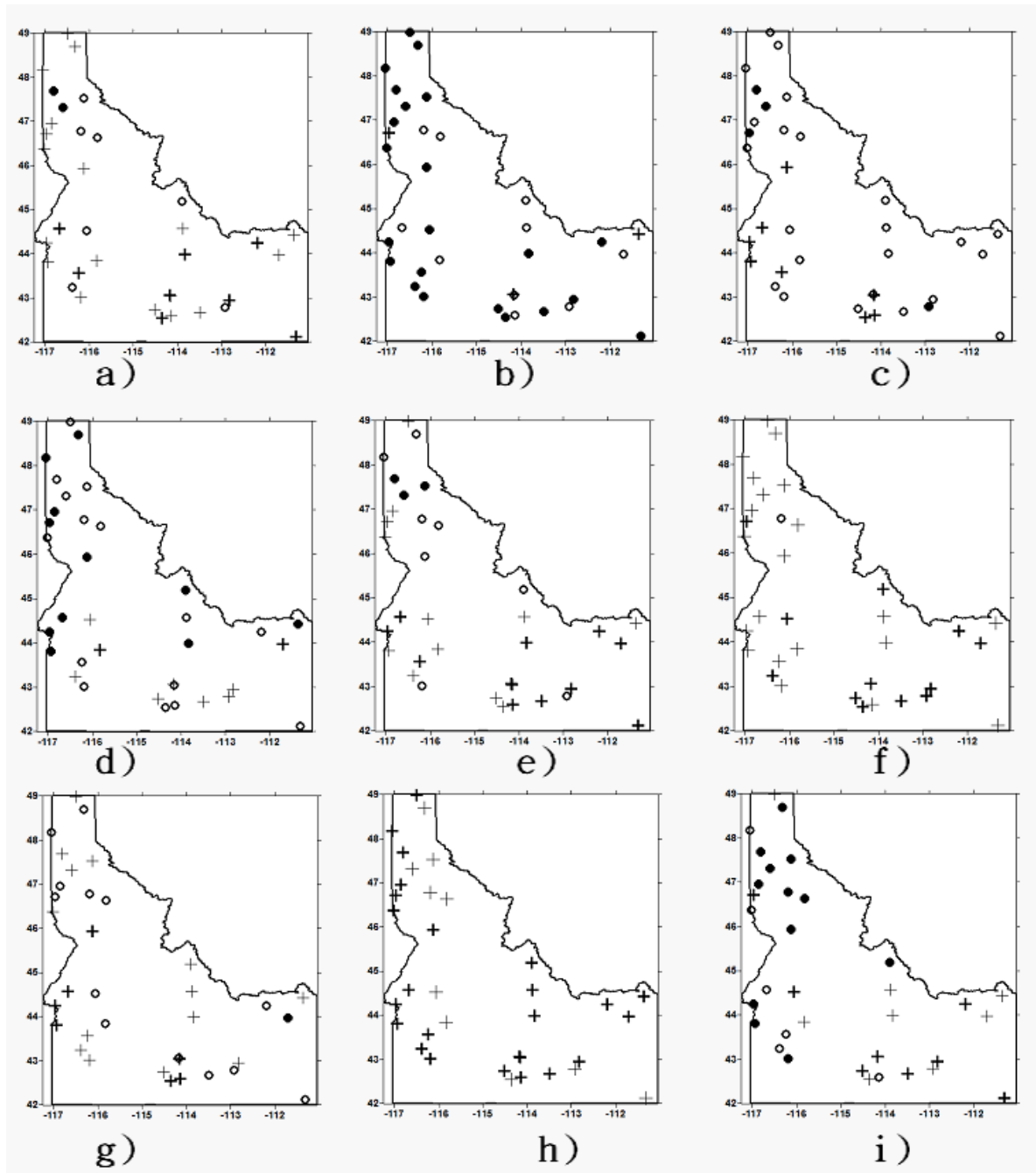
In addition, *Diurnal Temperature Range* (DTR) index shows negative trends at 12 stations and positive trends at 8 stations (Figure 2k), indicating that the monthly mean difference between maximum and

minimum temperature is decreasing in the northern part of the studied area. These results are in agreement with the results obtained for TXx, TXn, TNx and TNn indices and are similar to the results obtained by Alexander et al. (2006).

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

STATION	SU	ID	TR	FD	TXx	TXn	TNx	TNn	DTR
Aberdeen	0.376	-0.204	0.004	0.200	0.060	0.179	0.009	0.174	0.054
American Falls	-0.022	0.280	-0.015	0.200	-0.046	0.138	-0.012	0.122	0.000
Boise	0.419	-0.208	0.131	-0.174	0.045	0.128	0.045	0.257	-0.009
Bonniers Ferry	0.279	-0.070	0.000	-0.572	-0.017	0.079	-0.021	0.116	-0.026
Cambridge	0.363	0.162	0.057	-0.490	0.095	0.092	0.070	0.153	-0.014
Cascade	-0.229	-0.124	0.000	0.083	0.017	0.174	-0.033	0.123	0.026
Chilly Barton Flat	0.440	-0.277	0.081	-0.549	0.086	0.101	0.015	0.207	0.002
Couer Dalene	-0.436	-0.257	-0.004	-0.231	-0.075	0.113	0.006	0.335	-0.077
Dubois	0.502	-0.422	0.000	-0.225	0.058	0.194	-0.006	0.160	0.037
Elk River	-0.048	0.017	0.000	-0.390	-0.060	-0.103	-0.044	0.132	-0.040
Grace	0.532	-0.552	0.000	0.073	0.161	0.216	-0.013	0.160	0.068
Grand View	0.074	-0.145	0.031	-0.386	-0.022	0.059	0.045	0.193	-0.059
Grangeville	0.180	-0.221	0.012	-0.881	-0.002	0.070	0.074	0.162	-0.036
Hazelton	0.101	0.101	0.038	-0.347	0.059	0.128	0.080	0.170	-0.015
Headquarters	-0.183	0.054	0.000	-0.207	-0.036	0.057	-0.027	0.092	-0.033
Idaho City	0.032	0.057	0.000	0.550	0.046	0.081	-0.053	0.087	0.022
Island Park	0.458	-0.584	0.000	-0.315	0.022	0.116	0.019	0.219	0.024
Jerome	0.241	-0.182	0.010	0.021	0.043	0.119	0.016	0.169	0.024
Kellogg	-0.408	-0.311	0.008	-0.208	-0.052	0.099	0.024	0.143	-0.031
Lewiston	0.016	-0.248	0.028	-0.287	0.010	0.127	0.004	0.154	-0.009
Lifton Pumping	0.683	-0.007	0.000	-0.211	0.065	0.120	-0.028	0.121	0.038
May	0.015	0.254	0.000	-0.059	0.027	0.093	0.000	0.150	0.008
Minidoka Dam	0.047	-0.101	0.005	0.328	0.097	0.211	-0.002	0.180	0.044
Moscow	0.344	-0.428	-0.001	-0.482	0.009	0.157	-0.018	0.164	0.024
Newport	0.240	-0.238	0.002	-0.651	-0.007	0.091	-0.002	0.212	-0.007
Parma	0.281	-0.174	0.024	-0.554	0.010	0.156	0.058	0.245	-0.025
Porthill	0.418	-0.326	0.004	-0.079	0.029	0.104	0.040	0.161	0.015
Potlatch	0.127	-0.215	0.000	-0.889	0.017	0.077	-0.001	0.255	-0.025
Richfield	0.231	0.341	0.015	-0.282	0.137	0.060	0.052	0.134	0.001
Saint Anthony	0.310	0.269	0.000	0.484	0.064	0.191	-0.059	0.237	0.043
Saint Maries	-0.501	-0.153	-0.001	-0.555	-0.067	0.040	0.009	0.130	-0.053
Salmon - KSRA	-0.036	0.319	0.004	-0.511	-0.032	0.168	0.029	0.222	-0.041
Swan Falls	-0.093	-0.253	0.159	0.039	0.030	0.168	0.024	0.171	-0.019
Twin Falls	0.427	-0.113	0.011	-0.197	0.035	0.145	0.062	0.139	0.009
Weiser	0.273	-0.222	0.165	-0.899	0.106	0.127	0.127	0.312	-0.069

Figure 2 - Spatial distribution of temperature extreme trends for Idaho, USA. The symbol ($\oplus$) means positive trends, and ($\bullet$) means negative trends, statistically significant at 95% level ($p < 0.05$), while the symbols (+) means positive trends, and (O) means negative trends statistically non-significant.



DISCUSSIONS 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 ten annual extreme indices of air temperature 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.

An increase in the annual number of days when the maximum air temperature was higher than 25 °C, and a decrease in the annual number of days when the maximum air temperature was less than 0 °C were found. The annual number of days when the minimum air temperature is higher than 20 °C is increasing in the southwestern, and decreasing in the northern areas of Idaho. Predominantly, the annual number of days when the minimum air temperature is lower than 0 °C is decreasing. Monthly maximum and minimum values of daily maximum temperature are increasing and monthly maximum value of daily minimum air temperature is also increasing in this region. Most of part of Idaho have shown that the difference between maximum and minimum temperatures is decreasing, indicating that the minimum temperature is increasing faster than the maximum temperature.

Agriculture (crop production and livestock) is an important economic

activity in Idaho. Crops such as hay, alfalfa, corn, wheat and barley are grown in the arid climate, mostly under irrigation practices. Irrigated agriculture is dependent on winter snowpack accumulation and storage as the main water supply for the summer months. Warming winter trends will lead to more of the precipitation falling as rain, requiring the construction of additional storage capacity to control the runoff hydrograph and match agricultural needs. Rapid population growth will exacerbate the pressure on the water resources. Continuing changes in climate will affect water supply and soil moisture availability, making it less feasible to grow crops in certain regions. Increases in extreme events such as floods, droughts and heat waves predicted by the IPCC (2007) will pose further challenges to farmers.

Some important effects of an increase in temperature, especially in regions where agricultural production is seasonally limited by temperature as in Idaho, can be the extension of the growing season, increase soil evaporation rates and severe droughts (Linderholm, 2006). Others important factors that influence crop yields are soil erosion rates and soil moisture; both can be affected by changes in rainfall patterns. The analysis has identified that the temperature has increased in Idaho during the last 3 decades. The evaluation

of the extreme temperature indices and their trends may help to a better understanding of the possible regional and local scale impacts of climate change on agriculture and human health.

Trends in regional temperature extremes and their indication of climate change are of interest to Idaho and the rest of the world. The trends obtained herein corroborate the general idea that during the last century the globe has warmed. Additionally, the experience acquired with this study for Idaho, USA, can be extended to other regions. Future research should incorporate more regional stations in surrounding states, possibly stratifying the analysis by elevation and regional microclimates with a closer look to weather station location and possible urbanization effects.

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