Trend Analysis of January Temperature in Pakistan over the Period of 1961-2006: Geographical Perspective

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Abstract

Based on monthly data from 54 ground stations over the period of 1961 to 2006, the trend of January temperature has been analyzed in Pakistan and its different regions by statistical method. Tools of FORTRAN and GrADS have been used for computation and mapping. Like other subtropical regions of Asia, also January represents core month of the winter season in Pakistan. Based on analysis, the January temperature has been increased by about 0.6oC at national level in the study period. However, this change in temperature varies from region to region and decade to decade in Pakistan. In order to know the regional detail of temperature tendency, schematically Pakistan is divided into five regions. The northern parts, southwestern parts comprised of Balochistan Plateau, the upper and lower Indus plains have the warming trend but surprisingly northwestern hilly areas of the study domain have cooling trend in January. Furthermore, the northern and western rugged territories of the country show larger interannual temperature variability in January than plains of the country. A cool phase in 1970s, warm phases in 1980s, 1990s and onward is obvious. The study put emphasis on the decadal and regional spatial distribution of temperature anomalies in the month of January.

Key words: January, warming trend, decadal variation, regional trend, spatial distribution, rugged terrain.

Introduction

The surface air temperatures have certain effects on man's activities and his comfort in urban as well as in rural agglomerations (Nicol, 1999). The surface temperature and its spatial distribution in Pakistan are mainly shaped by a variety of geographical and astronomical factors and its tendency is further added by the variability of temperature through time. The accelerating pace of melting glaciers, intensification of extreme climate events including drought, and floods are the signs of climate variation (Cruz et al. 2007) hence Pakistan stands no exception in this case. Therefore, various studies with different approaches have documented the climate variation as well as the warming trend in the country (e.g. Chaudhry and Sheikh, 2002; Chaudhry and Rasul, 2007; Afzal et al. 2009). In response to global warming and temperature variation the mountains show high temperature trends as well as more inconsistency (Liu and Chen, 2000; Magnuson, 2000). The northern and northwestern rugged parts of the country are much sensitive. The upward shift of isotherms along the southern slopes of Himalayas is the clear indication of increase in temperature averages (Rasul et al. 2008).

The climatic classification, seasonal, annual and interdecadal temperatures, and their trends the Arabian Sea surface temperature and its impact on coastal areas remained under discussion in Pakistan (Chaudhry and Rasul 2004; Kruss et al. 1992; Islam et al. 2009; Khan et al. 2008; Afzal et al 2008). Therefore, it is envisaged to investigate January surface air temperature and its regional spatial anomalies in January which is the core month of winter in Pakistan. This paper is focused on the decadal spatial-temporal temperature anomalous trend in January and their characteristics over the period of 1961-2006 at national and regional levels. In this period, change in landuse has occurred in the wake of manifold increase in population and urbanization. The concern is growing that the developing society of Pakistan needs better understanding of climate and its impacts on agriculture (Hussain and Mudasser, 2007) where the faster growing population already faces climatic hazards. In this connection, the January temperature and its spatial trend got tremendous importance for the fruit growing areas in northern and western rugged terrain of the country including, Quetta, Kalat, Ziarat and Zhob valleys in Balochistan, western border ranges, Peshawar valley, Swat Valley, Hazara Division and Potwar Plateau. It is imperative to mention that the

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government and civil administration need better understanding of monthly surface temperature in the situation where they have to look after hundreds of thousands of internally displaced persons (IDPs) in temporary shelters in the wake of insurgencies going on in Pakistan.

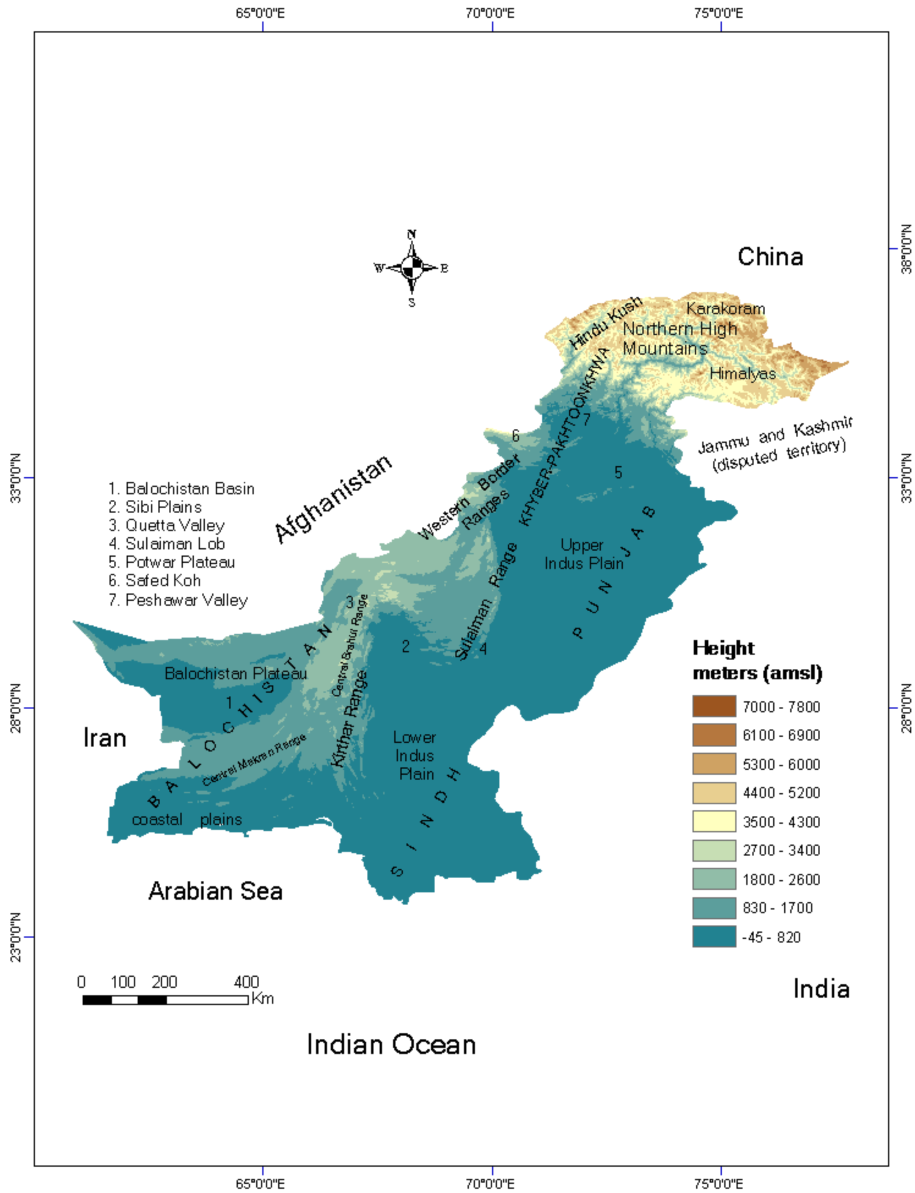

Figure 1: Pakistan, location and landforms detail. Map prepared with the help of digital elevation model (DEM) input into ArcGIS. DEM is based on 3-arc second resolution obtained from SRTM.

The paper is organized as follow; the Section 2 briefly describes data and methods. Section 3 is the major part of the paper which elucidates results and discussion including decadal trend and spatial distribution of January temperature anomalies, time series and their regional characteristics and distribution of trend coefficient of January temperature both at national and regional levels. Conclusion and discussion is given in Section 4.

Data and Methods

The monthly ground observed temperature data were obtained from Pakistan Meteorological Department (PMD), Government of Pakistan. We use the data of 54 stations shown in Figure 2 over the period of 1961-2006. The computation and analysis is done with the help of FORTRAN and GrADS. The analysis is done at national and regional levels. In order to have the regional detail and make the study methodical the whole study domain is schematically divided into five regions, the group of stations with the same symbols in Figure 2 denotes separate regions. The areas are arranged hierarchically on the basis of temperature variability they reflect.

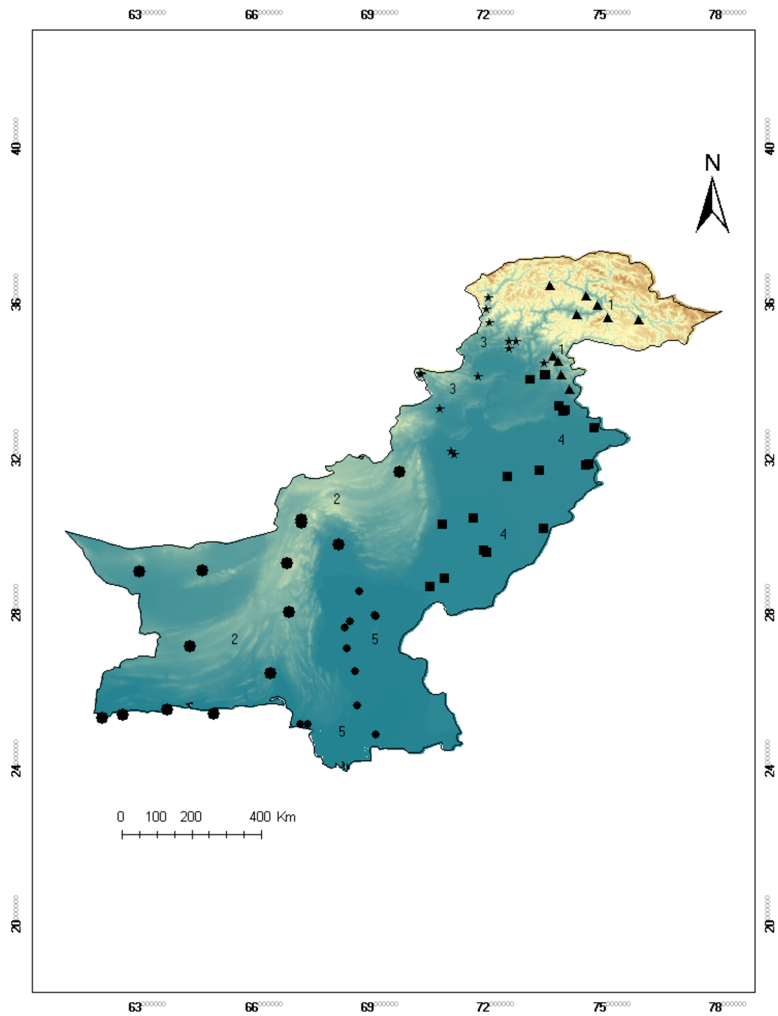

Figure 2: Distribution of station network and five regions, the stations with the same symbol denote separate regions, 1: Gilgit-Baltistan and Azad Kashmir (GB-AK), 2: Balochistan 3: Khyber-Pakhtoonkhwa and Tribal Areas (KP-TA), 4: Punjab, 5: Sindh.

The monthly means temperature of January comprised of 46 months were operated as continuous time series over the period of 1961 to 2006. The following approach has been adopted to perform the analysis,

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

The above equation establishes linear regression between, the time series ti, and climate variable xi (temperature) for the specified study time period.

Considering ti as independent and xi dependent variable, regression coefficient 'b' and the regression constant 'a' of least-squares estimation have been calculated respectively by using the following relations.

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

Results and Discussion

Decadal trend of January temperature anomalies and their spatial distribution

The decadal average temperature of January is mapped in the left column of Figure 3 which configures the spatial distribution of temperature and shift of isotherms in different decades. The slight intrusion of 18oC, 15oC, 12oC, 9oC and 6oC isotherms towards north and northwest since 1961 in different decades is evident of decadal variation in January temperature. Therefore, the detail of observed decadal January temperature anomalous trend and their spatial distribution is shown in the right column of Figure 3. It is imperative to note that the observed temperature anomalies are classified with the help of Table 1 to make the discussion systematic. The terms mild positive, high, higher, highest, mild negative, low, lower and lowest are defined in the Table 1 which denote the range of temperature anomalies with their respective temperature values. Therefore, the results interpretation in this section 3 is based on Figure 3 and Table 1. The Figure 3 marks the geographical distribution of anomalies while Table 1 denotes their values.

Table 1: Classification of observed temperature anomalies in the month of January from 1961-2006 (T represents temperature change)

positive temperature anomalies (o C)		**negative temperature anomalies (o C)**	
mild positive	$0.0 \leq \Delta T < 0.5$	mild negative	$-0.5 \leq \Delta T < 0.0$
high	$0.5 \leq \Delta T < 1.0$	low	$-1.0 \leq \Delta T < -0.5$
higher	$1.0 \leq \Delta T < 1.5$	lower	$-1.5 \leq \Delta T < -1.0$
highest	$\Delta T \geq 1.5$	lowest	$\Delta T < -1.5$

<u>The decade of 1960s</u>

In this decade, most of the study domain is under mild negative to lower temperature anomalies including most of Sindh, Punjab, Azad Kashmir and Balochistan except its southwestern part. Most of Khyber-Pakhtoonkhwa (KP) comes under mild positive temperature anomaly except its upper parts in Hindu Kush mountains, north of Peshawar valley. The Tribal Areas (TA) in the south west of Peshawar valley reflects high to higher temperature anomalies. The January temperature of Thar and Choolistan regions are indicative of mild positive anomaly. In the extreme northeast of the country in Himalayas and Karakoram mountains mild positive temperature anomaly persists.

<u>The Decade of 1970s</u>

In this decade, most of the country falls under negative temperature anomaly, acknowledges that the January temperature is below normal, and seems to be the cool among all the decades in the

study period. The anomalies from mild negative to lower category are dominant in January temperature throughout the decade. The two opposite poles of the country, the southwestern parts of Balochistan Plateau and northeastern rugged corner of the country in HKH show opposite characteristics with lower and mild positive temperature anomalies respectively. Responding to temperature variability in January, these two areas are found much susceptible throughout the decades of 1970s.

The decade of 1980s

The slight isothermal intrusion of 18oC, 15oC and 12oC towards north and northwest is clear indication of increasing average temperature. The spatial distribution of temperature anomalies also support, that the January temperature prevails above normal in the decade of 1980s. This is the opposite condition to that prevailed in 1970s. Higher temperature anomaly prevails in the TA centered over Parachinar and its surrounding. The same is true for the southwestern corner of Balochistan, moreover this corner of the country registers consistent warming trend except 1970s. In the decade of 1980, the anomalous temperature of January illustrates that temperature tendency stay between mild positive and high anomalous categories. Significantly, the northeastern corner of the country in the Himalayas-Karakoram has been shifted from mild positive to higher temperature anomaly as we proceed from 1970s to 1980s. The warming temperature in Himalayas could be the reason behind the high rate of glacial ablation as claimed by Working Group II in the Asian Chapter of IPCC (2007).

The decade of 1990s

The slight intrusion of isotherm further towards north is evident; especially one may observe the 15Co and 12Co isotherms and their eventual impact on the distribution of temperature anomaly. The subject anomaly is not as uniform over the country as it was in the decade of 1980s. From mild negative to lower temperature anomaly persists over Potwar Plateau in northern Punjab, AK and northeastern rugged territory of the country, TA, most of the KP except its northwestern parts in Hindu Kush mountains where mild positive anomaly prevails. Moreover, western Balochistan reflects high temperature anomaly. The comparison of 1980s and 1990s shows, extensive spatial

distribution of mild positive temperature anomaly with patches of high and lower temperature anomalies in 1980s, and less extensive spatial distribution of mild positive temperature anomaly in

1990s. On the contrary, in 1990s more area is found under mild negative and lower temperature anomalous categories in comparison to 1980s.

The period from 2000-2006

This is the period marked by abrupt warming in certain localities. Most of the country comes under positive temperature anomalies in January observed with in the range of mild positive up to highest category. It is unprecedented warmest period in Pakistan and obviously complies with global warming. In this context, some pockets are much conspicuous like rugged terrain of western Balochistan with high and highest temperature anomalies including Chaghi and Quetta regions. It is alarming that the mild negative temperature anomaly of the previous decade is taken over by high and higher temperature anomalies in HKH, the region already subjected to high glacial melting. From low to lowest temperature anomalies exists over the TA. The localities of KP north of Peshawar valley are found with mild positive to higher anomalies explicates rising temperature tendency. The southwestern coastal areas of Sindh also exhibit the high and higher anomalies, this rapid increase in temperature may have link with unrestrained urban growth of Karachi and its proximity. Most of the Punjab north of 29oN latitude falls under mild negative anomaly, except its piedmonts along the Sulaiman Range, southern Punjab including Rahimyarkhan District and its surroundings.

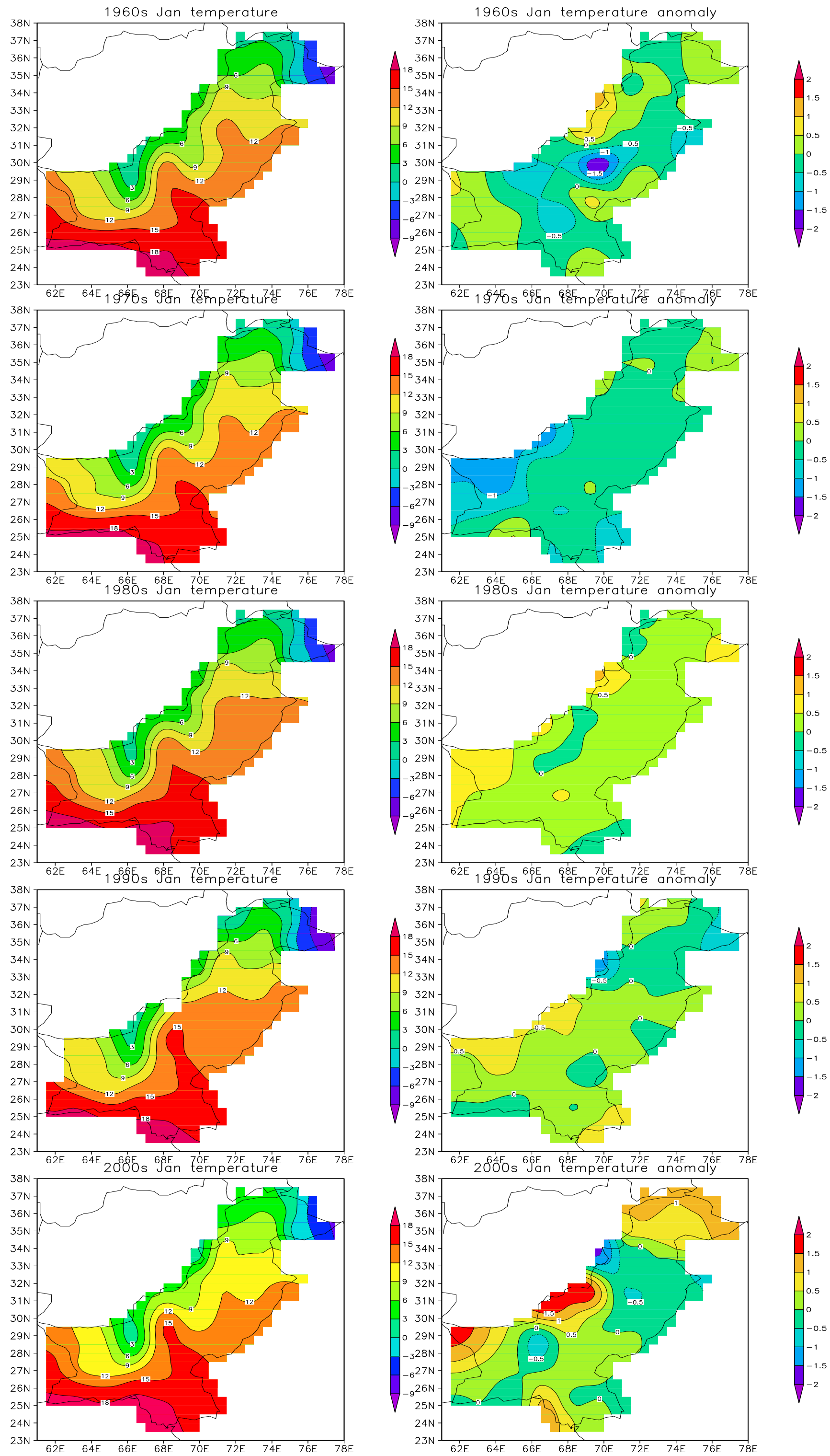

Figure 3: The decadal spatial distribution of January average temperature (left column) and spatial distribution of their respective temperature anomalies (right column) over the period of 1961-2006 (unit: o C).

Time series of January temperature and its characteristics at national level

Figure 4 shows the time series of January average temperature at national scale, its trend and 9-year running average over the study period. The ascending slope of the trend line acknowledges the temperature increase by 0.13℃/10 year. The interannual variability is the salient feature of January temperature in Pakistan it also reflects interdecadal signal of temperature change.

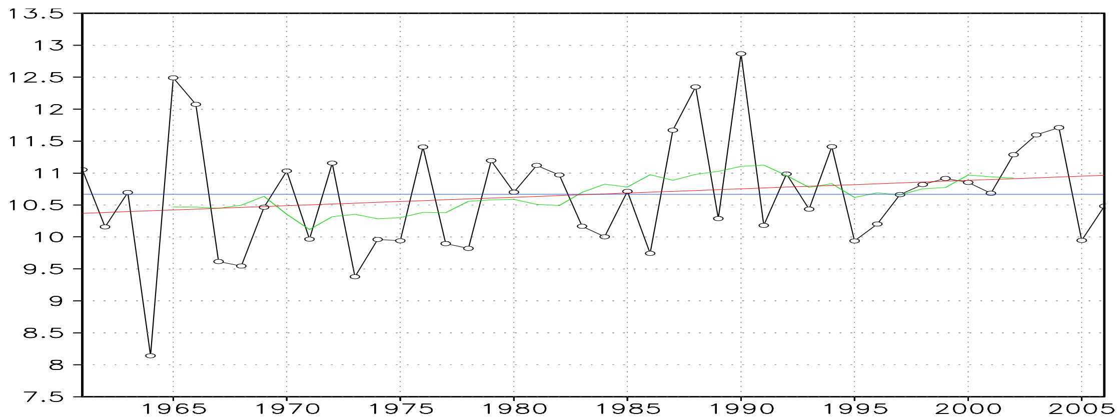

Figure 4: Time series of Pakistan January temperature (unit: o C) over the period of 1961-2006. Spiky line shows January averages in each year and reflects interannual variability. Horizontal line denotes average temperature of the 46 January months over the study period, sloped line shows temperature trend, and curved line reflects 9-year running average which mark the cool and warm temperature phases

The 9-year running average mark the cool and warm phases which shows that January temperature transforms from below average to above average in early 1980s. That further manifests cool January up to early 1980s which becomes warmer onward. The warmest period occurs in 1980s, late 1990s and onward by the turn of the century. The trend line shows warming trend but can not show the temperature fluctuation as well as the spiky line shows interannual variability but can not mark clearly the warming and cooling episodes, therefore the warming and cooling episodes in the study period can be seen from 9-year running average smooth curve.

Spatial distribution of linear trend coefficient of January temperature at national level

The spatial distribution of linear trend coefficient of January temperature in Pakistan over the period of 1961-2006 is shown in Figure 5. Most of the country is taken over by the positive trend coefficient indicative of increasing January temperature. Extreme positive temperature trend coefficient prevails in northwestern Balochistan, Central Brahui Ranges and Kirthar Mountains. A pocket of high trend coefficient can also be seen over Chitral in northwestern parts of the country. The trend coefficient over piedmonts mostly shows transitional character that is neither very high nor very low. Whereas, still some patches of negative trends coefficient are observed in northern parts of Sindh, Potwar region, southern and southeastern parts of the Punjab. Extreme negative coefficient is found over the TA and contiguous southern KP. In January, it seems obvious from the above scenario that the spatial pattern of temperature trend coefficient embraces the impact of physical relief in the country. The rising tendency of temperature in the hilly areas of Pakistan is more pronounced than the plains except Safed Koh region where declining temperature trend is apparent in the month of January.

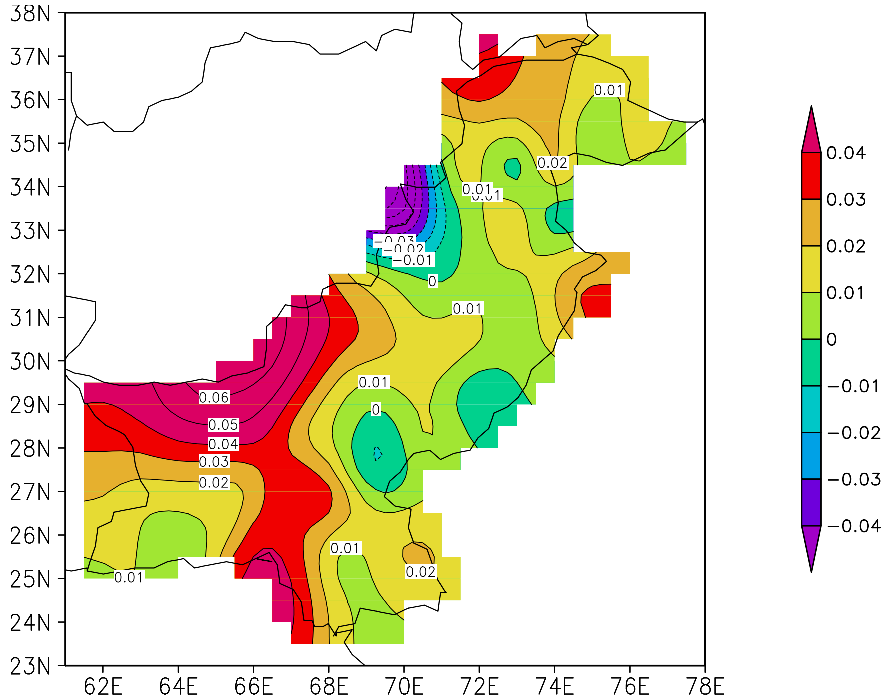

Figure 5: Spatial distribution of linear trend coefficient of January temperature in Pakistan over the period of 1961-2006 (unit: oC/year).

Regional characteristics of January temperature

Figure 6 demonstrates regional characteristics of January temperature. In GB-AK (Figure 6a), the January temperature has increasing trend with 0.10 oCo/10 year. The 9-year running average shows negative tendency in 1970s, and then onward running almost close to average temperature, but with little fluctuation up to the early 1990s, onward shows negative tendency in mid-1990s. Afterward, the tendency curve shifts to above normal with comparatively steep gradient and indicates rapid warming.

In Balochistan (Figure 6b), January temperature has warming trend of about 0.23oC/10 year. In the mid-1980s, the trend line shifts from below to above normal temperature. The cool phases occur in 1970s and 1990s, while 1980s and 2000s marks warm periods which indicates decadal variation. From the late 1970s to the mid-1980s as well as from the early 1990s and onward rapid warming tendencies are observed.

The KP-TA (Figure 6c) exceptionally shows negative temperature trend in January with -0.15℃/10 year. The interannual variability is larger in 1960s than any other decade. Like other regions, this also registers cooling phase in the 1970s. The 1980s are not as warm as other regions, however shows warming phase in the late-1980s and a cooling phase in the mid-1990s.

The Punjab (Figure 6d) has warming trend with a rate of about 0.06℃/10 year in January temperature. The warm period is measured from the mid-1980s to the mid-1990s. Dominated by plain topography, the Punjab Province does not record abrupt warming trend like some other parts of the country. The interannual variability is larger in 1960s. The interannual temperature variability is apparent but comparatively low than other regions, furthermore its range smoothes in the late 1990s and onward.

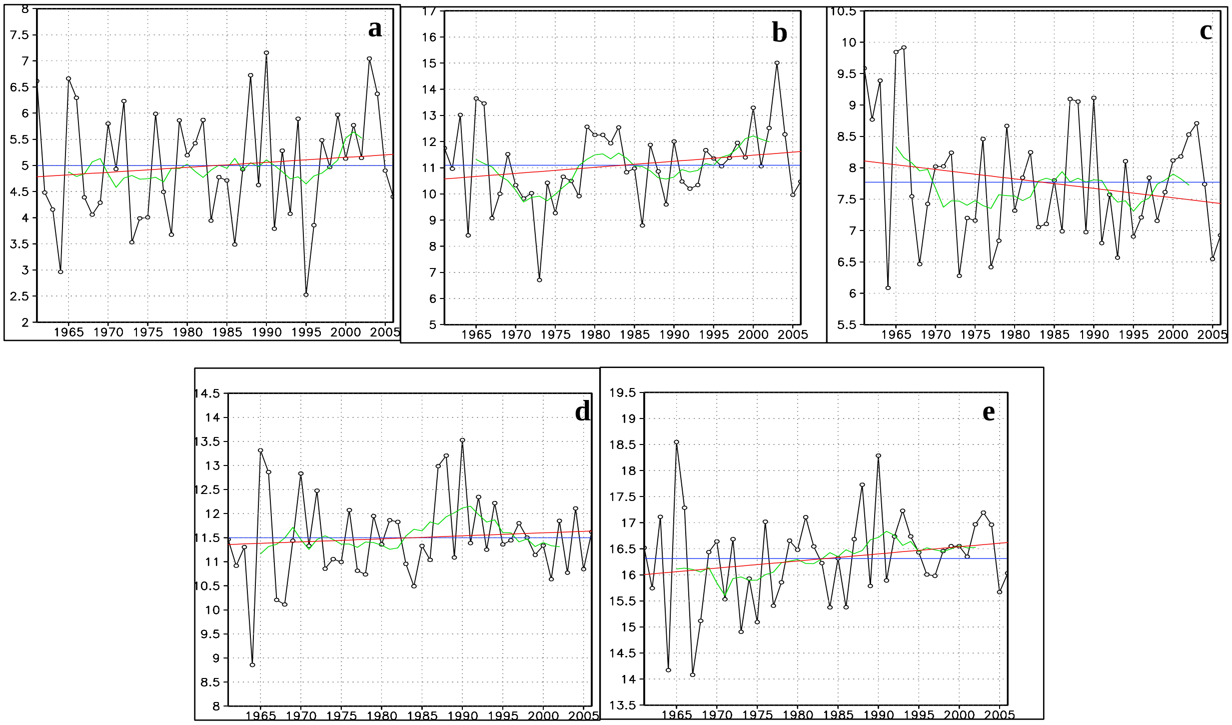

Figure 6: Regional time series of area-averaged January temperature over the period of 1961-2006.
The spiky line represents each year January averages which exhibit obvious interannual variability.
Horizontal line denotes January average temperature over the study period,
sloped line shows temperature trend and curved line reflects 9-year running average.
(a: GB-AK, b: Balochistan, c: KP-TA, d: Punjab and e: Sindh)

Sindh (Fig. 6e) is the southern most part of the country comprised of lowlands with comparatively high average temperature in January. The temperature trend line is steeper than Punjab, this region shows warming trend of about 0.16℃/10 year. The warming trend persists from the early 1980s to the early 2000s.

Change of temperature trend coefficient with different time scales at national and regional scales

The Figure 7 illustrates change in trend coefficient of January temperature at national level with different time scale. The distribution of trend coefficient depicts that in the first 25 years of the study period some considerable patches of negative signatures can be seen like in early 1970s, late 1980s and early 1990s. Positive coefficient is obvious and completely dominates above the first 25 years of the study period. Therefore, all over the study period, the distribution of trend coefficient supports that the study domain is dominated by positive temperature tendency.

Reference to Figure 8, the regional coefficient trend in January temperature has variable characteristics at regional level. The GB-AK (Fig. 8a) reveals unstable temperature tendency where the changing trend remains with in a range of 0-40 year timescale. However, as a whole this area is getting through warming trend in the month of January. In Balochistan (Fig. 8b) and Sindh (Fig 8e), the coefficient trend varies between positive and negative timescale of 0-25 years as well as remains positive above 25 years. In KP-TB (Fig. 8c), the trend coefficient in January temperature is quite unsteady. In this region, the tendency is negative in 1960s as well as in early 1970s at all time scales within the study period and becomes the only example of entirely negative trend coefficient area in 46 years of the study period. In Punjab (Fig. 8d), the positive and negative trend coefficient is distributed within the limit of 0-35 years and shows maximum variability within the limit of 0-25 years like other

regions. Negative tendency dominates between 0-25 years time scale in 1970s and early 1980s, while in the 1990s, and onward the negative values of trend coefficient remains overwhelmingly dominant within 0-35 year time scale. As a whole, the region is under positive tendency in the study period.

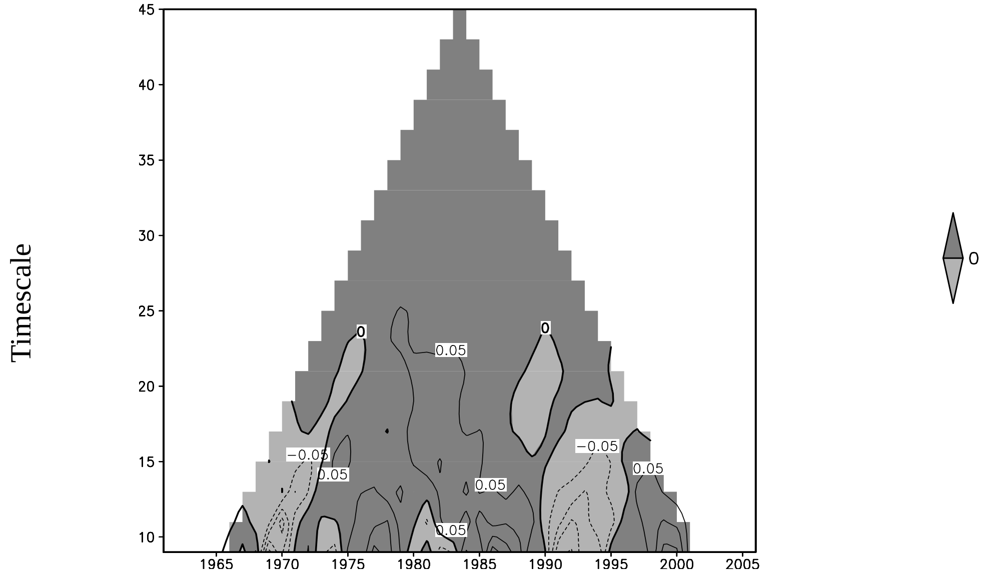

Figure 7: Trend Coefficient of January temperature in Pakistan with different timescale from 1961-2006 (unit: o C/year)

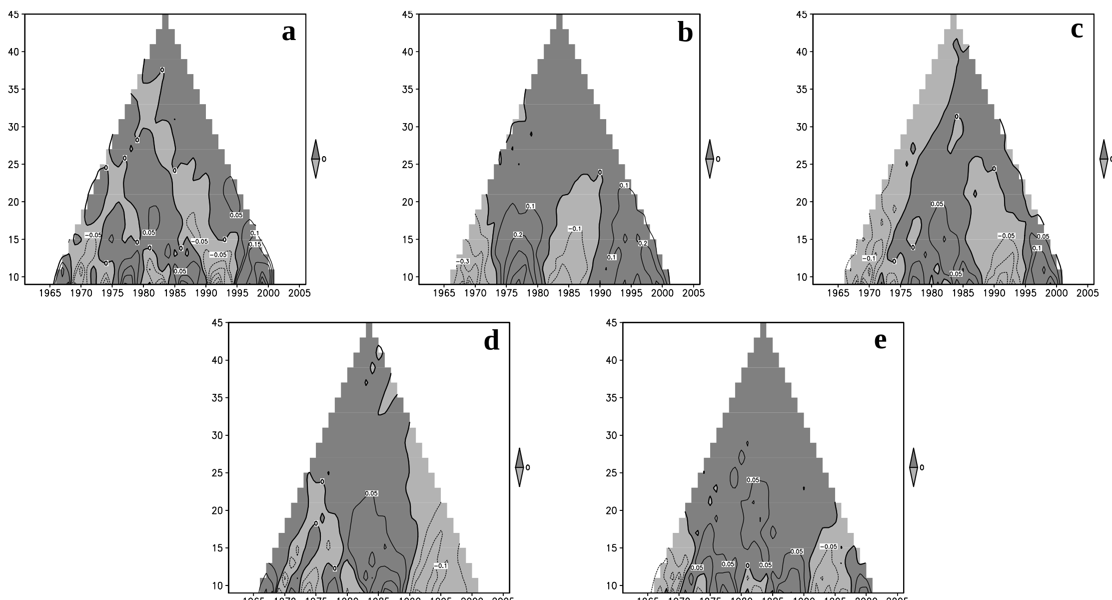

Figure 8: Trend coefficient of January temperature in five regions of Pakistan with different timescale (unit: o C/year) The trend coefficient varies from region to region with different time scale. In all five regions of Pakistan positive temperature coefficient dominates that indicates warming trend in the month of January. (a: Gligit-Baltistan and Azad Kashmir, b: Balochistan, c: KP-TA, d: Punjab and e: Sindh)

Conclusion and Discussion

Conclusion

In Pakistan, the change in January temperature over the study period varies from region to region, year to year and decade to decade. At national level about 0.6oC increase in January temperature is observed over the period of 1961-2006. The GB-AK, Balochistan, KP-TA, the Punjab and Sindh denote decadal temperature anomalies of 0.10oC, 0.23oC, -0.15oC, 0.06oC and 0.16oC, respectively. The 1970 is the only decade with predominantly below normal temperature anomaly that is $\Delta T \leq$-0.5oC. The southwestern part of Sindh centered over Karachi is found with higher temperature anomaly that may be because of urban heat island impact. In the last three decades, western parts of Balochistan Plateau including Chaghi and Quetta regions show extraordinary temperature anomalies between 0.5oC to 1.5oC in January that needs further investigations. Almost all regional time series reflects warming trend and the trend line shifts from below normal to above normal in the mid-1980s. Interannual variability is salient feature of all five regions. Comparatively, the interannual variability is larger in the 1960s. The rugged territories show much spiky and larger interannual temperature variability in January than plains of the country.

Discussion

The diversity in landforms is high from coastal belt up to northern HKH mountains in Pakistan, this can be judged by the height difference between Ormara station, the lowest observatory at the coast with 2 meters above mean sea level (msl) and Skardu station, the highest observatory in the northern lofty mountains with 2317 meters above msl. The high altitudes of the lofty mountains remain unattended because most of the available observatories are located at the bottom of the valleys in northern and western rugged parts of Pakistan, therefore these observatories may not be the true representative of the high altitudes. To shape the temperature of southern Pakistan, the frequency and intensity of cyclones in Arabian Sea could also be a contributing factor that needs further scientific inquiry. Most of the observatories are located in the cities which may not appropriately present the temperature of vast rural areas. At the same time, the role of urban heat island cannot be ignored in the study of temperature variation in Pakistan, where the rural way of life is being rapidly transferring into urban way life.

In January often, Pakistan remains under the highly variable westerly system and its ground level impacts exerted through western disturbances (WDs) (Syed et al. 2006). In Pakistan, the obvious warming trend in the winter months (Islam et al.2009) follows the global warming and rise in surface air temperature (Salinger, 2005) coupled with local urban heat island impact. For example, Karachi, the hub of economic activities in Pakistan has registered increase in the mean temperature by 2.25oC in the last 59 years (Sajjad, et al. 2009). However, the said increase in Karachi since national independence to 2005 seems very high. Apart of the above mentioned factors the role of other factors also exists which may increase (decrease) the warming of the near surface temperature like overgrazing, deforestation and desertification because these processes potentially can disrupt albedo (Charney, 1975).

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References

Afzal, M., 2008: Changes in Temperature and precipitation Trends over Pakistan. Proceedings of 6th APN Workshop, Seoul, Korea.

Afza1, M., M. A. Haroon., Chaudhary, Q.Z. 2009: Interdecadal Oscillations and the Warming Trend in the Area-Weighted Annual Mean Temperature of Pakistan. Pakistan Journal of Meteorology, 6 (11), 13-19

Chaudhry Q.Z. and G. Rasul, 2007: Global Warming and Expected snowline shift along Northern Mountains of Pakistan. Proceedings of 1st Asiaclic symposium, Yokohama, Japan.

Chaudhary, Q.Z. and G. Rasul 2004: Climatic Classification of Pakistan. Science Vision, Vol. 9 No. 1-2 (Jul-Dec, 2003) & No. 3-4 (Jan-Jun, 2004). Pp. 59-66.

Chaudhry, Q.Z. and Sheikh M. M., 2002: Climate Change and its Impact on the Water Resources of Mountain Regions of Pakistan, Pakistan Journal of Geography, Vol.11, & 12, No.172 June-December.

Charney, J. G., 1975 : Dynamics of deserts and drought in the Sahel. Quarterly Journal of the Royal Meteorological Society, 101, 179-172.

Cruz, V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Liand N. HuuNinh, 2007: Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. vanderLinden and C. E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp.471.

Hussain, S. S. and Mudasser, M., 2007: Prospects for wheat production under changing climate in mountain areas of Pakistan – An econometric analysis. Agricultural Systems Vol.94, No.2, pp. 494-501.

Islam, S., Rehman, N. and Sheikh, M. M., 2009: Future change in the frequency of warm and cold spells over Pakistan simulated by the PRECIS regional climate model, Climate Change, Springer Science + Business Media B.V. 2009, Published on line 17 Feb. 2009.

Khan T. M. A., Khan, F. A. and Jilani, R. 2008: Sea surface temperature variability along Pakistan coast and its relation to El Niño-Southern Oscillation. Journal of Basic and Applied Sciences 4(2), pp 67-72.

Kruss, P. O., K. A. Y .Khan, F. M. Q. Malik, M. Muslehuddin and A. Majeed 1992: Cooling over monsoonal Pakistan. Proceedings of 5th International Meeting on Statistical Climatology.Environment Canada, Toronto, pp 27.

Liu, X. and B. Chen. 2000: Climatic warming in the Tibetan Plateau during recent decades. International Journal of Climatology, 20. 1729-1742.

Magnuson, J. et al., 2000: Historical trends in lake and river ice cover in the Northern Hemisphere. Science, 289. 1743-1746.

Nicol, J. F., I. A. Raja., A. Allaudin., G. N. Jamy. 1999: Climatic variations in comfortable temperatures: the Pakistan projects. Energy and Buildings, 30, 261–279.

Rasul Ghulam, QIN Dahe, Chaudhry Q. Z. 2008: Global warming and melting glaciers along southern slopes of HKH Ranges; Pakistan Journal of Meteorology Vol.5, No.1, pp.63-76.

Sajjad S. H., et al. 2009: On rising temperature trends of Karachi in Pakistan. Climatic Change Vol.96, pp.539-547.

Salinger M. J. 2005: Guest editorial, increasing climate variability and change: reducing the vulnerability. Clim Change, 70, 1-3

Syed, F. S., Giorgi F., Pal, J. S. and King M. P. 2006: Effect of remote forcings on the winter precipitation of central southwest Asia part 1: observations, Theor. Appl. Climatol. 86:147-160.