# Future Climate Extremes under 2°C Scenarios in Agro Climate Zone Of Rice-Wheat Punjab

Bashir, F.

***Abstract***

*The policies of the comity of nations are committed to hold the rise in global temperature well below 2°C as compared to the pre-industrial levels to reduce the risk and impacts of climate change on the Planet Earth. It is therefore, important to identify the changes in distribution, frequency, severity and duration of extreme events in future warming scenarios when global temperature will increase by2°C. The primal sector of human socioeconomic life that is vulnerable to climate change is agriculture. Being agriculture-based economy, therefore, Pakistan is extremely vulnerable to climate change. This study aims to identify the change in temperature and precipitation distributions in agro-climate zone of Rice-Wheat Punjab that is highly populated and pivotal to food security of Pakistan, under 2°C warmer scenario from baseline period of 1971-2000. Ensemble averages of 21 downscaled GCM on 0.25° grid resolution is utilized to compute the change in temperature and precipitation in Rice-Wheat Punjab under 2°C warming scenario. Various WMO approved climate indices are employed to identify the change in temperature and precipitation, and to estimate the probability of the occurrence of extreme events in future. Overall, annually accumulated precipitation is expected to increase with higher variability coupled with prolonged dry spells terminated with intermittent short intense rainy periods. Vulnerability to heatwaves is expected to increase in spring season. Length of warm, hot, very hot and extremely hot seasons is expected to increase in future warm period. On the other hand, frequency of cold nights and very cold night is expected to decrease. Annual frequency of wet days is expected to decrease with likelihood of an increase in intense precipitation (micro and meso-scale) events that may reduce the amount of effective rainfall and may cause flooding. On the seasonal scales, the precipitation in winter, spring and autumn is decreasing, while monsoon precipitation is increasing in this zone. Early monsoon season is expected to receive relatively less rainfall in comparison to baseline period, whereas late monsoon is expected to receive more rainfall that is dominated by extreme intensity events which may lead to flooding and inundation. Wet summer are expected to lead to wet winters. It is concluded that with increase in 2°C in mean annual temperature of Pakistan, this zone is expected to be warmer with an oscillation of climate between prolonged hot dry and relatively shorter cool wet cycles on inter-annual to inter-decadal scales.*

**Keywords:** Climate Change,2°C Warmer Scenarios, Extreme Events, Agro-climate Zone of Pakistan, Rice-Wheat Punjab.

## Introduction

During Conference of Parties (COP-21) in Paris in December 2015 (United Nations, 2015), organized under the United Nations Framework Convention on Climate Change (UNFCCC), 195 countries adopted the Paris Agreement which includes a long-term temperature goal:

> Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change; (Article 2.1.a).

And

> In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity,

> and in the context of sustainable development and efforts to eradicate poverty. (Article4.1, Meteorological, WMO, Nations, & Programme, n.d.).

The Paris Agreement reached in December 2015 under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC) with an explicit intention to "pursue efforts to limit the global temperature increase to 1.5°C above pre-industrial level"(Hulme, 2016).

Since the increase in global temperature is unavoidable, and weather and climate extremes that are inherent part of our weather and climate are expected to change in terms of their frequency, intensity and areal coverage. Extremes of weather and climate can have devastating effects on human society and the environment (Min et al., 2011; Parry et al., 2007).

The most important sector of human socioeconomic life that is vulnerable to climate change is agriculture. Developing countries, such as Pakistan, where extraction of natural resources and agriculture are contributing more in economy than industry, and subsistence farming is being practiced at large, are more vulnerable to climate change and resultant food security threats. It has been suggested that climate change will change the sowing and harvesting dates in many locations and in some cases a crop may cease to exist in a specific location. The threats to food security in the wake of climate change are mainly because of rising temperatures and change in precipitation patterns. Presently, Pakistan commands the highest ratio of irrigated cropland in the region with four-fifth of its total cropland being currently irrigated and the remainder being rain-fed (Bhatti et al., 2018), and such rain-fed areas are more vulnerable to deficiency of water in case of decrease in precipitation because, few alternatives are available to irrigate such areas.

It has been pointed out (Bhatti et al., 2018) that in addition to the magnitude and pace of climate change, the stage of growth during which a crop is exposed to drought or heat is important as temperature and seasonal precipitation patterns vary from year-to-year and region-to-region, regardless of long-term trends in climate. Water availability is the most important resource for food production globally. Additionally, variations in genotype, growing period, agricultural practices, meteorological and soil conditions also affect the magnitude of yield from the crop, moreover, phenological development is the most important aspect of climate adaptation to climate shifting. Climate change may alter the rate of phenological development and the amount and distribution of precipitation during the growing season. Therefore, such changes may result in a mismatch between water demand by crops and water availability from precipitation. Climate change may result in a change in the temporal distribution of meteorological variables during the crop growing season. One particular concern is the crop phenological development which is largely determined by temperature and photoperiod, may be out of phase with precipitation and hence water availability during critical periods of grain yield determination (Huda et al., 2011). Since, the amount of water vapor in the atmosphere is expected to increase roughly exponentially with an increase in temperature (Trenberth, 2011), especially when a source with an uninterrupted supply of water is present in ambience, therefore, it is expected that human induced global warming is contributing in increase in heavy precipitation on the regional scale for the existing moist locations (Tapiador et al., 2017) such as monsoon receiving areas. Changes (increase) in extreme precipitation are projected by the models, however, impacts of future changes in extreme precipitation may be under estimated because models seem to underestimate the observed increase in heavy precipitation with warming.

## Data and Methodology

Assessments of global warming impacts indicate that it will affect the frequency, severity, and duration of extreme events that will affect socio-economic affairs of people. The monitoring, identification, detection, and attribution of changes in climate extremes require fine resolution spatially continuous daily data. Recent advancement in computation and collective human knowledge on dynamic and physical characteristics of climate has enabled scientific community to deliver public with fine resolution Global Circulation Models (GCMs). General Circulation Models describe how the air in the atmosphere moves, or circulates, around the globe. They utilize the human collective understanding on the description of the conservation and movement of momentum, energy, and the mass of atmospheric constituents (including water vapor), along with transfer of momentum, energy, and mass into and out of the atmosphere from oceans and continents, and the energy incoming to the atmosphere as shortwave radiation from the Sun and outgoing as longwave radiation to deep space. GCMs also describe the evolution of atmospheric constituents with time (addition of human-induced greenhouse gases and increase in water vapor due to an increase in temperature). This may require the description of chemical reactions but much more commonly it requires that the phase changes for atmospheric constituents are described, the description of the phase changes of water being the most important need (Shuttleworth, 2012).

NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) dataset (see Table 1) are utilized for the analyses of future extreme events in Pakistan. The NEX-GDDP dataset is comprised of downscaled climate scenarios for the whole globe, that are derived from the GCM runs conducted under the Coupled Model Inter-Comparison Project Phase 5 (CMIP5) and across two of the four greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs) (Meinshausen et al., 2011). The CMIP5 GCM runs were developed in the support of the Fifth Assessment Report of the Inter-governmental Panel on Climate Change (IPCC AR5). This dataset includes downscaled projections from 21 models and scenarios for which daily dataset are produced and distributed under CMIP5. The purpose of this dataset is to provide a set of global, high resolution (*0.25° x 0.25°* degree), bias-corrected climate change projections that can be used to evaluate climate change impacts on processes that are sensitive to finer-scale climate gradients and the effects of local topography on climate conditions.

**Table 1:** List of CMIP5 models included in GDDP dataset.

| | | |
|---|---|---|
| ACCESS1-0 | CSIRO-MK3-6-0 | MIROC-ESM |
| BCC-CSM1-1 | GFDL-CM3 | MIROC-ESM-CHEM |
| BNU-ESM | GFDL-ESM2G | MIROC5 |
| CanESM2 | GFDL-ESM2M | MPI-ESM-LR |
| CCSM4 | INMCM4 | MPI-ESM-MR |
| CESM1-BGC | IPSL-CM5A-LR | MRI-CGCM3 |
| CNRM-CM5 | IPSL-CM5A-MR | NorESM1-M |

Each climatic projection of NEX-GDDP includes daily maximum temperature ($T_x$,°$K$), daily minimum temperature ($T_n$,°$K$) and precipitation ($P_r, Kg^{-2}s^{-1}$) for the periods from 1950 through 2005 (“Retrospective Run”) and from 2006 to 2100 (“Prospective Run”). Over here, we have further computed the ensembles of the 21 downscaled CMIP5 GCMs runs in both RCP 4.5 and 8.5 scenarios, as an ensemble is closer to in-situ observations than individual members (Surcel et al., 2014).

Since the comity of the nations is committed to limit global warming well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C as compared to pre-industrial levels, recognizing that, this would significantly reduce the risks and impacts of climate change. Another important hypothesis in continuation of 2°C rise in global warming and change in intensity and frequency of extreme events is the rise of 2°C with respect to recent climate and how climatic extremes will shape in such scenario, locally. Therefore, over here we are examining how climate extremes will shape when annual mean temperature of Pakistan will be increased by 2°C from a baseline climate (1971-2000) that is before the onset of world warmest years in the 21st century (Cheng & Zhu, 2018). Therefore a 2°C warm Pakistan is defined as years under RCP 4.5 (2027-2069) and RCP 8.5 (2027-2045) scenarios when areal average annual mean temperature of Pakistan is 1.5°C to 2.5°C higher than that of baseline period. Both the RCP 4.5 and 8.5 scenarios present gradual warming toward the end of present centurary, with a gradual increase in $CO_2$ emissions in respective scenario, where, warming in RCP 8.5 is higher then that of RCP 4.5, therefore, upper threshould of 2.5°C will be crossed in RCP 8.5 sooner then RCP 4.5 scenario. Over here we are adopting 2°C increase in annual temperature of Pakistan that covers same period as that of 2°C increae in global annual average temperature (Karmalkar & Bradley, 2017).

There are a number of ways extreme climate events can be defined, such as extreme daily temperatures, extreme daily rainfall amounts, large areas experiencing unusually warm monthly temperatures, or even storm events such as tropical cyclones (Easterling et al., 2000). Extreme events can also be defined by the impact an event has on society. That impact may involve excessive loss of life, excessive economic or monetary losses, or both.

Rice-Wheat Punjab is comprised of districts of Sialkot, Gujrat, Gujranwala, Sheikhupura, Lahore, Kasur, Narowal, Mandi Bahauddin, and Hafizabad (see Figure 1). The population of this zone is recorded as 35 million in Year 2017, whereas it was 23 million in year1998 (PBS, 2018). The annual growth rate of the zone is almost 2.2%.

Rice, Wheat, and Sugarcane are the main crops grown in the zone. The source of irrigation is perennial and non-perennial canals supplemented by tube wells (ground-water abstractions). Rice and Wheat are the major food crops while Rice dominates with an earning, as foreign exchange. Besides them, Jawar, Bajra, Mash, Moong, Masoor, Gram, Maize, Tobacco, Oil Seed such as Rape/Mustard, and sunflower are also grown in minor quantities in this zone.

To analyze the changes in the nature of the climate extreme with 2°C rise in mean annual temperature of Pakistan in Rice-Wheat agro-climate zone (ACZ, see Figure 2), the comparison of future climate extremes with baseline period are performed using various WMO approved standard climate indices (Klein Tank, A. M. G., Zwiers, F. W., and Zhang, 2009). Areal average of daily means for the baseline period (365-days cycle) of maximum ($T_x$, magenta Line and red circle markers, see Figure 2) and minimum temperature ($T_n$ , dark blue line and circle markers. see Figure 2) are compared with that of RCP 4.5 and RCP 8.5 for Rice-Wheat. Since we are computing the areal average of the whole climatic zone that must be not as high as in-situ observations recorded at individual stations, nevertheless, their distributions are still comparable, and they will reveal a lot of information regarding nature of change in extreme events. Similarly, daily mean precipitation presenting 365-days annual cycle from baseline period (see Figure 3, blue line) is compared to that of 2°C warm Pakistan in both RCP 4.5 and RCP 8.5 scenarios (see Figure 3, red dashed line and yellow dotted line, respectively).

The distribution of temperature and precipitation in baseline and 2°C warmer Pakistan are compared though box and whiskers plots that provides a visual presentation of data. A box and whisker plot (boxplot) is a graph that presents information from a five-number summary. It does not show a distribution in as much detail but indicates whether a distribution is skewed and whether there are potential unusual observations (outliers) in the data set. Box and whisker plots are also very useful to compare baseline distribution of temperature and precipitation with that of 2°C warmer Pakistan as it compares the spread and overall range of the distributions. In such a plot (see Figure 4 and Figure 5) the end of the box are the upper and lower quartiles (75$^{th}$ and 25$^{th}$ percentiles of the cumulative distribution function, respectively), so the box spans the interquartile range and delineates the outliers. The whiskers extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the red '+' symbol (McGill et al., 1978). Median value (50$^{th}$ percentile) of the distribution is presented by the central bar of the box plot.

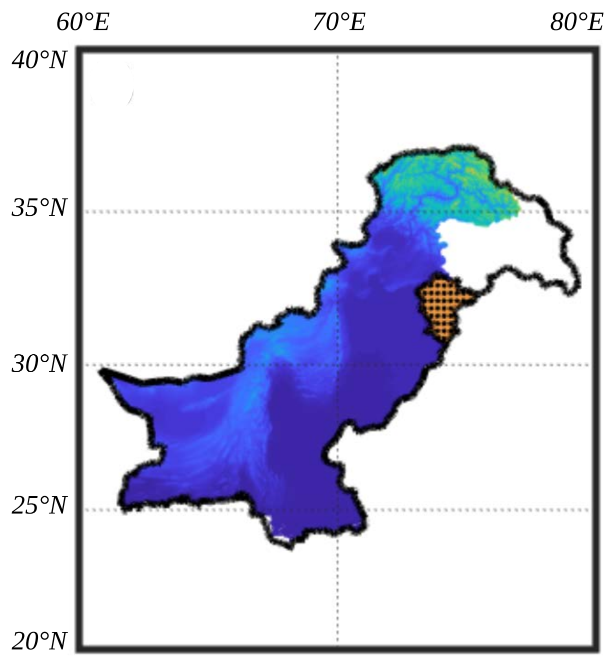


**Figure 1:** The location of Agro-climate Zone (dotted polygon) in Pakistan is presented.

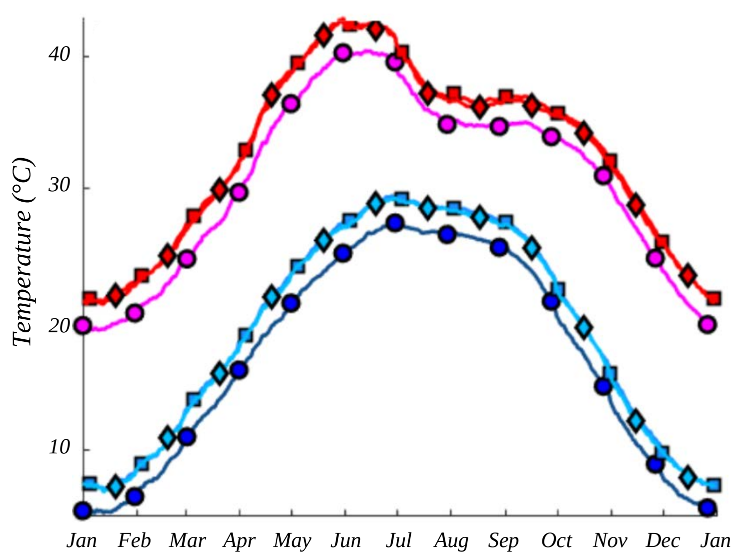


**Figure 2:** The daily mean (365-day annual cycle) of the areal average maximum temperature ($T_x, °C$) of the Baseline (1971-2000) GCM ensemble median is presented is with magenta Line and red circles. The 365-day annual cycle of the areal average daily maximum temperature ($T_x, °C$) of the Rice Wheat Punjab under future RCP 4.5 (2027-2069) and RCP 8.5 (2027-2045) GCM ensemble median are presented with red Lines (red filled squares and squares, respectively). Similarly, the 365-day annual cycle of the areal average daily minimum temperature ($T_n, °C$) of the baseline is presented with dark blue line (dark blue circles) , whereas, same of the future RCP 4.5 and 8.5 are presented with light blue lines along with filled squares and diamonds, respectively.

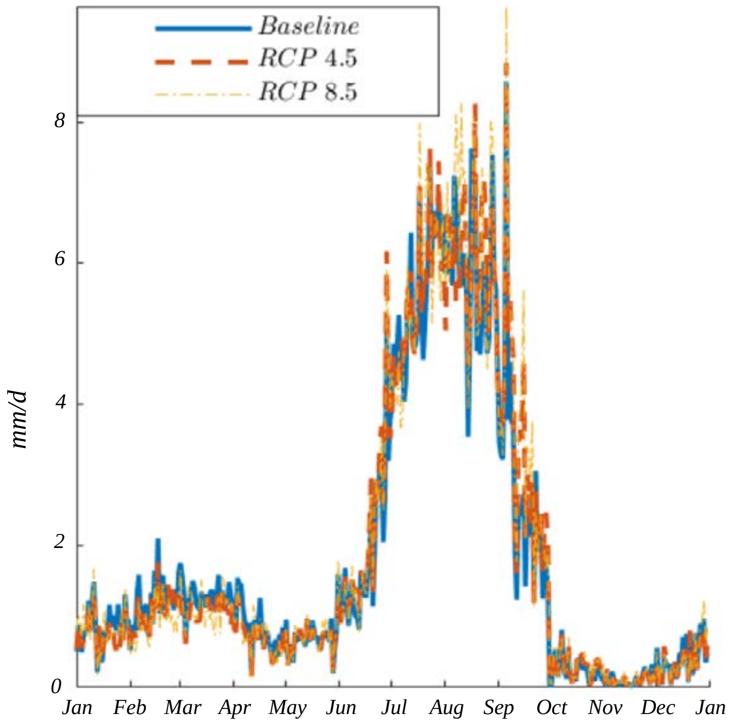


**Figure 3:** the 365-day annual cycle of the areal average daily precipitation ($mm/d$) computed from the ensemble mean of GCM for the baseline (blue line) and the future (red dashed line for RCP 4.5 and yellow dotted line for RCP 8.5) are presented for the ACZ of Rice-Wheat Punjab.

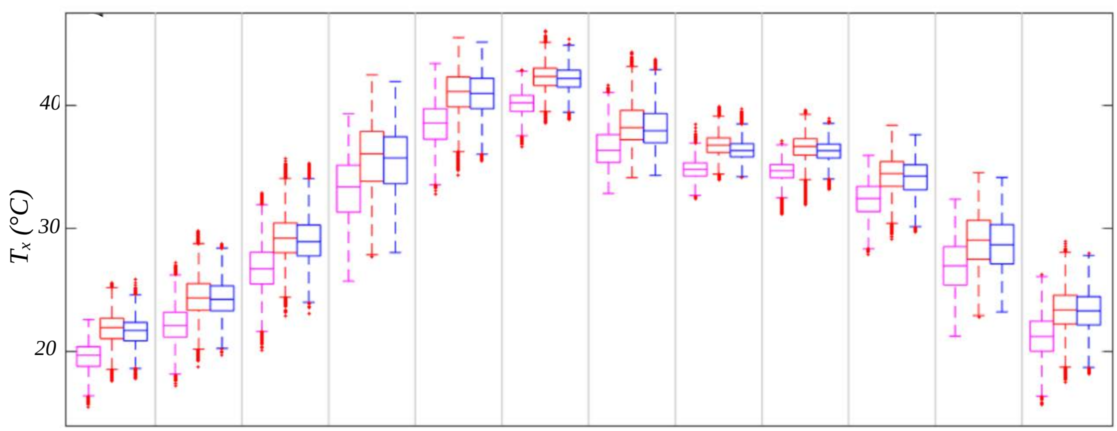


**Figure 4:** Statistical summaries of the daily maximum temperature ($T_x$, $°C$) under the Historical Baseline (1971-2000, magenta) period and the future period under RCP 4.5 (2027-2069, red) and 8.5 (2027-2045, blue) of Rice-Wheat Punjab are presented through Box Plots on the monthly scales.

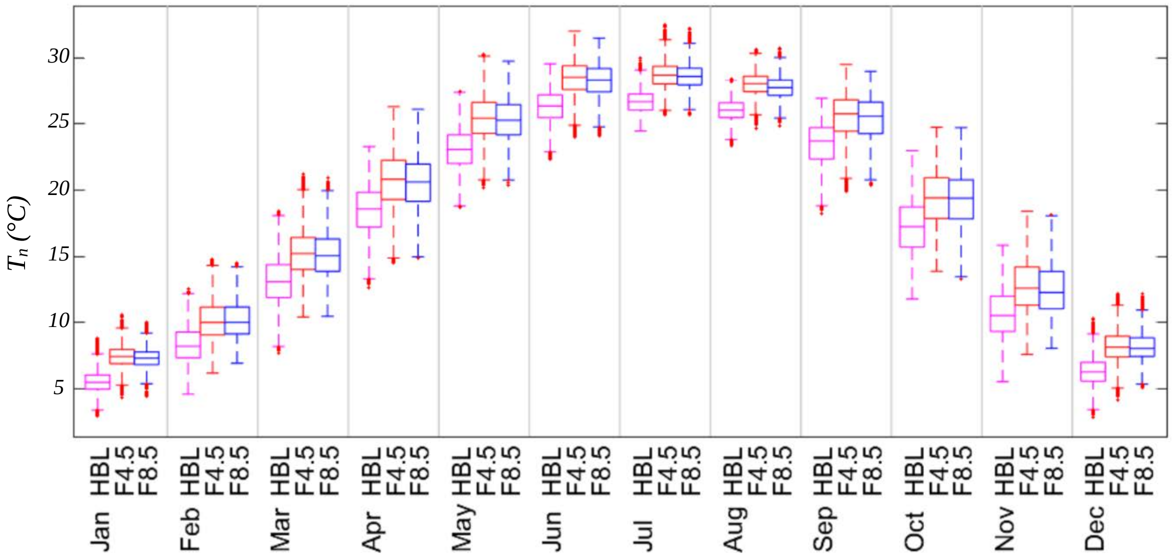


**Figure 5:** Statistical summaries of the daily minimum temperature ($\boldsymbol{T_n}, \boldsymbol{°C}$) under the Historical Baseline (1971-2000) period and the future period under RCP 4.5 (2027-2069) and 8.5 (2027-2045) of Rice-Wheat Punjab are presented through Box Plots on the monthly scales.

We have computed some very informative climates indices that helps to identify the characteristics of extreme events in 2°C ACZ of Rice-Wheat Punjab. Theses indices includes;

i) Total count of days where maximum temperature ($T_x$) is above 25°C that also refers to count of summer days in a calendar year.

ii) Total count of days where maximum temperature ($T_x$) is above30°C, in a calendar year, that refers to count of hot days in a calendar year.

iii) Total count of days where maximum temperature ($T_x$) is above35°C, in a calendar year, that refers to count of very hot days in a calendar year.

iv) Total count of days where maximum temperature ($T_x$) is above40°C, in a calendar year, that refers to count of extremely hot days in a calendar year.

v) Total count of nights where minimum temperature ($T_n$) is above 25°C, in a calendar year, that refers to count of extremely hot nights in a calendar year.

vi) Total count of nights where minimum temperature ($T_n$) is below 10°C, in a calendar year, that refers to count of cold nights in a calendar year.

vii) Total count of nights where minimum temperature ($T_n$) is below 5°C, in a calendar year, that refers to count of very cold nights in a calendar year.

viii) Total count of wet days with precipitation ($P_r$) is greater than 1 mm, in a calendar year.

ix) Total count of days with moderately intense precipitation ($P_r$>*5mm*), in a calendar year.

x) Total count of days with intense precipitation ($P_r$>*10mm*), in a calendar year.

xi) Total count of days with extremely intense precipitation ($P_r$>*20mm*), in a calendar year.

xii) Total count of dry days ($P_r$<*1mm*), in a calendar year.

In addition to these climate indices, the average precipitation for each Julian day (365-days cycle) from baseline years and future warm years is presented (see Figure 3). This reveals seasonal changes in precipitation in the future warm period with respect to the baseline period. Furthermore, we have used a single mass curve to present mean daily cumulative precipitation for the baseline period and 2°C warm periods for comparison. The mass curve revels long-term sustained trends. The comparison of the mean annual trend of baseline period to 2°C warm Pakistan in ACZ of Rice-Wheat Punjab reveals how precipitation in the different season will be affected (see Figure 8).

## Results

In Agro-Climate Zone of Rice-Wheat Punjab winters are mild, whereas late spring and summers are warm followed by a rainy summer (Monsoon) season that ends in dry autumn. Both historical and future ensemble of GCM runs capture 365 days annual changes in temperature and precipitation very effectively. The rise in spring and summers maximum temperature (see Figure 2) indicates the accumulation of sensible heat with limited precipitation. However, the monsoon season that starts in early July and ends in the middle of September delivers the copious amount of rainfall (as high as 8 mm/day (~450mm for the season, see Figure 3 and Figure 7). Autumn is relatively a dry season, although winters receives rain from western disturbances, time to time. Maximum temperature drops in the rainy season and diurnal temperature range (DTR) decreases (See Figure 2). With an increase in annual mean areal average temperature of Pakistan by 2°C, future GCM simulation suggest an increase in both maximum and minimum temperature in all months (see Figure 4 and Figure 5). An increase in the likelihood of extreme events in maximum temperature is expected in spring and autumn seasons (April and November) that are mainly dry. 40°C lies almost on 50th percentile of future GCM Projections in the months of May and June. It indicates the increase in the likelihood of maximum temperature above half of the time. On the other hand, in the month of June the likelihood of extreme daytime temperature increases if it goes dry.

In the case of minimum temperature, (see Figure 5) likelihood of an increase in extreme events is higher for the whole year. The future minimum temperature of the summer and winter seasons is significantly higher than the historical baseline period. The annual number of days with maximum temperature above 25°C is expected to increase in fthe uture warm period. In the baseline period, it is almost nine months (~265 days) with a temperature above 25°C, while in future it is expected to increase by another ~ 20 days. It indicates that winter are shrinking, and the summer season is expanding. There is a substantial increase (almost a month, see Figure 6, 'h') in annual frequency of hot days i.e., $T_x$> 30°C. Frequency of days above 35°C (very hot) and 40°C (extremely hot) is expected to increase drastically, increase in duration is more than two months for former and 1.5 months for later, respectively. Temperature higher than 40°C is more likely to prevail in late spring and early summer before the onset of monsoon, and it is marked by extreme events in both historical and future scenarios. Similar to maximum temperatures the night time minimum temperatures are also increasing (see Figure 6, 'k'). On the other hand, the frequency of cold nights ($T_n$<10°C) is decreasing by 30 days and very cold night will cease to exist with 2°C increase in mean annual temperature. Annual number of wet days ($P_r$> 1mm) are decreasing in the future warm climate in this agro-climate zone. Whereas, moderate to extreme intensity precipitation events are likely to increase (see Figure 6, 'o' and 'p'). It indicates that in warming world intense precipitation (micro and meso-scale) events are more likely to happen, whereas, large scale and less intense events are less likely to happen in this zone in the future warm climate. Together with this, the annual frequency of dry days is expected to increase in the future warm climate, as well (see Figure 6). On the seasonal scale, the precipitation in winter, spring and autumn is decreasing, while monsoon precipitation is increasing in this zone. That indicates a decrease in precipitation from large scale western disturbances and increase in micro and meso-scale precipitation from monsoon with more chances of flooding (see Figure 7). Comparison of yearly cumulative precipitation in the baseline period and the future warming periods indicates that late winter and spring will turn drier in warm scenario (see Figure 7). Early monsoon will receive less rainfall whereas late monsoon will receive more rainfall dominated by extreme intensity events that may lead to flooding and inundation.

## Conclusions

With an increase in 2°C in mean annual temperature of Pakistan this zone is expected to be warmer. However, the presence of extreme events on the both ends of temperature's probability distribution (above the 75th percentile and below 25th percentile) indicates an oscillation of climate between prolonged hot dry and relatively shorter cool wet cycles on inter-annual to inter-decadal scales. Since this region is one of the densely populated agro-climate zones of Pakistan and it provides essential food grains that beefs up the regional food security, therefore, there is need to device strategies that can ensure water from snow and glacial ice melts in dry seasons. In addition to this, since, late winter and spring are expected to be warmer and dryer, therefore, it may affect sowing of Kharif crops (sown in spring and harvested in autumn) due to limited availability of soil moisture, on the other hand, the Rabi (sown in autumn and harvested in spring) may be affected by an increase in late monsoon precipitation especially if it is causing flood and inundation. Overall, annually cumulative precipitation is expected to increase with higher variability coupled with prolonged dry spells terminated with intermittent short intense rainy periods.

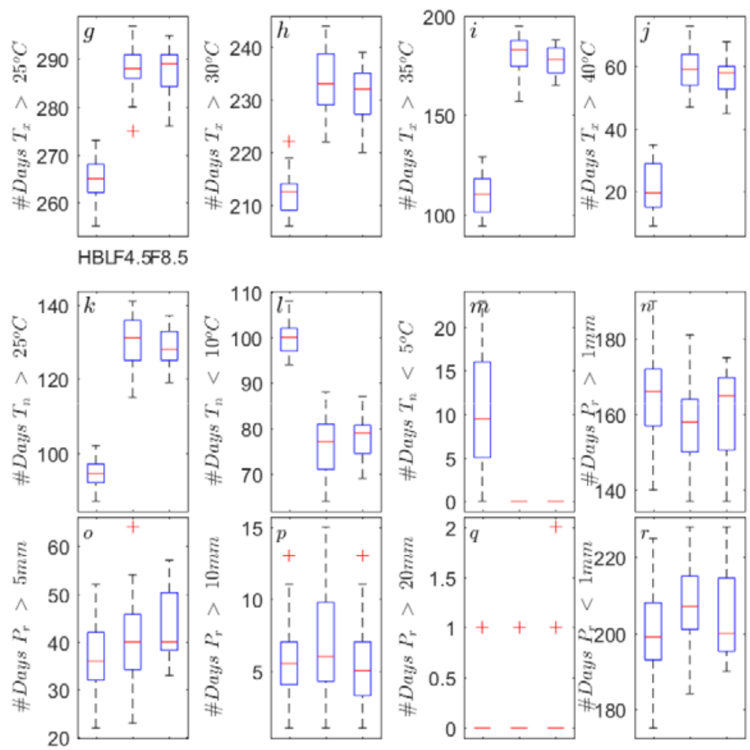


**Figure 6:** Presents the annual frequency of days ($T_x > 25°C$) in the historical baseline period (1971-2000) and the future RCP 4.5 (2027-2069) and RCP 8.5 (2027-2045) period, respectively. ($h$) similar to ($g$) with ($T_x > 30°C$). ($i$) similar to ($g$) with ($T_x > 35°C$). ($j$) similar to ($g$) with ($T_x > 40°C$). ($k$) similar to ($g$) with ($T_n > 25°C$). ($l$) similar to ($k$) with ($T_n < 10°C$). ($m$) similar to ($k$) with ($T_n < 5°C$). ($n$) the annual frequency of wet days ($P_r > 1mm$). ($o$) the annual frequency of wet days ($P_r > 5mm$). ($p$) the annual frequency of wet days ($P_r > 10mm$). ($q$) the annual frequency of wet days ($P_r > 20mm$). ($r$) the annual frequency of wet days ($P_r < 1mm$). Horizontal labels indicated in panel (g) are applicable to other panels.

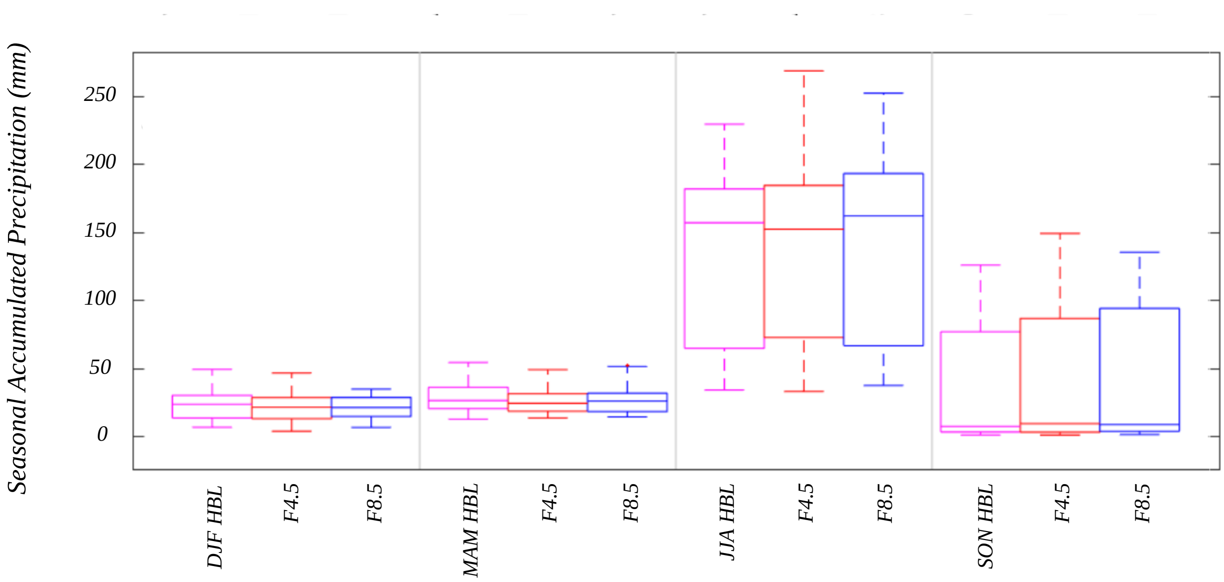


**Figure 7:** The statistical summaries of the monthly accumulated precipitation ($mm$) under the Historical Baseline (1971-2000) period and the future period under RCP 4.5 (2027-2069) and RCP 8.5 (2027-2045) of Rice-Wheat Punjab are presented through Box Plots on monthly scales.

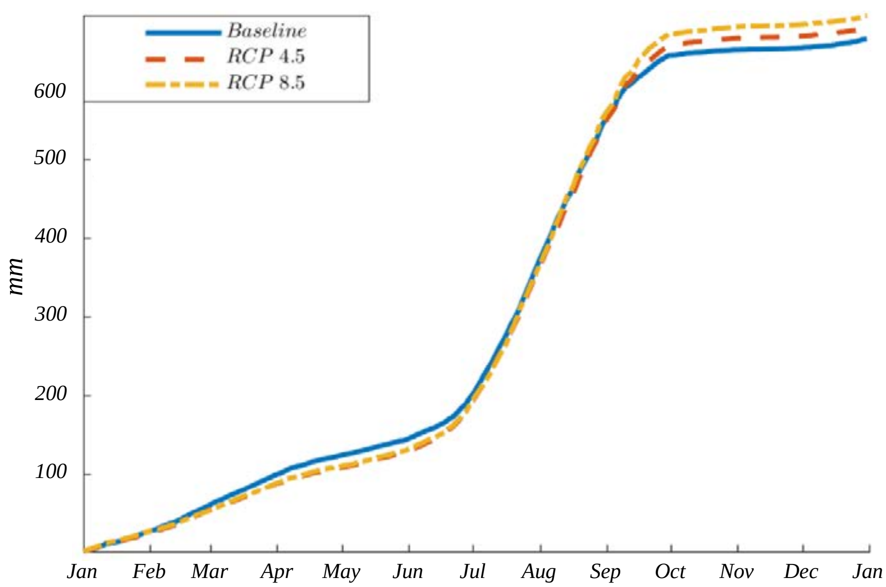


**Figure 8:** The intern-annual mean single mass curve of the daily rainfall for the historical baseline period (1971-2000) and the future RCP 4.5 (2027-2069) and RCP 8.5 (2027-2045) scenarios.

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