Atmospheric and Climate Sciences, 2014, 4, 721-726
Published Online October 2014 in SciRes. http://www.scirp.org/journal/acs
http://dx.doi.org/10.4236/acs.2014.44065

Regional Characteristics of Temperature Anomalies in Pakistan with Emphasis on Spatial Distribution at Decadal Scale: A Case Study of August (1950s-2000s)

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Received 20 June 2014; revised 6 August 2014; accepted 2 October 2014

Abstract

In this paper the month of August was assessed from 1950s-2000s based on the temperature data from 53 stations that covers almost all Pakistan. The temperature coefficient has been calculated by making use of linear regression. The results have been mapped that show considerable variability of temperature at decadal scale in different areas of Pakistan. The rugged terrains especially and rest of Pakistan generally reflect significant temperature variability in the decades of 1950s, 1960s, 1970s, 1980s, 1990s and 2000s as well. This change in temperature varies from region to region and decade to decade in Pakistan. The temperature anomalies achieved in the country are complicated at local level and did not follow the simple perception that winter months are warming and summer months are cooling. In this study, a geographical approach has been adopted to explain the spatial-temporal dynamics of temperature variation over the study period in Pakistan with emphasis on regional detail.

Keywords

Temperature Anomalies, August, Decadal Scale, Spatial Distribution, Pakistan

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How to cite this paper: Ahmad, I., Ambreen, R., Sultan, S., Sun, Z.B. and Nawaz, M. (2014) Regional Characteristics of Temperature Anomalies in Pakistan with Emphasis on Spatial Distribution at Decadal Scale: A Case Study of August (1950s-2000s). *Atmospheric and Climate Sciences*, **4**, 721-726. http://dx.doi.org/10.4236/acs.2014.44065

1. Introduction

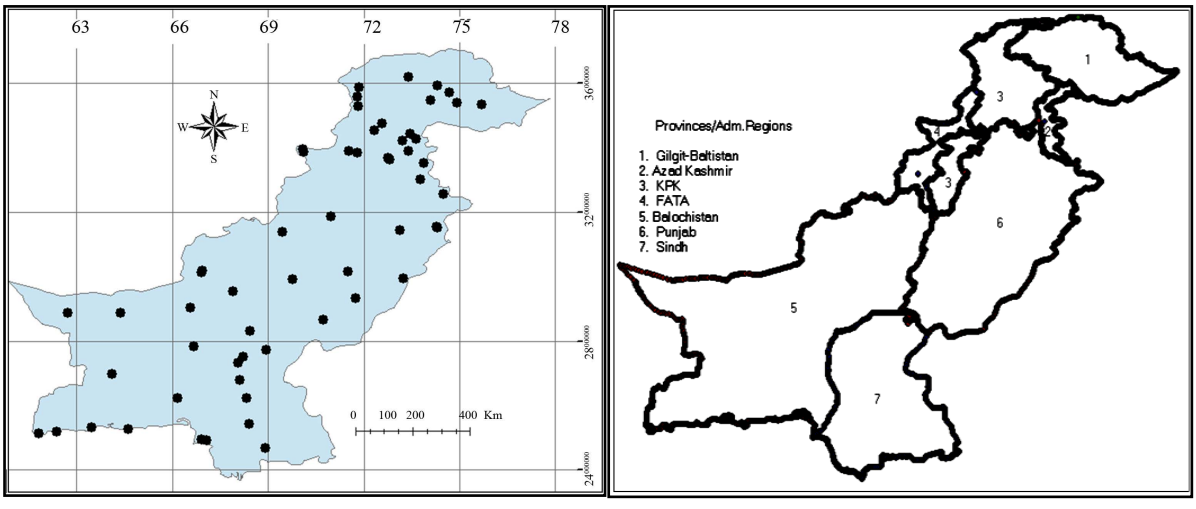
In Asia, about a billion people could face drought, land degradation and water shortage by 2050s [1] [2]. The linkages between climate change, food security and trade in South Asia are significant where the communities are mostly dependent on agriculture for both employment and subsistence [3] [4]. Pakistan is among the countries, which faces changes in temperature, where extreme weather events are creating major environment problems like drought, floods and heat waves [5]-[8]. The study of surface air temperature in complex rugged terrains caught attention of the searchers in climate sciences e.g. [9] [10] and temperature is the most important climate elements that helps in detecting climate change [11]. The monthly diagnostic of temperature variability is instrumental in future climate policy [12] [13]. For understanding the interannual changes, we need monthly temperature analysis which is also effective in intraseasonal changes, therefore, monthly temperature anomaly is considered handy tool in climate diagnostic process [14]. The anomalies more precisely elucidate climate variability over the areas than absolute temperatures do, and they give a frame of reference that allows meaningful comparison between geographical locations. The mountainous regions are more consistent in temperature variability in the contemporary warming global episode [15] [16]. The mountainous regions are more susceptible to temperature variability [17] and Himalayan region in Pakistan registered increase in temperature averages [18]. The atmospheric analogue pertaining to climate of Pakistan remained under discussion where the analysis of seasonal and annual temperatures and their trends remained under scientific discussion in Pakistan by adopting deferent approaches [19]-[23] where the rapid growing population already faces meteorological hazards. Therefore need is felt to put emphasis on ground parameterization and mapping of temperature variability. On experimental basis, the paper is focused on the spatial-temporal dynamics of temperature anomalous state of surface air temperature with emphasis on its regional characteristics in August over the decades of 1950s-2000s.

2. Materials and Methods

The term temperature anomaly refers to deviation from long-term averages. A positive anomaly specifies that the observed temperature is warmer than the reference value, while a negative anomaly is indicative of temperature cooler than the reference value.

The monthly ground observed temperature data from 53 stations (**Figure 1**) were obtained from Pakistan Meteorological Department (PMD), Government of Pakistan. The analysis is performed on decadal scale from 1950s to 2000s. In this study, total 60 months of August were taken and 10 months of each decade were analyzed separately. First, the monthly averages were calculated and the data voids were covered by interpolation. The mapped anomalies show deviations from the means of decadal temperature.

The analysis is based on the following principles,



(a) (b)

Figure 1. (a) The Geographical distribution of meteorological stations in the study area that provide data for the study. (b) The locations of provinces and regions have been marked which are frequently mentioned in the results.

$$\hat{x}_i = a + bt_i \left(i = 1, 2, \cdots, n\right)$$

The above equation expresses linear regression between, the time series t_i, and climate variable x_i (temperature) for the specified time period. Consider t_i as independent and x_i as dependent variable, regression coefficient "*b*" and the regression constant "*a*" of least-squares estimation have been calculated by making use of the following relations.

$$\begin{cases} b = \dfrac{\sum_{i=1}^{n} x_i t_i - \dfrac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} t_i\right)}{\sum_{i=1}^{n} t_i^2 - \dfrac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2} \\ a = \dfrac{1}{n}\sum_{i=1}^{n} x_i - \dfrac{b}{n}\sum_{i=1}^{n} t_i \end{cases}$$

The linear regression coefficients were calculated for each decade. The coefficient "*b*" has been simulated for selected decades (**Figure 1**) that indicates the temperature increase or decrease with regional detail, the key bar with each figure provide guidance about the level of statistical significance.

3. Results and Discussion

3.1. Decade of 1950s

Figure 2(a) configures the geographical distribution of temperature coefficient in 1950s which reflects temperature above average in most parts of the country but nevertheless few regions stand exceptions like most of Balochistan. The positive temperature anomalies have been observed in plains of Punjab and most of Sindh. The Federally Administered Tribal Areas (FATA) and Peshawar valley with its immediate surrounding experienced the positive temperature coefficient with value range from 0.5 to 1.5 that represents temperature above average. The rugged northeastern, southwestern corners of the country, Potwar plateau and Brahui ranges reflect negative temperature anomalies indicative of moderate cooling in 1950s. The Swat valley also experienced warming surface temperatures. The cooling and warming tendency in the decade was acknowledged by coefficient values that lie between the confidence levels from −1 to 1.

3.2. Decade of 1960s

Reference to **Figure 2(b)** the values of temperature anomalies in the month of August acknowledges that eastern and western Balochistan experienced warming and cooling temperatures respectively in 1960s; furthermore, the Gawadar and surrounding coastal areas are found with temperatures well above the average. The sea surface temperature may be the reason behind but needs further intensive investigations.

The rugged terrains of northern Pakistan have slightly warmer temperatures especially in Hindukush and Karakoram ranges. August is also found warmer in the western border mountains. The upper and lower Indus plains experienced little warming while ample area that extends from Sulaiman ranges to south Punjab, Khyber Pakhtunkhwa (KPK), Sindh and Balochistan were under obvious warming condition. Based on results, 1960s is warmer than 1950s.

3.3. Decade of 1970s

The decade of 1970s symbolized by **Figure 2(c)** shows temperature variation where most of Balochistan is found with complicated response. The coastal areas show temperature below average with coefficient value of −2, this area was quite warm in the previous decade. The Chaghi and Quetta region responded with temperatures below average. The Kalat district and its surrounding was the warmest region of the decade. The upper and lower Indus plains were found with negative and positive temperature anomalies respectively. The observations show that the areas which are normally under the influence of summer monsoon configures uniform decline or rise in temperature while the areas which are away from the summer monsoon access reflecting complex anomalous situation for example most of Balochistan.

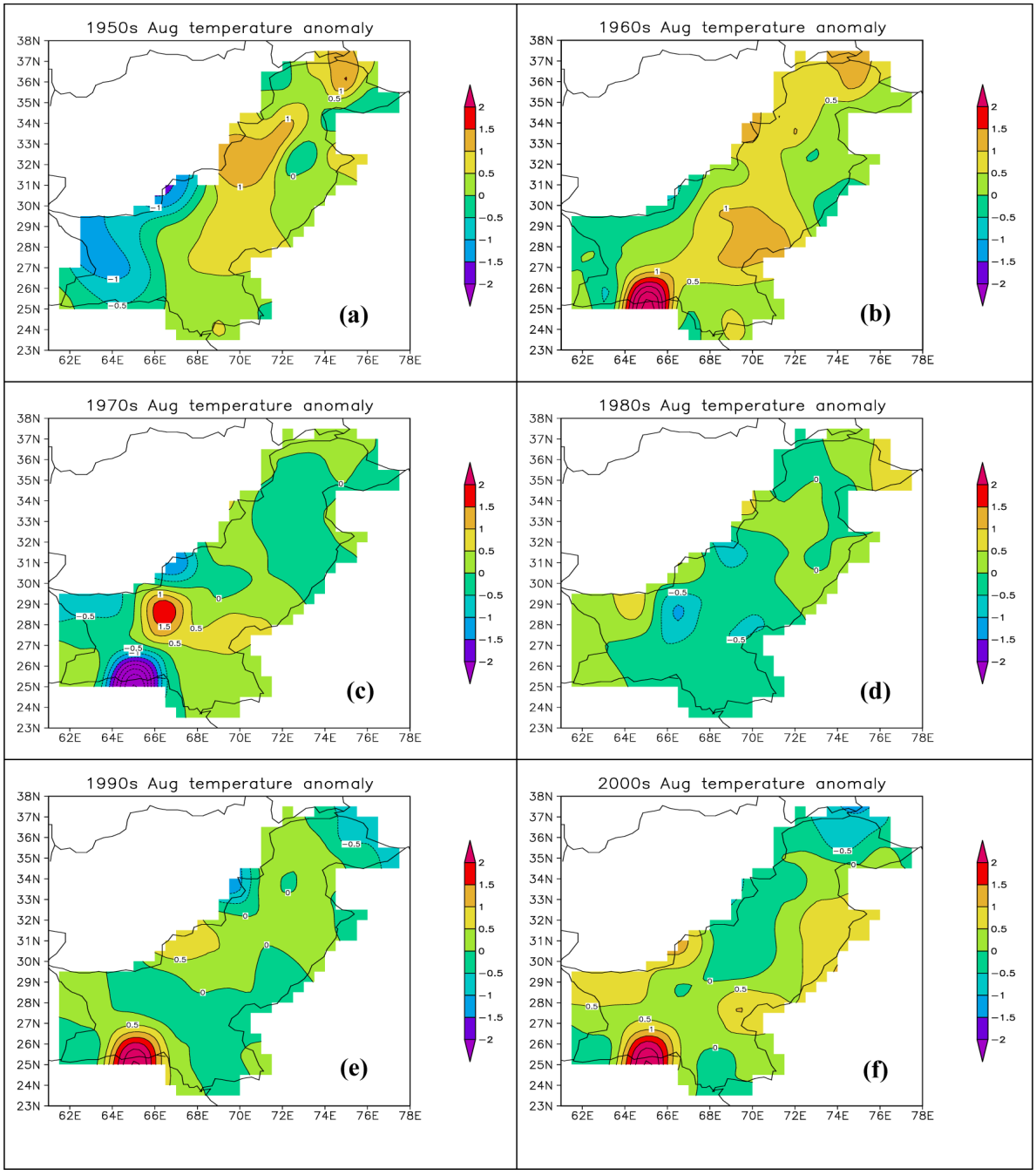


Figure 2. The geography of temperature anomalies in August for the selected decades in Pakistan: (a) 1950s; (b) 1960s; (c) 1970s; (d) 1980s; (e) 1990s; (f) 2000s.

3.4. Decade of 1980s

The temperature rise (fall) with reference to normal temperature found in the decade of 1980 (**Figure 2(d)**) seems comparatively stable than any other decade under discussion. All over the country, spatial variability of August temperature was found just close to the level of statistical significance that exhibit small temperature changes in 1980s. Even little variations in temperature were noticed in Balochistan. Small patches, like Noshki area, Safed Koh area, and Himalayas in northeast corner of the country registered temperature above average. In this decade, the Kalat area responded with low temperatures if compared with the previous decade. Moreover,

lower Indus plains, most of Balochistan and Sindh are slightly below average temperatures and on the contrary, Peshawar valley, Potwar Plateau and Bahawalpur region are slightly above average temperatures.

3.5. Decade of 1990s

Most of the country (**Figure 2(e)**) is dominated by temperature change above the average within the range from 0 to 0.5 (−0.5) coefficient values with few exceptions including Balochistan coastal belt, Quetta and surrounding, and Gilgit-Baltistan. The achieved results show that this decade is obviously seems warmer than 1980s.

3.6. Decade of 2000s

The highest temperature anomalies are observed at Coastal areas, Balochistan province and Indus Plains in the decade of 2000s (**Figure 2(f)**). The western parts of Indus plains, Kirthar ranges and Brahui ranges, Kharan were found above average temperature but in this scenario, the eastern parts of Indus plains Chaghi, Noshki and Quetta valley are warmer rather. The Balochistan again reflects complicated warming situation, temperature rise is escalating as one proceeds from Panjgur to Turbat to Gawadar. The Hindukush Karakoram Himalaya (HKH) and western border mountains including Waziristan hills and western Sulaiman ranges were slightly below average surface temperature. Thus, it was uncovered that in this decade the mountains and plains behave differently. In both 1990s and 2000s, the Balochistan coastal areas were quite warm. There is great probability that the sea surface temperature (SST) of Arabian Sea have relation with these coastal surface temperature anomalies. The leading warming regions were Balochistan and Indus plains.

The northern and northwestern rugged parts of the country are seems to be more sensible in case of temperature variability. A general perception exist that winter months are warming and summer months are cooling, the concept is true at hemispheric, continental or synoptic level however this point of view is questionable at local and monthly scale when we analyze the geography of average surface air temperature based on ground observed data in Pakistan with diversity of physiography.

4. Conclusion

Based on results we observed that the spatial distribution of temperature anomalies in Pakistan is quite complex and varies from place to place. The details are evident that the temperature was above average in some places while it was below average in other places. The 1950s reflects temperature above average in most parts of the country but nevertheless few regions stand exceptions like most of Balochistan. The 1960s is warmer than 1950s furthermore, the Gawadar and surrounding coastal areas were found with temperatures well above average in 1960s. The areas which are normally under the influence of summer monsoon in Pakistan configures comparatively uniform decline or rise in temperature over larger areas while the areas which are away from the summer monsoon access reflecting complex anomalous situation that vary from place to place at small scale, for example in the province of Balochistan. However, this assumption needs further intensive investigations. The 1980s seems comparatively stable than any other decade under discussion and all over the country, spatial variability of August temperature was found just close to the level of statistical significance that exhibit small temperature changes. The achieved results in 1990s were evident that this decade was obviously warmer than 1980s. The highest temperature anomalies are observed at coastal areas, Balochistan province and Indus plains in the decade of 2000s. The western parts of Indus plains, Kirthar ranges, Brahui ranges and Kharan were found above average temperature but in this scenario, the eastern parts of Indus plains, Chaghi, Noshki and Quetta valley were warmer rather. In 1960s, 1990s and 2000s, the Balochistan coastal areas reflected temperatures above the reference point.

Acknowledgements

The help and cooperation of PMD is highly acknowledged. The comments and suggestions of anonymous reviewers are highly appreciated that improved the paper.

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