Journal of Geoscience and Environment Protection, 2025, 13(5), 200-229
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Climatological Variability of Diurnal Temperature Range across Pakistan during Transitional Seasons and Its Link to Indian Ocean SST Anomalies (1980-2016)

Anas Farooq[1], Iqra Zainab[1], Hasnain Farooq[2], Aminu Dalhatu Datti[1,3], Hassnain Haider[4], Muhammad Asad Farooq[5], Khansa Amina[6]

[1]Department of Meteorology, School of Atmospheric Science, Nanjing University of Information Science and Technology, Nanjing, China
[2]School of Remote Sensing and Geomatics Engineering, Nanjing University of Information Science and Technology, Nanjing, China
[3]Nigerian Meteorological Agency (NiMet), Nnamdi Azikiwe International Airport, Abuja, Nigeria
[4]School of Ecology and Applied Meteorology, Nanjing University of Information Science and Technology, Nanjing, China
[5]School of Agricultural Science, University of Agriculture, Faisalabad (UAF), Faisalabad, Pakistan
[6]School of Environmental Sciences, University of Agriculture, Faisalabad (UAF), Faisalabad, Pakistan
Email: anasfarooq7061@outlook.com

How to cite this paper: Farooq, A., Zainab, I., Farooq, H., Datti, A. D., Haider, H., Farooq, M. A., & Amina, K. (2025). Climatological Variability of Diurnal Temperature Range across Pakistan during Transitional Seasons and Its Link to Indian Ocean SST Anomalies (1980-2016). *Journal of Geoscience and Environment Protection, 13,* 200-229.
https://doi.org/10.4236/gep.2025.135014

Received: April 24, 2025
Accepted: May 26, 2025
Published: May 29, 2025

Abstract

An investigation has been conducted on Diurnal Temperature Range (DTR) variations throughout Pakistan during spring (MAM) and autumn (SON) from 1980 to 2016 while exploring their relationship with Indian Ocean Sea Surface Temperature (SST) anomalies. Analysis of seasonal DTR patterns along with their atmospheric-oceanic drivers required the combination of temperature data (CRU TS4.08) with cloud cover (ERA5), SST anomalies (ERSST v5), and upper-level wind fields (NCEP/NCAR) through anomaly detection and Empirical Orthogonal Function (EOF) analysis and regression techniques. Research data indicates that southern Pakistan experiences higher DTR values than the northern regions primarily because of geographical features and atmospheric cover. The first EOF mode demonstrates its ability to account for 45.5% of the spring DTR dataset and 40.6% of autumn DTR values. Spring excessive SSTs registered in the western Arabian Sea produced an anti-correlated effect on daily temperature range by approximately −0.035 which reduced DTR by −1.2˚C for every ˚C rise in SST. The relationship between SST and DTR displayed weak but noticeable associations during autumn in 2010 and 2015 with r ≈ 0.011. The relationship between cloud cover and daily temperature range is clear in spring where the correlation reaches −0.72 and in autumn it shows moderate influence at −0.14. Indian Ocean SST anomalies play a substantial role in controlling Pakistan's seasonal thermal patterns through transitional periods thus providing essential knowledge for future climate predictions and sectoral operational planning.

Keywords

Diurnal Temperature Range, Sea Surface Temperature, Autumn, Spring, Indian Ocean, Seasonal Variability, Pakistan

1. Introduction

The Diurnal Temperature Range (DTR) represents the numerical difference between T_{max} and T_{min} temperatures which provides key information about surface energy management along with atmospheric conditions and land-alteration connections (Zhou et al., 2009a; Liu et al., 2016). In the context of climate variability and environmental change, DTR serves as a sensitive indicator of physical processes such as cloud dynamics, soil moisture fluxes, greenhouse gas concentrations, aerosol levels, and land-use transformations (Braganza et al., 2004; Lim et al., 2012; Xue et al., 2019). DTR variations have immediate impacts on the agricultural sector together with hydrological systems and ecosystem productivity and human wellness (Na et al., 2022; Yang et al., 2013).

The Diurnal Temperature Range in Pakistan presents significant temporal and spatial variations because of the country's different climatic regions extending from northern highlands with snow over extensive territories until the arid regions in the southern lowlands (Na et al., 2022; Zhai et al., 2022; Wang & Clow, 2020). The past decades have shown decreasing DTR patterns in South Asian regions due to faster T_{max} growth compared to T_{min} which led to reduced daytime temperature spans (Khan et al., 2019b; Vose et al., 2005).

The Pakistani territories demonstrate decreased DTR in their rural and urban zones as urban development grows while irrigation mechanics and deforestation progress (Sajjad et al., 2022; Nawaz et al., 2020; Zhang et al., 2009). The regional processes in Punjab and Sindh areas enhance T_{min} elevation combined with T_{max} reduction because of heavy agricultural development in these regions. The combination of land management methods with atmospheric feedback loops strengthens local and regional elements that affect DTR modification.

Analysts have dedicated research to exploring Daytime Temperature Range changes significantly in winter (DJF) with summer monsoon (JJA), but there is minimal investigation into the seasonal changes in spring (MAM) and autumn (SON) which manage vital surface and atmospheric operations. The rising solar insolation along with early convective activity strongly affects temperature extremes throughout central and northern Pakistan in MAM. SON is characterized by monsoon withdrawal and decreasing clouds together with strengthened radiative cooling that occurs primarily in the southern regions (Cao et al., 2022; Haider et al., 2014).

Researchers now acknowledge how Sea Surface Temperature (SST) anomalies in the Indian Ocean contribute to influencing regional temperature patterns. The Arabian Sea and western Indian Ocean SST anomalies shape atmospheric moisture availability as well as cloud formation and upper-level circulation patterns across Pakistan according to Shenoi et al. (2009), Ionita et al. (2012) and Hussain et al. (2023). The process of evaporation intensifies and cloud formation happens more frequently when Sea Surface Temperatures are warmer which leads to higher nighttime temperatures and less daytime heating. The interaction between these atmospheric phenomena leads to decreased DTR mostly during times of SST anomaly patterns like 1997-98 and 2010 according to Ullah et al. (2019) and Babaousmail et al. (2023).

A compounding effect occurs between SST anomalies alongside land-surface processes which especially affects DTR behavior in monsoon agricultural regions. The excessive irrigation along with surface wetting in southern Punjab and Sindh makes latent heat flux stronger which enhances humidity and cloud formation according to Shelton et al. (2022) and Hussain et al. (2023). The northern mountain areas experience clear atmospheric conditions as well as snow accumulations together with their high elevation creating conditions that strongly affect DTR responses to changes in upper-atmospheric circulation patterns (Haider et al., 2014; Nawaz et al., 2020).

The connection between changes in DTR extends to public health results as well as hydrological effects. Research has shown that extensive day-night temperature differences in DTR corresponds to greater health risks in rural residents inhabiting elevated regions (Zhai et al., 2022). The water supply together with agricultural productivity in water-stressed provinces including Baluchistan is affected by modifications to DTR because these changes impact moisture in the soil as well as evapotranspiration and glacier melt rates (Nawaz et al., 2019; Zhou et al., 2010).

2. Study Area and Methodology

2.1. Study Area

The research examines Diurnal Temperature Range (DTR) variability patterns across Pakistan during spring March-May (MAM) and autumn September-November (SON) seasons from 1980 up to 2016. Pakistan extends from 23.75˚N to 37.25˚N and from 60.75˚E to 76.75˚E covering regions that transition from moist mountainous northern terrain to dry plains alongside maritime coastal areas in the southern sections and southwestern parts. The diversity of Pakistan's geography creates an excellent context to investigate DTR variations that happen during spring and autumn while understanding their connections to seasonal patterns and oceanic changes.

March-May temperatures in northern and central Pakistan lead to increasing solar radiation and rising surface temperatures with initial convective activity emerging throughout the period. Southern Pakistan warms up during the premonsoon season because of accumulating moisture and increased latent heat processes. The southern and western areas of Pakistan experience clear skies throughout SON (September-November) that results in intensified radiative cooling because of reducing post-monsoonal humidity. The climatic sensitivity together with land-atmosphere energy balance and ocean-atmosphere coupling through DTR variability requires analysis during MAM and SON because of seasonal effects which include spring radiation rise and autumn nighttime cooling.

Figure 1 shows Pakistan experiences varying daytime to nighttime temperature differences according to spatial location. Favorable conditions of clear skies along with low humidity led to higher DTR readings within the southern and central regions of Pakistan which reach their peaks in Sindh Province along with southern Punjab Province and eastern Baluchistan. The regions characterized by lower DTR levels exist in the northern highlands because snowfall layers together with mountaintop elevations limit daytime temperature increases while maintaining nighttime chill by increasing thermal storage.

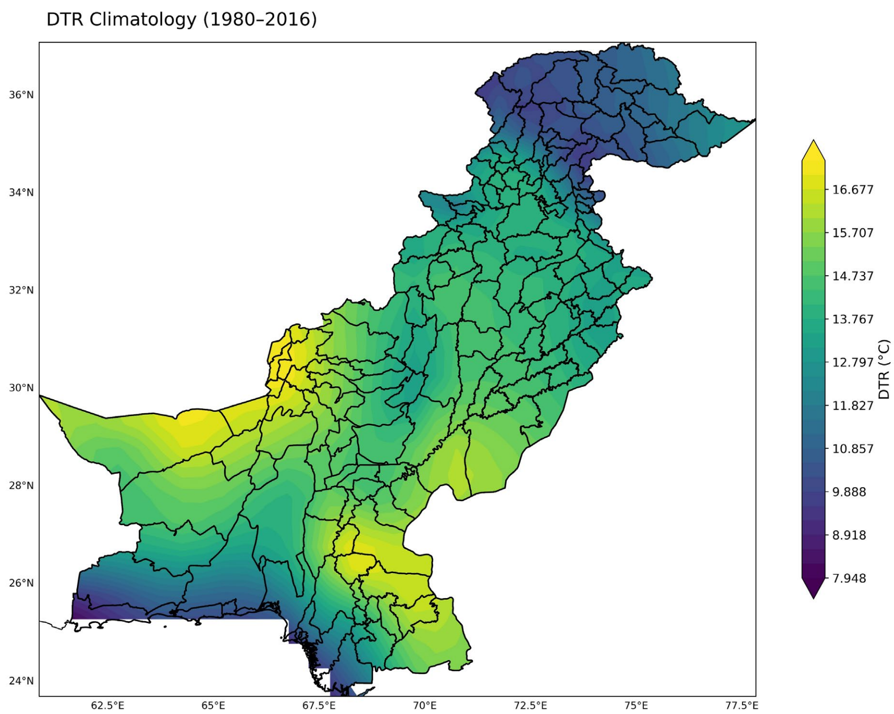

Figure 1. Climatological average of Diurnal Temperature Range (DTR) in Pakistan (1980-2016), showing higher values in the southern and central regions and lower values in the northern highlands. This map also represents the spatial extent of the study area analyzed in this research.

Temperature changes in MAM and SON result mainly from pre-monsoonal heating followed by post-monsoon radiative cooling across the regions.

2.2. Data Sources and Processing

The main data sources and methods applied in this study appear in Table 1. The research drew its key climate variables from established worldwide datasets through the 1980-2016 period and included DTR alongside cloud cover and SST anomalies and upper-tropospheric winds which had spatial resolutions between 0.25˚ and 2.5˚. The CRU TS4.08 dataset analyzed daily T_{max} and T_{min} data to compute DTR anomalies alongside high-resolution cloud fraction measurements from ERA5 reanalysis data. Analysis of Indian Ocean oceanic variability and atmospheric circulation patterns used SST anomalies from NOAA ERSST v5 alongside zonal wind data from NCEP/NCAR reanalysis. The analysis involved removing outliers through HOMER v2.6 while applying quantile mapping for bias correction and confirming data accuracy by comparing results to station records from Pakistani cities.

Table 1. Summary of datasets and methods used in the study.

Variable	Description	Resolution	Period	Source
Diurnal Temperature Range	Daily T_{max} and T_{min} used to compute DTR anomalies	0.5˚ × 0.5˚	1980-2016	CRU TS4.08
Total Cloud Cover	Cloud fraction data used to assess radiative influence	0.25˚ × 0.25˚	1980-2016	ERA5 Reanalysis
Sea Surface Temperature (SST)	Indian Ocean SST anomalies used in correlation analysis	2˚ × 2˚	1980-2016	NOAA ERSST v5
Upper-Tropospheric Wind (UV200)	Zonal wind data to evaluate circulation dynamics	~2.5˚	1980-2016	NCEP/NCAR Reanalysis

2.3. Methodology

A period analysis of Diurnal Temperature Range (DTR) changes occurred throughout Pakistan during spring (MAM) and autumn (SON) transitional seasons between 1980 and 2016. The study used CRU TS4.08 dataset at 0.5˚ × 0.5˚ spatial resolution to obtain gridded temperature data for T_{max} and T_{min} (Harris et al., 2020). The study obtained Indian Ocean sea surface temperature (SST) anomalies through retrieval from NOAA ERSST.v5 (Liu et al., 2021). Total cloud cover data were obtained through the ERA5 reanalysis at 0.25˚ × 0.25˚ resolution (Hersbach et al., 2020) while upper-tropospheric zonal winds (200 hPa) originated from NCEP/NCAR reanalysis (Kalnay et al., 1996).

Data quality assurance involved removing all observations beyond ±3σ from all datasets before inspecting them visually. An observational validation process took place using surface station data monitored in Lahore, Multan, Peshawar, and Quetta which followed the methods described in Haider et al. (2021) and Hussain et al. (2021). The HOMER v2.6 software performed dataset homogenization followed by quantile mapping for gridded dataset correction against observed station values according to Sajjad et al. (2022) and Zhou et al. (2010).

DTR Anomaly Calculation

To capture deviations from the seasonal climatological baseline, DTR anomalies were calculated using:

$$\mathrm{DTR}'_{i,j,t} = \mathrm{DTR}_{i,j,t} - \overline{\mathrm{DTR}}_{i,j} \tag{1}$$

where $\mathrm{DTR}_{i,j,t}$ is the DTR at grid point i, j and year t, and $\overline{\mathrm{DTR}}_{i,j}$ is the climatological mean for the 1981-2010 base period.

This equation helps identify interannual anomalies in the DTR field during MAM and SON.

Seasonal Mean DTR

Seasonal means were calculated to evaluate spatiotemporal trends as follows:

$$\overline{\mathrm{DTR}}_{\mathrm{season}} = \frac{1}{N}\sum_{t=1}^{N}\mathrm{DTR}_t \tag{2}$$

where N represents the number of years in the dataset for each transitional season. This allowed for comparisons of seasonal means across decades.

Empirical Orthogonal Function (EOF) Analysis

To detect dominant spatial modes and their associated temporal behavior, EOF analysis was applied to DTR anomalies using:

$$X(i,t) = \sum_{k=1}^{K} PC_k(t).\mathrm{EOF}_k(i) \tag{3}$$

Here, $\mathrm{EOF}_k(i)$ are the spatial patterns (eigenvectors), and $PC_k(t)$ are the corresponding time series (principal components). This method revealed that: EOF-1 primarily reflects variability over the southern and central plains, closely linked to irrigation and cloud cover (Ionita et al., 2012; Sajjad et al., 2022).

Regression Analysis

To quantify the influence of SST anomalies and upper-tropospheric dynamics on DTR, linear regression models were used:

$$\mathrm{DTR}_t = \alpha + \beta \cdot \mathrm{SST}_t + \varepsilon_t \tag{4a}$$

and

$$\mathrm{DTR}_t = \alpha + \beta_1 \cdot \mathrm{SST}_t + 2 \cdot \mathrm{UV}_{200\mathrm{hPa},t}\varepsilon_t \tag{4b}$$

Where α is the intercept, β, β_1, β_2 are regression coefficients, ε_t is the residual error, SST_t represents Indian Ocean SST anomalies, and $\mathrm{UV}_{200\mathrm{hPa},t}$ denotes the zonal wind at 200 hPa.

These models allow the decomposition of thermodynamic and dynamic forcing mechanisms acting on DTR across both transitional seasons (Haider et al., 2014; Cao et al., 2022).

Correlation Analysis

The strength of association between DTR anomalies and climate drivers (e.g., SST, cloud cover) was measured using Pearson correlation:

$$r = \frac{\sum\left(\mathrm{DTR}_t - \mathrm{D\bar{T}R}\right)\left(X_t - \bar{X}\right)}{\sqrt{\sum\left(\mathrm{DTR}_t - \mathrm{D\bar{T}R}\right)^2 \cdot \sum\left(X_t - \bar{X}\right)^2}} \tag{5}$$

The computed coefficient determines the linear relationship between variables which include SST anomalies with regional DTR variations (Zhai et al., 2022; Shelton et al., 2022).

This framework consists of EOF analysis together with regression statistics and correlations and seasonal averaging to provide an all-encompassing evaluation of DTR seasonal patterns in Pakistan's MAM and SON periods and identify their relations with Indian Ocean Sea surface temperature anomalies and atmospheric dynamics.

3. Results and Discussion

3.1. Seasonal DTR Patterns: Spatial and Temporal Insights

3.1.1. Spring (MAM)

The spatial pattern of DTR in Pakistan during the spring months (MAM) from 1980 to 2016 is depicted in Figure 2. The southern Punjab and Sindh together with eastern Baluchistan hold the highest DTR values that surpass 17.5˚C. The combination of clear skies and low water content and minimal cloud cover at these locations craves high daytime temperature boosts leading to strong DTR readings. Regionally specific snowfall distribution and higher elevations lead to clear DTR value minimization across the northern highland's areas of Pakistan.

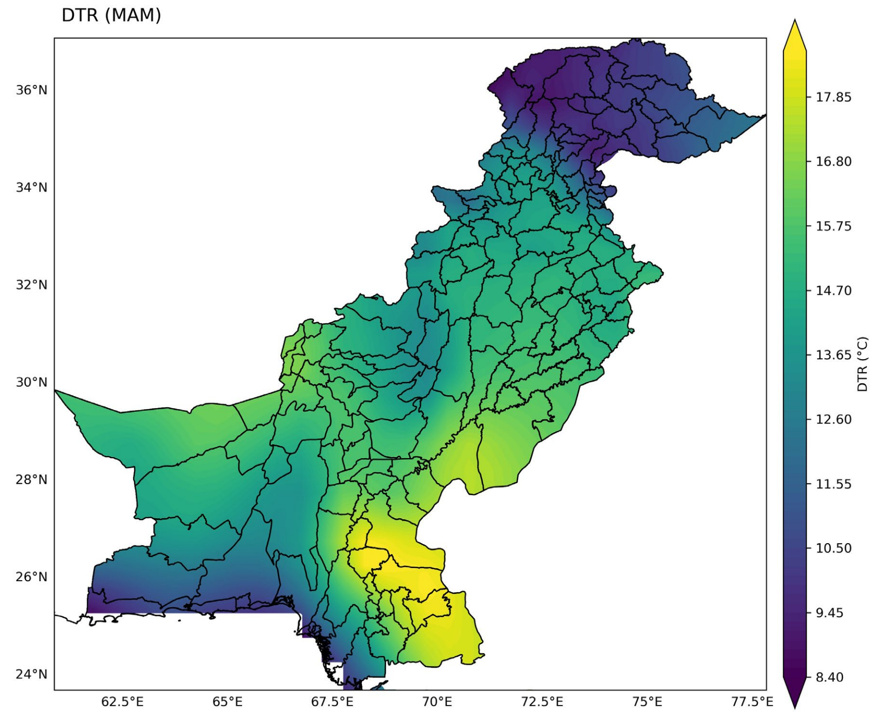

Figure 2. Climatological distribution of Diurnal Temperature Range (DTR) across Pakistan during spring (MAM) from 1980 to 2016. Higher values are observed in southern Punjab, Sindh, and eastern Baluchistan.

The study data supports the conclusions of (Makowski et al., 2008) who showed that areas in continental interiors with higher spring DTR values experience both increased solar radiation and drier atmospheric conditions. The analysis of cloud cover in ERA5 indicates that reduced MAM cloud fractions permit greater incoming shortwave radiation to raise daytime temperatures and reduce nighttime lows according to Cao et al. (2022) and Hussain et al. (2023).

The MAM temporal graphs in **Figure 3** reveal a positive anomaly period throughout the 1980s and alternating positive and negative patterns starting in the mid-1990s. The data indicates that 2001 along with 2005 displayed powerful positive anomalies yet the years 2013 and 2015 exhibited sizeable negative variations.

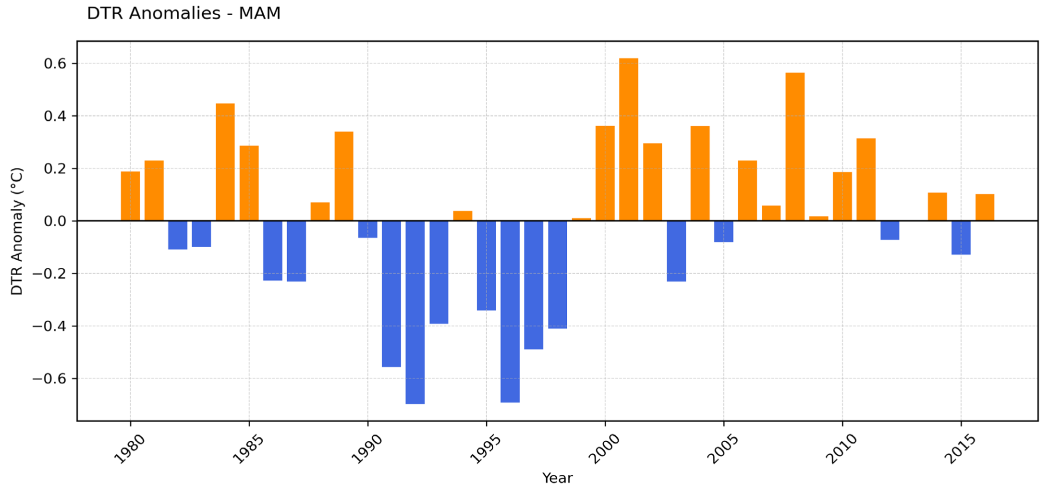

Figure 3. Annual anomalies of Diurnal Temperature Range (DTR) during spring (MAM) from 1980 to 2016. Positive anomalies dominate the early 2000s, while negative anomalies are frequent after 2010.

The researchers Haider et al. (2021) and Sajjad et al. (2022) established that growth in irrigation and urbanization and increased vegetation cover throughout Punjab areas during recent times is responsible for springtime DTR reductions. Climatic variables boost nighttime evaporative loss whereas strengthening humidity leads to reduced daily temperature difference between high and low points. Positive SST anomalies in western Indian Ocean and Arabian Sea regions enhance nighttime cloud warming and degrade daytime solar exposure thus reducing MAM DTR ranges according to Shenoi et al. (2009), Liu et al. (2021), and Ionita et al. (2012).

3.1.2. Autumn (SON)

The autumn season spatial climatology for DTR is shown in **Figure 4**. The southwestern and western areas of Pakistan extending to southern Baluchistan and Sindh maintain the highest DTR readings that reach almost 20˚C. The region experiences both powerful nighttime cooling in addition to day-long heating because clear skies combined with summer monsoon departure creates extremely strong radiative effects. Northern KP and Gilgit-Baltistan areas as well as the northeast region maintain minimal DTR values.

The increased radiative loss observed during SON matches previous reports by Haider et al. (2021) and Nawaz et al. (2019) who studied the development of increased radiative effects during this post-monsoon period especially in dry surface areas. After the monsoon season when the Arabian sea cools down oceanic humidity transfer becomes less frequent while skies remain clearer (Ullah et al., 2019; Hussain et al., 2023).

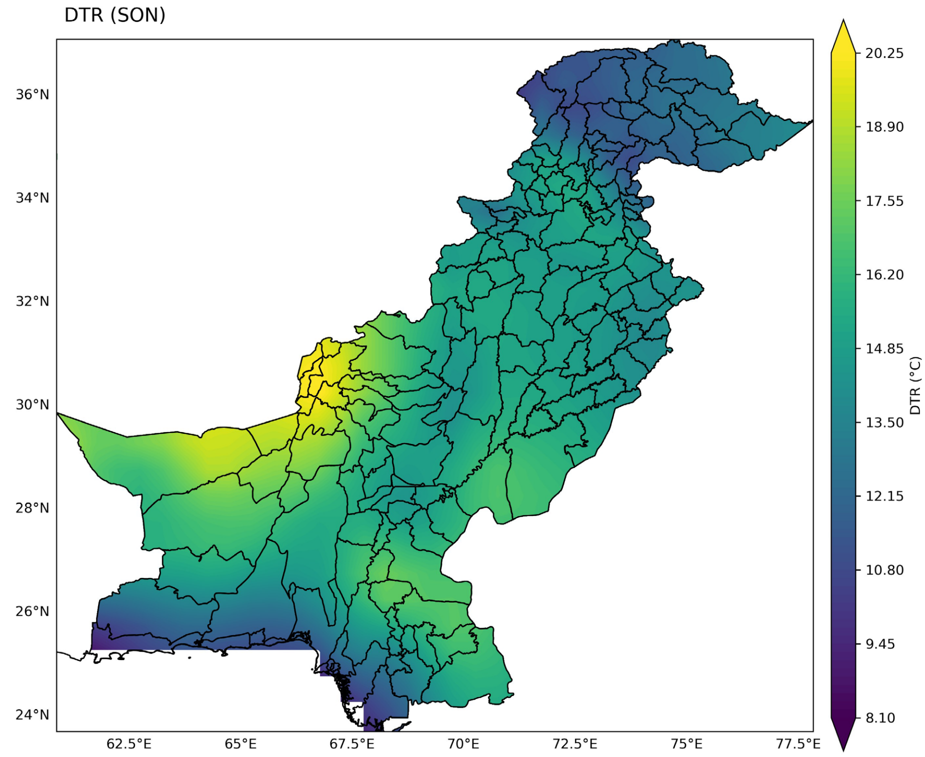

Figure 4. Climatological distribution of Diurnal Temperature Range (DTR) across Pakistan during autumn (SON) from 1980 to 2016. The highest values are found in southern Baluchistan and parts of Sindh.

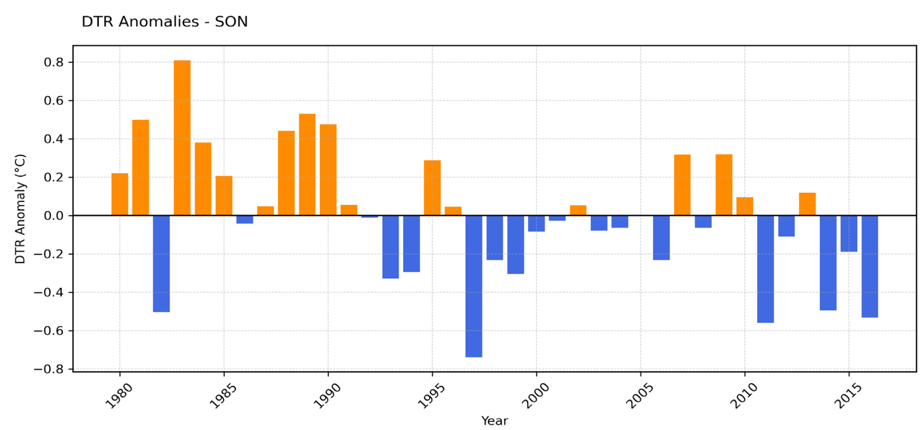

Figure 5. Annual anomalies of Diurnal Temperature Range (DTR) during autumn (SON) from 1980 to 2016. Positive anomalies occur mostly before 1995, while negative anomalies are more common after 2000.

The time series display for SON DTR anomalies appears in Figure 5. During the early 1980s as well as the late 1980s there were extended periods where radiative cycles performed strongly according to anomaly results. From the mid-1990s negative anomalies started appearing frequently and continuing persistently throughout 2010 until 2015 which corresponded to observed SST-induced moisture surges as well as urban surface modification.

DTR presents negative trends because positive SST anomalies in the equatorial Indian Ocean amplify atmospheric moisture alongside cloud cover during SON thereby reducing longwave night time radiation loss (Ionita et al., 2012; Shelton et al., 2022). Extreme SST events occurring in 1997-98, 2007, and 2010 seem to have intensified feedback effects according to Babaousmail et al. (2023) and Cao et al. (2022).

3.2. Influence of Cloud Cover Patterns on Seasonal DTR Changes in Pakistan

3.2.1. Spring (MAM)

The mean DTR during spring (MAM) reaches values above 17˚C in southern and central Pakistan through Sindh and southern Punjab and Baluchistan regions according to **Figure 6**. Stations in Turbat (17.17˚C) Jacobabad (17.35˚C) and Sibbi (17.47˚C) support these findings indicating dry air together with strong solar heating conditions and limited cloud cover result in enhanced daily temperature variations in their regions. Northwestern highland stations Gilgit, Abbottabad, and Islamabad experience substantial decreases in DTR values because they operate in cloudy conditions and elevated terrain and snowmelt processes occur there.

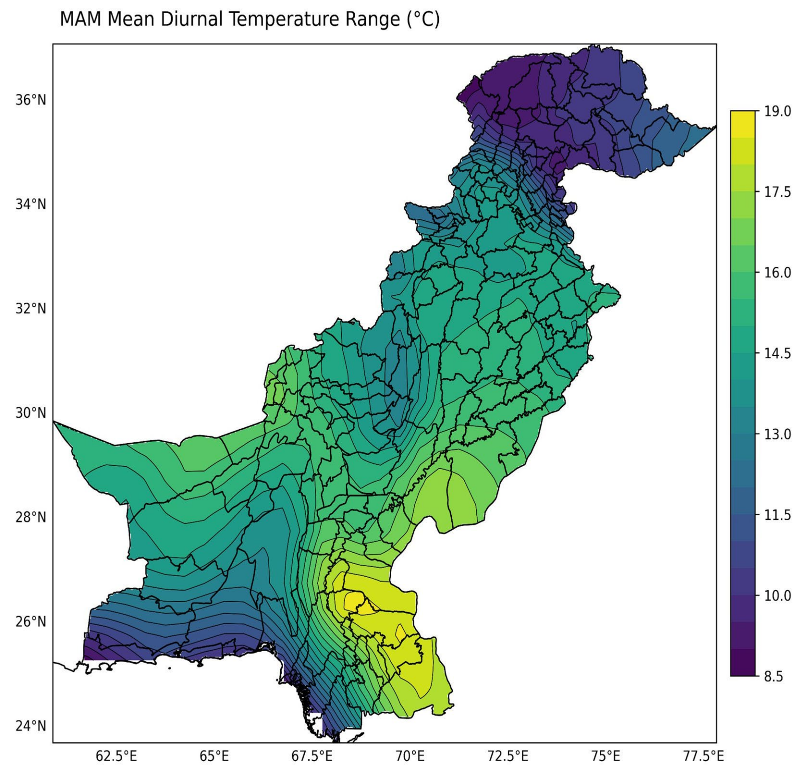

Figure 6. Spring mean diurnal temperature range (1980-2016).

The Total Cloud Cover measurements during MAM period are displayed in **Figure 7** in a spatial distribution. The analysis reveals excessive cloud cover exceeds 45% over northern Pakistan especially in Gilgit-Baltistan combined with specific locations in Khyber Pakhtunkhwa territories. TCC anomalies show a negative inverse correlation with DTR anomalies according to **Figure 8** which presents this relationship during the spring season. The negative Pearson correlation strength of −0.72 demonstrates that cloud cover plays the leading role in reducing daily temperature range during MAM. Clouds in the atmosphere absorb daylight rays during daytime while trapping thermal energy from the Earth during nighttime thus reducing daily temperature contrasts.

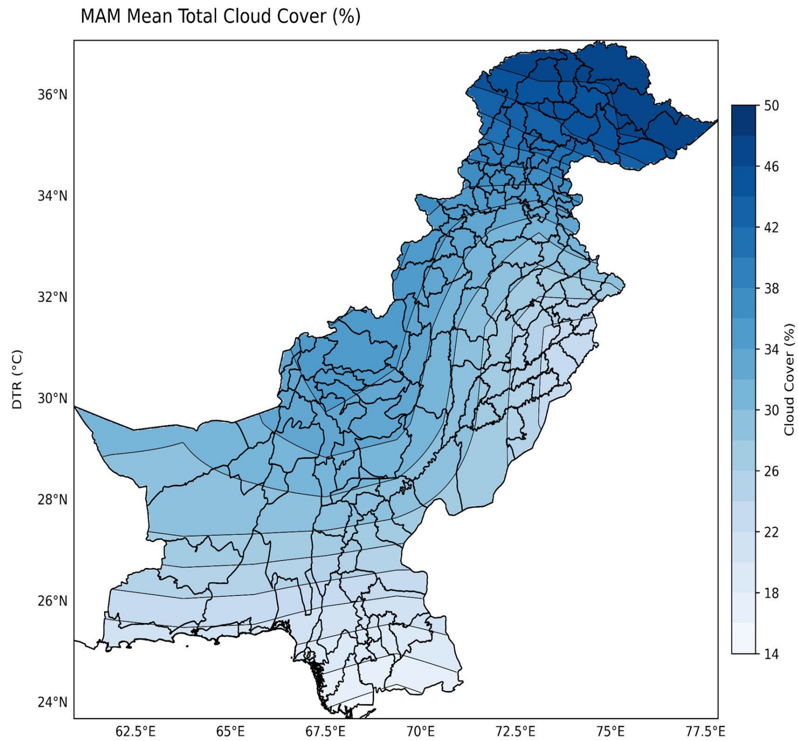

Figure 7. MAM mean total cloud (%).

The study confirms existing evidence presented by Sajjad et al. (2022) and Shen et al. (2014) about cloud-radiation mechanisms during seasonal transitions. Both surface radiation balancing and snow-cloud feedback processes caused the discernible differences in spring DTR patterns throughout Pakistan but particularly in northern regions.

3.2.2. Autumn (SON)

The figure shows DTR climatology data for summer season in **Figure 9**. The arid and semi-arid regions of southern Baluchistan and Sindh show elevated DTR values since Sibbi reaches 17.41˚C and Jacobabad reaches 17.10˚C. Smooth climatic conditions with drying trends combined with radiative heat loss become possible during post-monsoon periods in these regions. The post-monsoon temperatures in Sialkot and Lahore and Muzaffarabad range from 13.93˚C to 14.28˚C to 12.85˚C due to persistent residual humidity and cloud coverage in these regions.

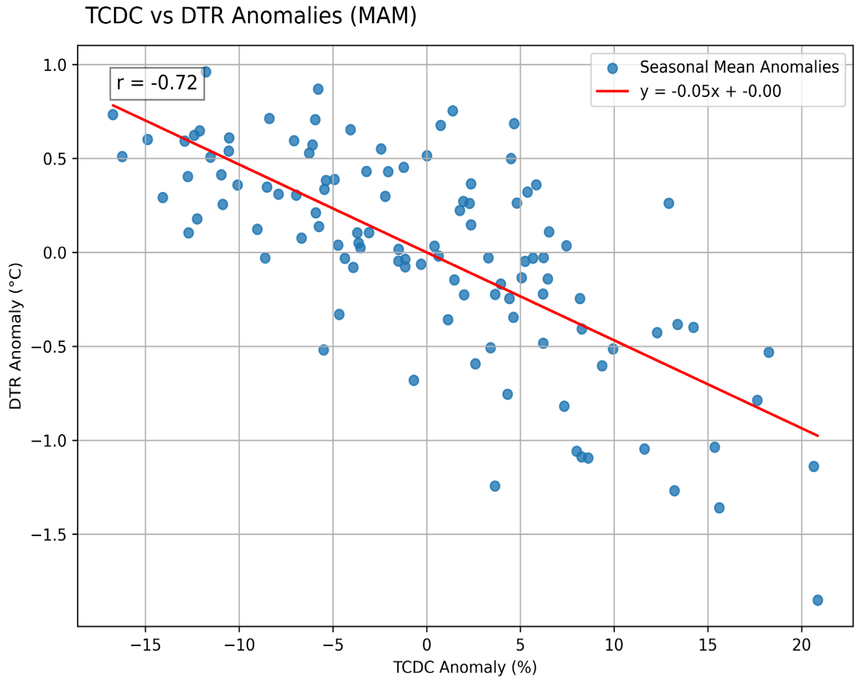

Figure 8. Scatter plot showing a strong negative correlation (r = −0.72) between TCC and DTR anomalies during spring (MAM), indicating cloud cover's suppressing effect on DTR.

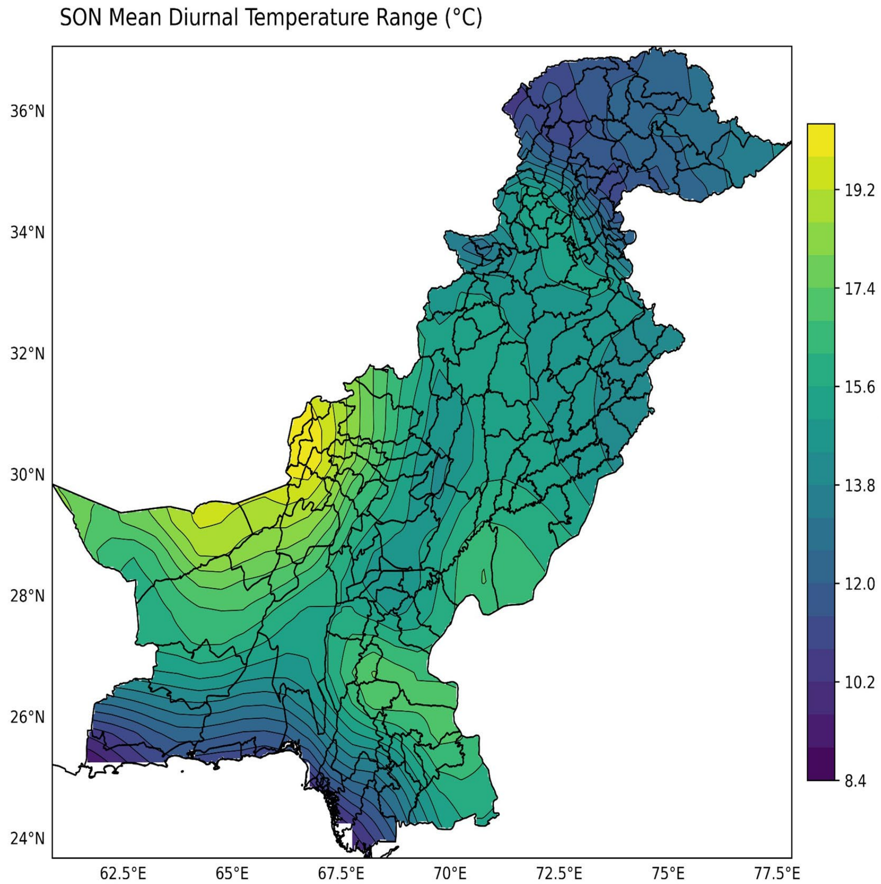

Figure 9. SON mean diurnal temperature range (˚C).

The northern regions of Pakistan maintain substantial mean cloud cover of 28 percent throughout the September to November period according to Figure 10. The cloudiness level remains lower in SON than MAM because the maximum TCC reaches only 31.5%. Monsoon atmospheric haze gradually disappears from various regions of Pakistan especially in elevations above sea level. Nevertheless, areas like Muzaffarabad and the upper Indus basin exhibit longer-lasting post-monsoon cloud presence.

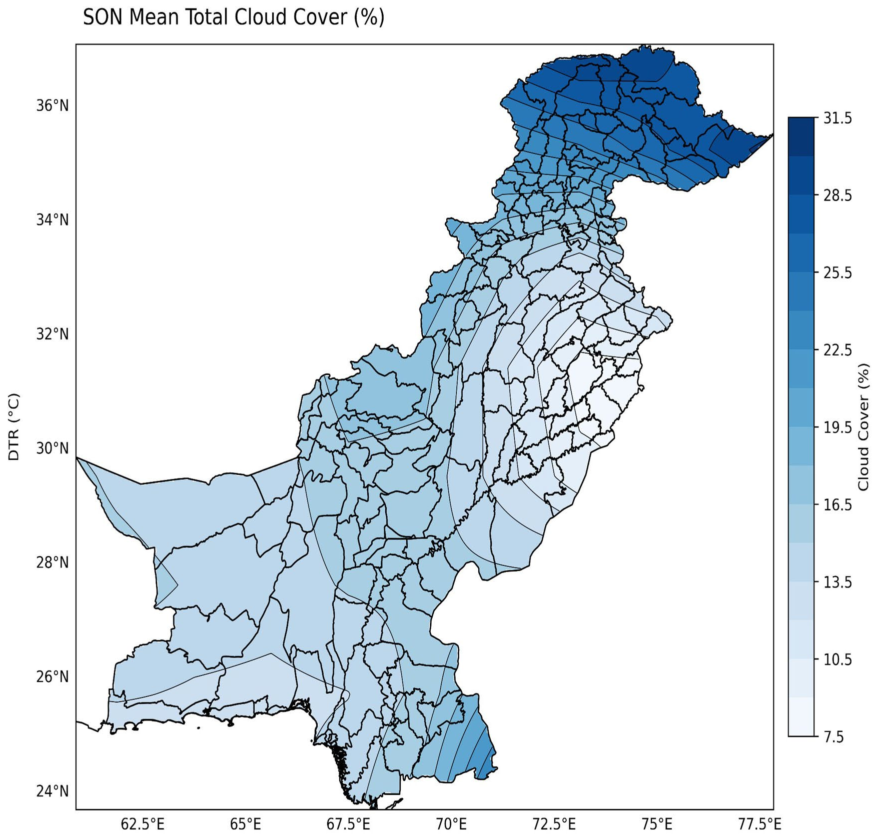

Figure 10. SON mean total cloud cover (%).

A connection between SON DTR anomalies and anomalies of TCC appears in Figure 11. During the post-monsoon season cloud cover influences daily temperature range less intensively as suggested by a weaker correlation value (r = −0.14). The combination of radiative effects involving humidity produces nighttime heating yet daytime illumination remains unaffected in the same way spring did. The mixture of urban heat retention with surface moisture and aerosol loading produces additional variability for autumn periods according to Zhou et al. (2009a) and Shen et al. (2014).

Research by Zhou et al. (2010) and Na et al. (2022) supports the weaker cloud-DTR relationship established in SON regarding transitional cloud condensation patterns within northern Pakistan.

Table 2 presents the main DTR and cloud cover patterns across Pakistan's MAM and SON transitional period between 1980 and 2016. Southern Punjab, Sindh, and eastern Balochistan maintain peak DTR measurements whereas northern areas comprising Gilgit, Abbottabad, and Islamabad exhibit the lowest measurements throughout MAM. During SON southern Sindh and Balochistan stand as high-DTR areas whereas northern KP and upper Indus maintain the lowest DTR ratings. Cloud cover exceeding 45% in MAM across northern areas displays a strong negative correlation with DTR (r = −0.72) indicating cloud-driven cooling impacts predominate. Counterpoint to this trend SON cloud cover descends to 28% - 31.5% within northern areas resulting in a diminished correlation between clouds and daily temperature range (r = −0.14). Each transition period shows different states because humidity conditions together with radiation feedbacks and heat retention affect regions distinctly.

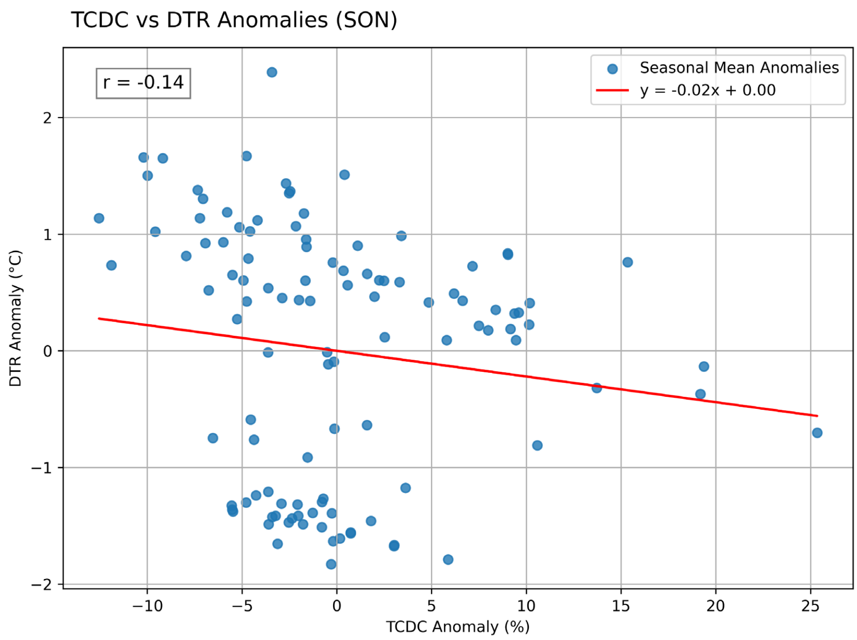

Figure 11. Scatter plot showing a weak negative correlation (r = −0.14) between TCC and DTR anomalies during autumn (SON), indicating a less significant cloud impact on DTR.

Table 2. Summary of DTR and cloud cover characteristics in Pakistan during transitional seasons (1980-2016).

Feature	Spring (MAM)	Autumn (SON)
Highest DTR Regions	Southern Punjab, Sindh, Eastern Balochistan	Southern Balochistan, Sindh
Lowest DTR Regions	Northern Highlands (Gilgit, Abbottabad, Islamabad)	Northern KP, Gilgit-Baltistan, Upper Indus Basin
Example High DTR Stations	Sibbi (17.47˚C), Jacobabad (17.35˚C), Turbat (17.17˚C)	Sibbi (17.41˚C), Jacobabad (17.10˚C)
Example Low DTR Stations	Gilgit (10.22˚C), Abbottabad (12.07˚C), Islamabad (13.62˚C)	Muzaffarabad (12.85˚C), Sialkot (13.93˚C), Lahore (14.28˚C)
Mean Cloud Cover (High Areas)	>45% in Northern Pakistan (Gilgit-Baltistan, KP)	~28% - 31.5% in northern areas
Correlation (TCC vs DTR)	Strong negative correlation (r = −0.72)	Weak negative correlation (r = −0.14)
Key Influencing Factors	Low humidity, clear skies, snowmelt, radiation feedbacks	Post-monsoon dryness, residual humidity, urban retention

3.3. Leading Modes of Diurnal Temperature Range Variability in Pakistan

3.3.1. Spring (MAM)

The leading Empirical Orthogonal Function (EOF1) of Diurnal Temperature Range (DTR) variability in spring (MAM) season over Pakistan explains 45.5% of the total variability as illustrated in **Figure 12**. The spatial pattern of DTR variability shows its greatest signals across Sindh and southern Punjab and Baluchistan regions at the center and south of Pakistan. The areas display extra sensitivity to DTR variations because of their combination of intense sunlight exposure combined with dry environmental factors and minimal cloud opacity resulting in significant temperature differences between daytime and nighttime periods (Makowski et al., 2008; Wang et al., 2014).

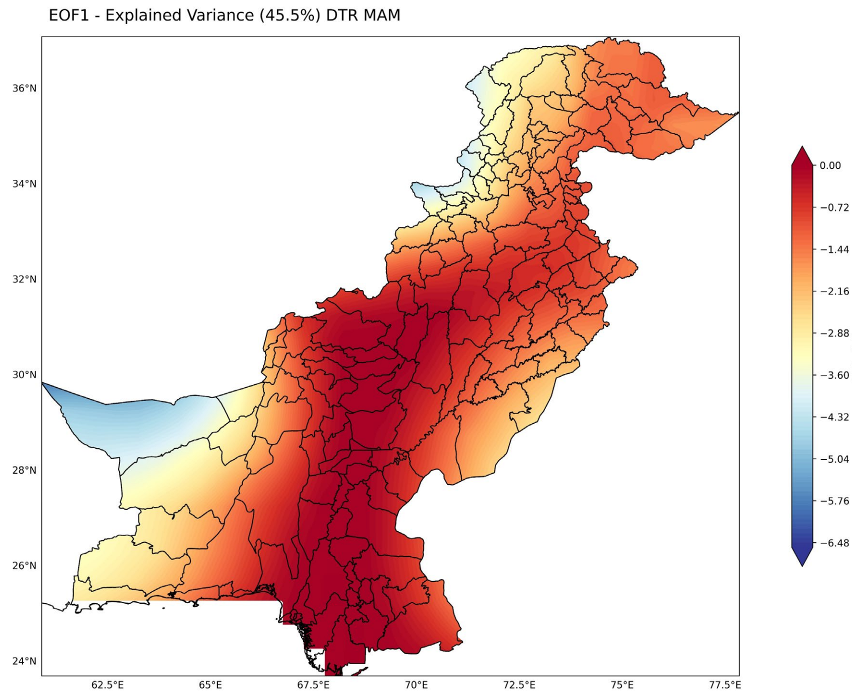

Figure 12. Spatial pattern of EOF1 mode of DTR variability during spring (MAM) in Pakistan, explaining 45.5% of total variance with highest variability across southern and central regions.

Northern Pakistan experienced minimal variability in the Diurnal Temperature Range because the region remains covered by cloud decks and exhibits high humidity and temperature fluctuations from snowmelt per (Shen et al. 2014; Sajjad et al. 2022). The elevation and the landscapes operate together as vital factors that minimize temperature variations across these areas.

A positive anomaly existed continuously throughout the early to late 1990s within **Figure 13** (PC1) and reached its peak in 1998 and 1999 which shows higher-than-average DTR during those times. Open skies together with dry atmospheric conditions created opportunities for increased daytime heating alongside reduced nighttime temperatures. Negative anomalies began to appear in significant numbers starting from 2003 until 2011 with emphasized occurrences in 2006 and 2011 that resulted in lowered DTR as a result of higher moisture conditions and atmospheric cloudiness possibly linked to human activities such as increasing urbanization and new irrigation systems.

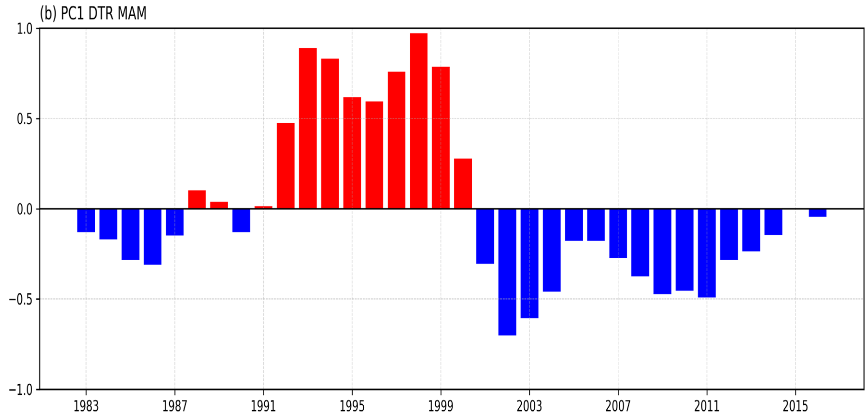

Figure 13. PC1 time series of MAM DTR variability, showing strong positive anomalies from 1995 to 2000 and persistent negative anomalies after 2003, reflecting seasonal radiative and surface feedback effects.

Analytical results published by Zhou et al. (2009b) and Hussain et al. (2023) back up the same argument that adjustments in surface radiation coupling with aerosol amounts and land use adjustments generate powerful impacts on DTR. Overall data from EOF1 mode validates that DTR variability in spring operates through two factors which include Pakistan's surface energy balance and climate feedback processes in southern regions.

3.3.2. Autumn (SON)

The leading EOF1 mode of DTR variability reaches 40.6% of the total variance during the autumn season according to **Figure 14**. The greatest spatial variability in Pakistan occurs when combined with Punjab, Sindh and lower Baluchistan so DTR changes result from post-monsoon radiative recovery as well as decreasing humidity and reduced cloud cover. The seasonal process creates larger daytime solar radiation and swift nighttime temperature decreases which strengthens the DTR signal in this geographic area (Khan et al., 2019b; Nawaz et al., 2020).

The EOF lobes in SON maintain lower values throughout Gilgit-Baltistan together with the upper portion of KP which indicates the regional post-monsoon adjustments to diurnal patterns remain subtle. Slower cloud dissipation and persistent moisture retention explain these findings in accordance with Shen et al. (2014).

From 1982 until 1992 PC1 exhibited positive anomalies which corresponded to intensified DTR conditions possibly because of strong daytime sun heating combined with clear skies (**Figure 15**). Negative anomalies prevailed through the late

1990s to 2015 in which 2002, 2012 and 2015 displayed significant drops relating to heightened minimum temperatures, increased relative humidity and greater cloud cover and their suppressive effect on DTR.

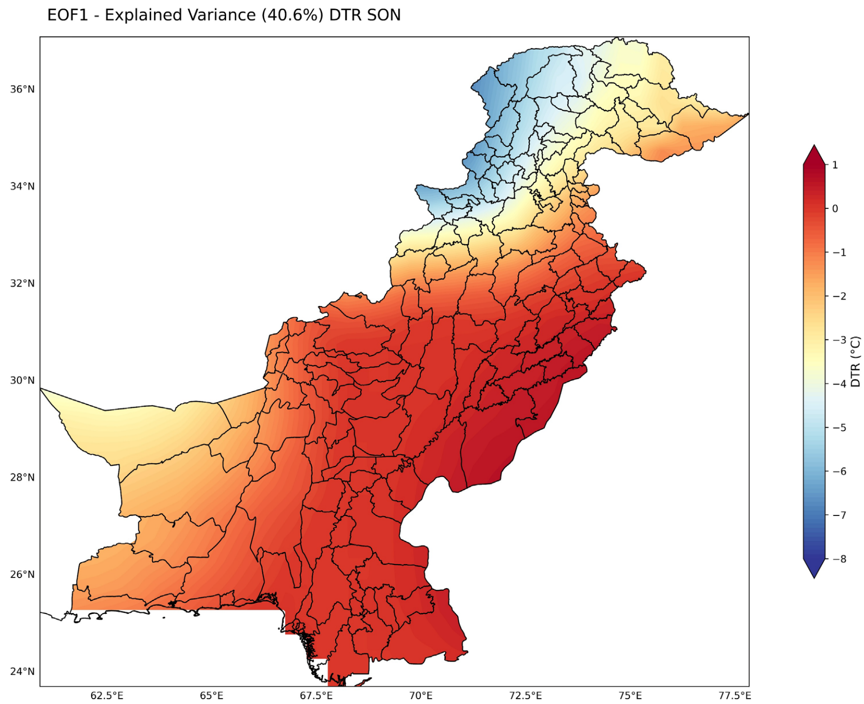

Figure 14. Spatial pattern of EOF1 mode of DTR variability during autumn (SON) in Pakistan, explaining 40.6% of total variance with maximum expression in central and southern regions.

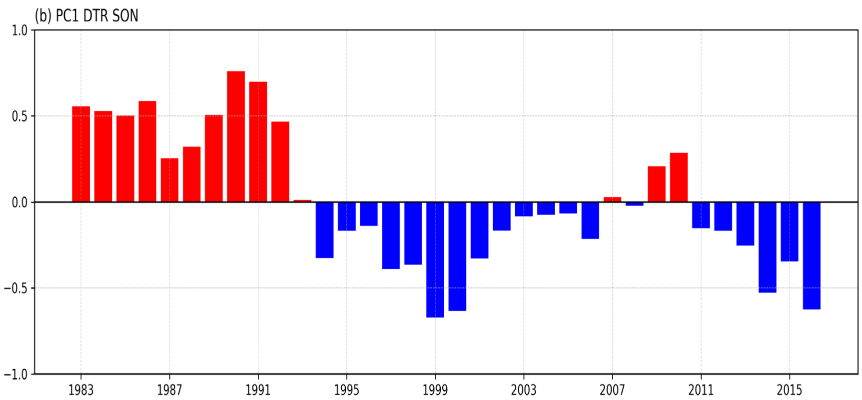

Figure 15. PC1 time series of SON DTR variability, highlighting enhanced DTR in the early 1980s and sustained suppression from mid-1990s to 2015 due to climatic and anthropogenic influences.

The research findings exhibit similar patterns to Ionita et al. (2012) and Babaousmail et al. (2023) who discovered SST anomalies and regional precipitation contribute to DTR suppression. Research from Sajjad et al. (2022) establishes urban growth coupled with Punjab irrigation as two principal factors that reduce nighttime temperature decreases alongside Zhou et al. (2009a) who demonstrate cloud-particular longwave radiation and land surface adjustments govern the changes in DTR.

Table 3 shows how Pakistan's autumn daily temperature range patterns result from monsoon withdrawal along with natural and anthropogenic land-atmosphere feedbacks particularly in northern plains and southern urban areas. EOF1-based DTR variability in the table demonstrates the spatial variation alongside dominant influencing components across both seasons.

Table 3. Summary of EOF1-based DTR variability across Pakistan during MAM and SON, showing variance, key regions, anomalies, and influencing factors.

Season	EOF1 Variance (%)	High Variability Regions	Low Variability Regions	Key PC1 Anomalies	Major Influencing Factors
MAM	45.5%	Sindh, Southern Punjab, Balochistan	Northern Pakistan (Gilgit-Baltistan, KP Highlands)	Positive in 1995-2000; Negative in 2003-2011	Clear skies, dry surface, low cloud cover; Urbanization, irrigation
SON	40.6%	Punjab, Sindh, Lower Balochistan	Gilgit-Baltistan, Upper KP	Positive in 1982-1992; Negative in 1998-2015	Post-monsoon radiative recovery, reduced humidity; SST anomalies, urban growth

3.4. Influence of Indian Ocean SST Anomalies on Seasonal DTR Patterns in Pakistan

3.4.1. Spring (MAM)

The Diurnal Temperature Range (DTR) across Pakistan experiences large changing patterns during March-May because of oceanic temperature variations throughout the western Indian Ocean with emphasis on the Arabian Sea region. The negative relationship between SST anomalies and temperature shown in Figure 16 displays strong association through regression coefficients reaching −1.2˚C per 1˚C SST midpoint change in the Arabian Sea near Oman and southeastern Yemen.

The upper-tropospheric wind vectors (UV at 200 hPa) show that humid air masses move northward into Sindh and southern Punjab and eastern Baluchistan since these regions demonstrate high sensitivity to DTR variations. According to Shenoi et al. (2009) and Na et al. (2022), elevated western Indian Ocean temperatures lead to enhanced monsoonal circulation in spring.

The SST hotspot displayed in Figure 16 encloses an area linked to Pakistan whereas dark spots in this figure illustrate SST-DTR relationships that have statistical significance throughout the country's southern territories. Storage areas of agriculture combined with semi-arid territory display close connections between surface energy-budget and radiative processes because of their spatial relations.

A positive phase of SST leads to increased cloud cover across the northern Arabian Sea according to Figure 17. Surface radiation levels decrease during daytime due to dense clouds while heat retention increases at night which leads to decreased DTR values. Scientific research conducted by Cao et al. (2022) together with Zhou et al. (2009a) demonstrates that cloud-mediated radiation trapping delivers its best results during transitional seasons.

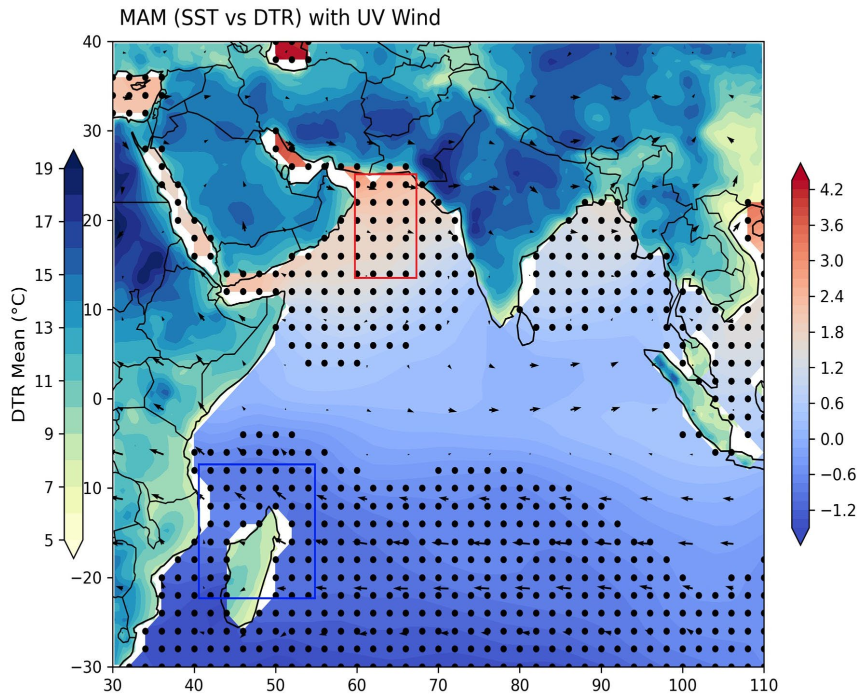

Figure 16. MAM (SST vs DTR) with UV wind.

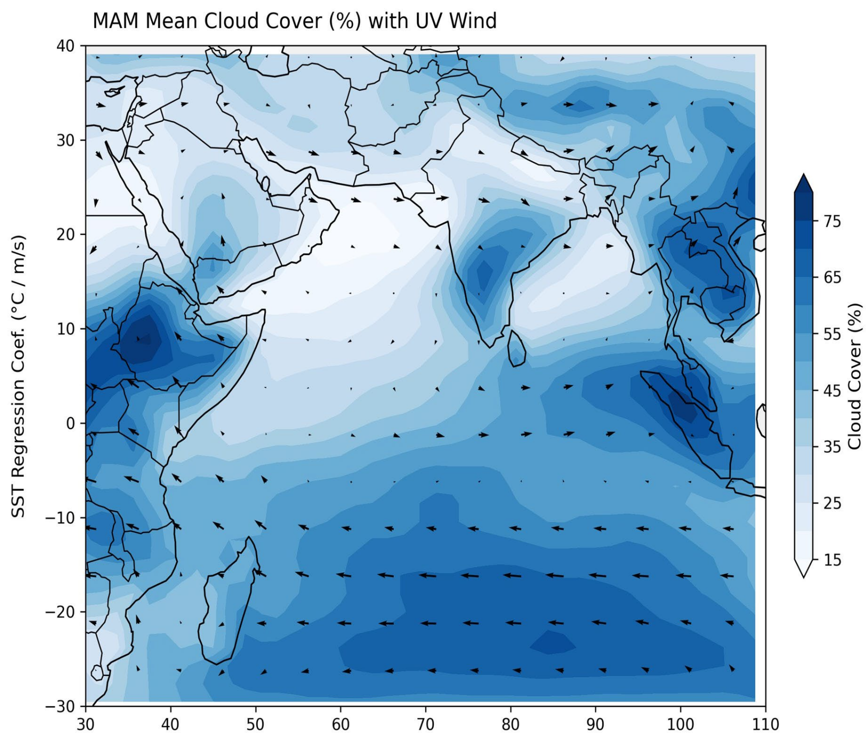

Figure 17. MAM mean cloud cover (%) with UV wind.

The data in Figure 18 shows major SST peaks causing swift reductions of DTR anomalies during 1998, 2005, and 2010 which backs up solar-mediated signal transmission from ocean to land areas. The correlation map in Figure 19 shows (r ≈ −0.035) spatial connection between these effects mainly in Sindh and southern Punjab although the strength of connection remains small overall.

The physical mechanism linking Indian Ocean SST anomalies to reduced diurnal temperature range (DTR) during spring (MAM) is explained in Figure 20.

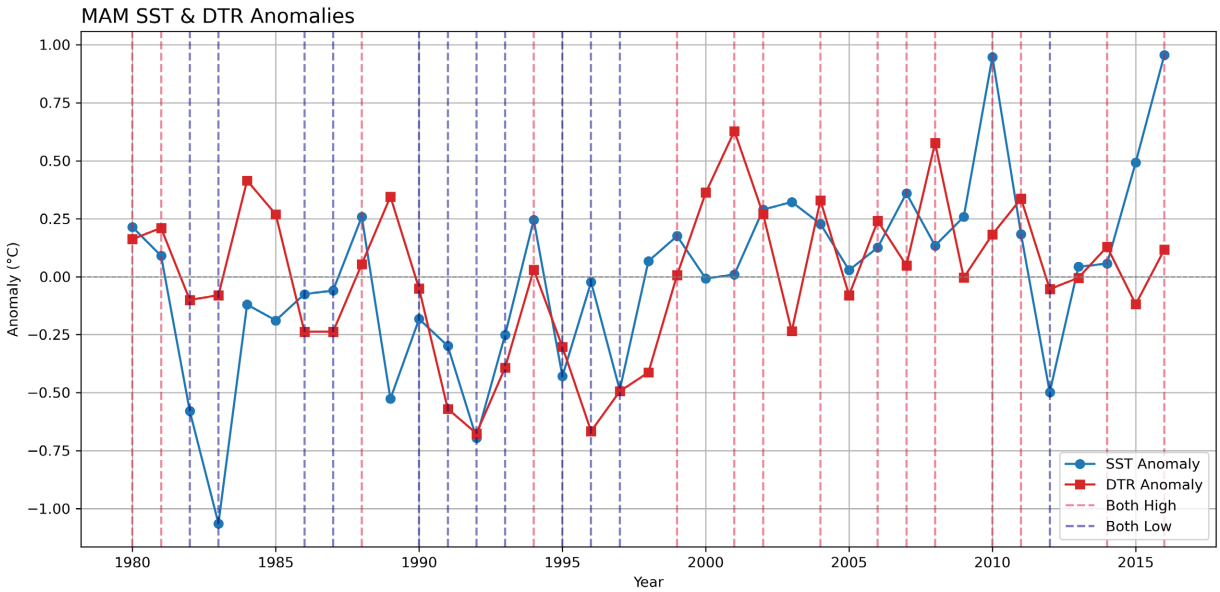

Figure 18. MAM time series of SST and DTR anomalies. Years 1998, 2005, and 2010 show high SSTs linked with reduced DTR.

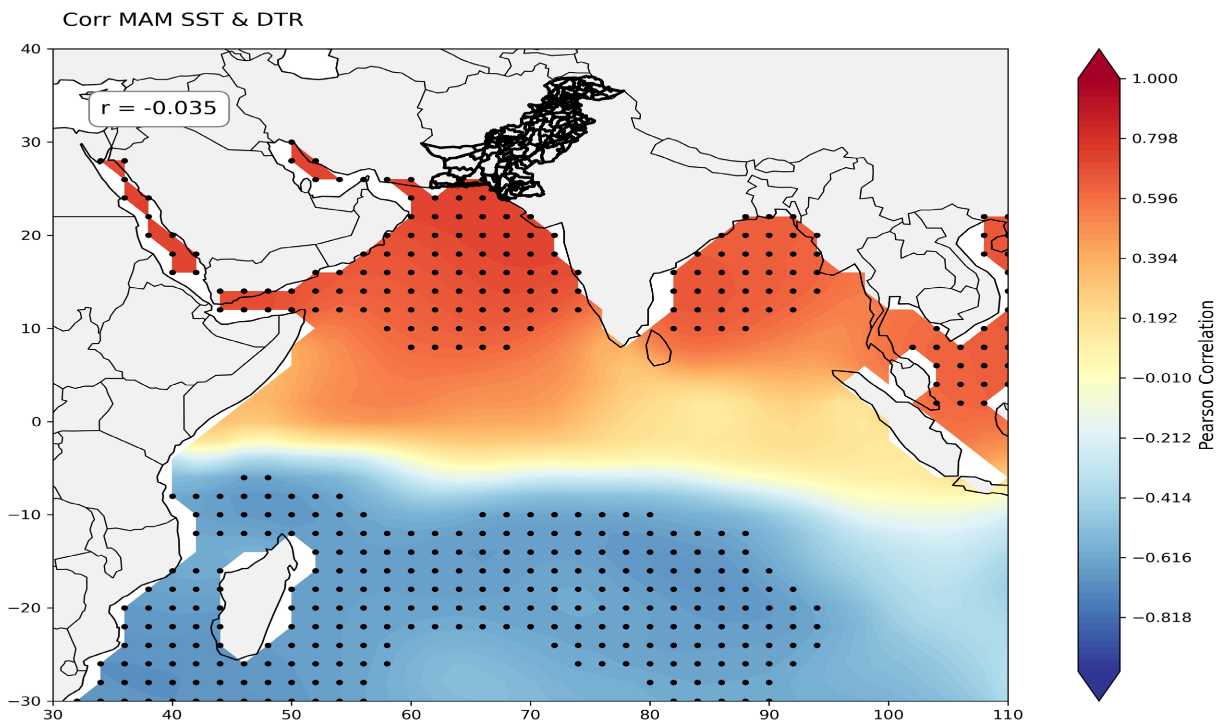

Figure 19. Correlation between MAM DTR and SSTs, with negative values concentrated near Pakistan's coastal zones. Black dots show significant areas.

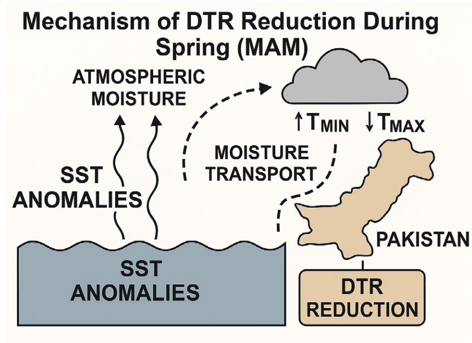

Figure 20. Mechanism of DTR reduction during spring (MAM). SST anomalies enhance atmospheric moisture and cloud formation over Pakistan, leading to increased T_{min} and decreased T_{max}, resulting in reduced DTR.

SST warming in the western Indian Ocean leads to greater evaporation which raises the amount of water vapor in the atmosphere. Strong zonal and meridional wind sections at the 850 hPa level bring moisture into Pakistan during the monsoon season according to our wind field composite analysis. The arriving humidity results in augmented cloud generation that affects the southern and central regions of Pakistan. Cloud cover functions as a radiative modifier because it lowers the daytime high temperature by blocking sunlight while it heats the nighttime low temperature through its trapping of longwave radiation thus decreasing the daily temperature range.

The observed results confirm previous academic findings. Research conducted by Nawaz et al. (2019) showed that areas below 2000 meters in Pakistan experienced pronounced T_{min} elevation from SST effects but Sajjad et al. (2022) verified that early spring cloud formation occurred during times of warm Indian Ocean conditions.

The data from our regression maps supports the findings which show direct correlations between SSTs and DTR and SSTs with cloud levels. The studies performed by Xue et al. (2019) and Manatsa et al. (2015) have heavily substantiated how cloud cover directly regulates DTR values because it changes daytime heat levels and nighttime heat differently.

An extensive analysis shows that ocean-atmosphere coupling at a climate scale influences DTR in Pakistan by sustaining high humidity and creating cloud feedbacks while transporting moisture through atmospheric winds.

3.4.2. Autumn (SON)

The relationship between India Ocean sea surface temperature anomalies and daily temperature range over Pakistan remains active during autumn months after monsoon withdrawal however the link weakens relative to the spring season.

Figure 21 reveals a remarkable negative SST-DTR link of −0.6 degrees Celsius for every Celsius change in sea surface temperature across the Indian Ocean equator especially within the Maldives zone and near Seychelles alongside the Sri Lanka to Madagascar area. The atmospheric flow from southeast to northwest brings moisture into Pakistan which mainly affects the western regions of Baluchistan and central Punjab together with upper Sindh. The areas experience continued exposure to moisture after the monsoon season that reduces daytime temperature drops.

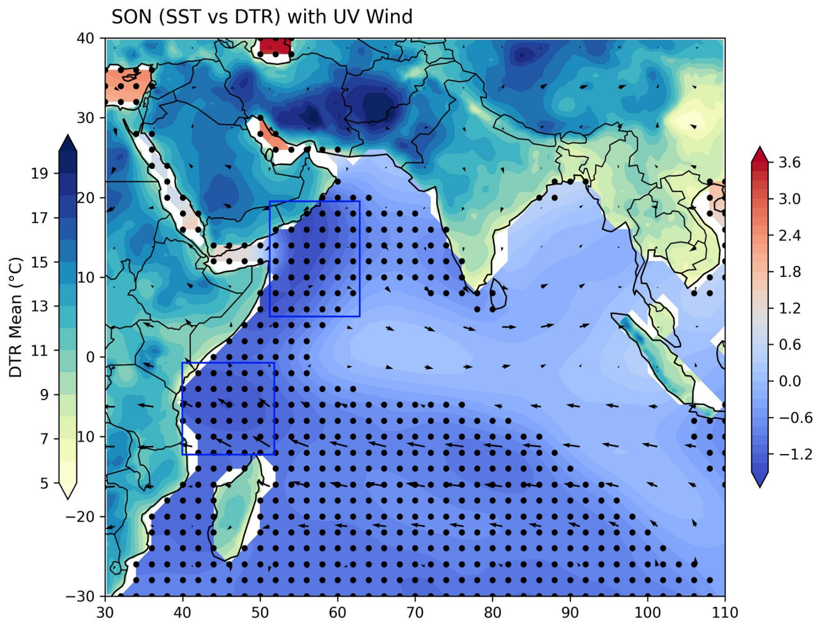

Figure 21. SON (SST vs DTR) with UV wind.

The Arabian Sea together with adjacent Pakistan areas experience a persistent cover of moderate clouds ranging from 35 to 50 percent during SON as observed in Figure 22. The prolonged cloudiness produces higher than average low temperatures which prevents nighttime cooling so that the daytime-nighttime temperature difference becomes smaller.

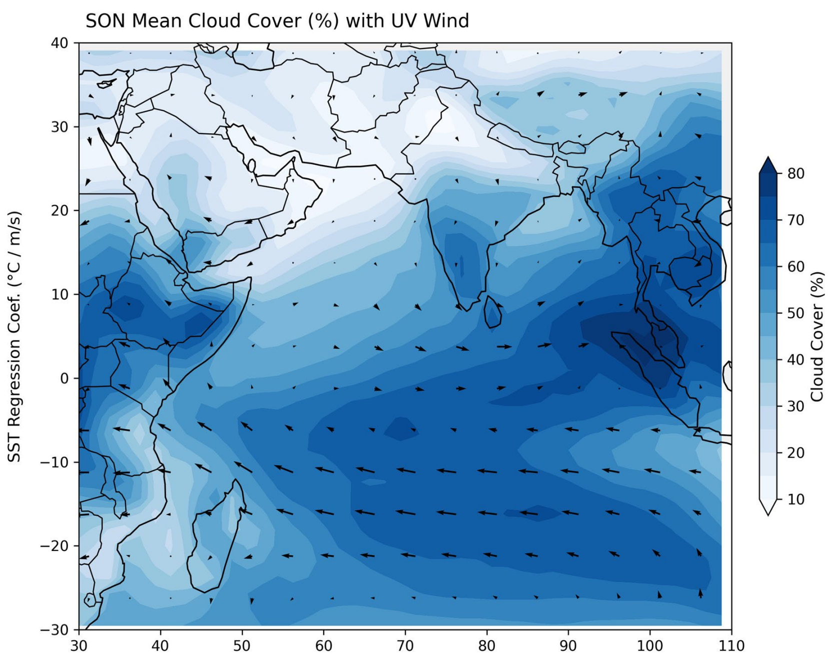

Figure 22. SON mean cloud cover (%) with UV wind.

According to Figure 23 the outcomes from correlation patterns allow detection of a minimal positive alignment (r = 0.011) through many sections of the Indian Ocean yet do not represent an exclusive impact. The positive sign of correlation results represents the complex nature of regional conditions which show that SST anomalies within certain western and central Indian Ocean areas sometimes match local increases in DTR but the reasons include differing regional climate conditions during specific years.

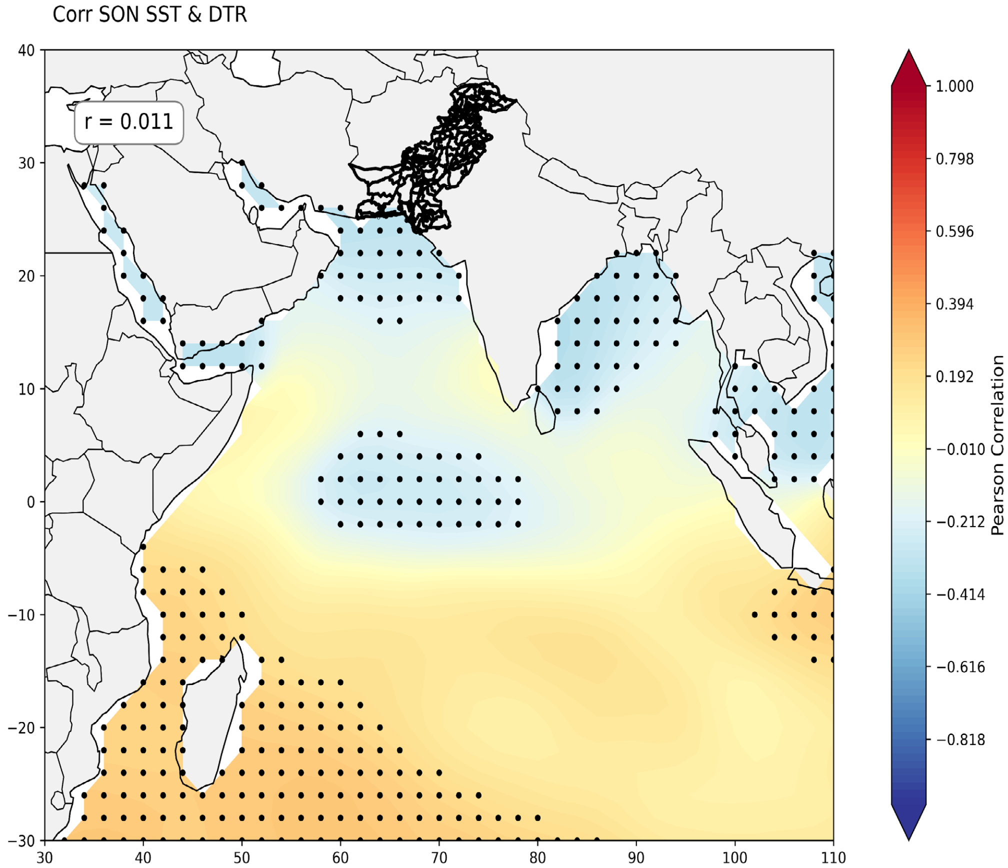

Figure 23. Correlation of SON DTR with SSTs. Weak overall correlation (r ≈ 0.011), with significant points near the northern Arabian Sea.

The inconsistent relationship between SON-season SST influence and DTR exists because various drivers including land-surface moisture and urban heat retention and elevation factors now play a more dominant role in altering the DTR signal. The localized atmospheric circulation patterns including subtropical jet displacement along with Rossby wave anomalies can cancel out SST-induced effects during post-monsoon periods and lead to the present weak and inconsistent relationship.

The link between Indian Ocean Sea surface temperature anomalies and daily temperature difference responses differently in the Indian peninsula's SON (autumn) season compared to MAM season according to Figure 24. Strong monsoonal winds at the post-monsoon stage hinder the movement of atmospheric moisture caused by positive SST anomalies (Xue et al., 2019). The SST-DTR direct relationship observed in spring experiences reduced influence because of these events.

The DTR variability in Punjab and Sindh expresses mainly through terrestrial feedback mechanisms. The combination of summer monsoon-derived soil moisture and urban warming and extended cloud cover reduces daytime T_{max} while raising nighttime T_{min} which together creates a smaller DTR (Khan et al., 2019a; Nawaz et al., 2019); Recent studies by Nawaz et al. (2019) and Sajjad et al. (2022) found this pattern. The surface interactions of land dominate temperature changes compared to SST variations.

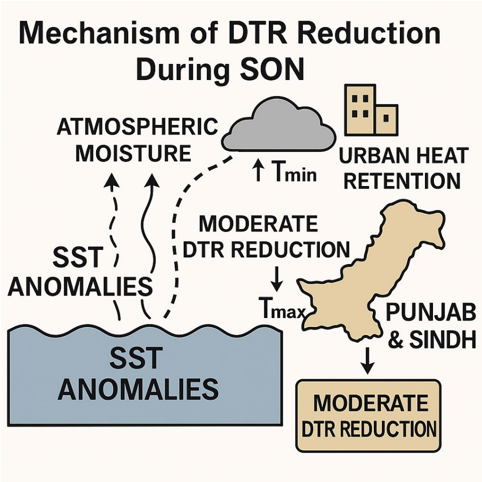

Figure 24. Mechanism of DTR reduction during SON. SST anomalies, urban heat, and residual cloud cover lead to higher T_{min} and slightly lower T_{max}, causing moderate DTR reduction in Punjab and Sindh.

During the SON season weak statistical linkages exist between climate phenomena even though physical atmospheric activities continue to operate. Liu et al. provide supporting evidence for this statement. Cloud-radiation interactions and land-atmosphere coupling produce effective changes in T_{min} and T_{max} despite low levels of linear SST-DTR correlations according to Liu and Zeng (2004). Research conducted in the region by Sajjad et al. (2022) supports these findings. Khan et al. (2019b), and Nawaz et al. (2020) and other urban climate researchers attributed most of the SON-time T_{min} increases to urban heat effects combined with residual humidity.

Global studies (Xue et al., 2019; Liu et al., 2016) along with other researchers support the conclusion that non-linear multiple-factor drivers produce Daytime Temperature Range variations that cannot be measured through linear correlation methods. The physically meaningful and supportive of climatological knowledge moderate decrease in daytime temperature range in SON proves valid despite weak SST anomaly correlations.

Several black dots indicative of statistical significance appear in the geographical region surrounding Pakistan during periods of elevated SST-DTR correlation even though the correlation value remains low. This demonstrates localized SST-DTR coupling occurs in specific locations of the northern Arabian Sea.

A detailed examination of SST variation relationships with DTR anomalies through Figure 25 presents evidence during individual years. Observed subdued DTR levels occurred after elevated SST anomalies during 1994, 2010 and 2015 thus establishing physical SST-DTR relationships beyond weak linear correlations.

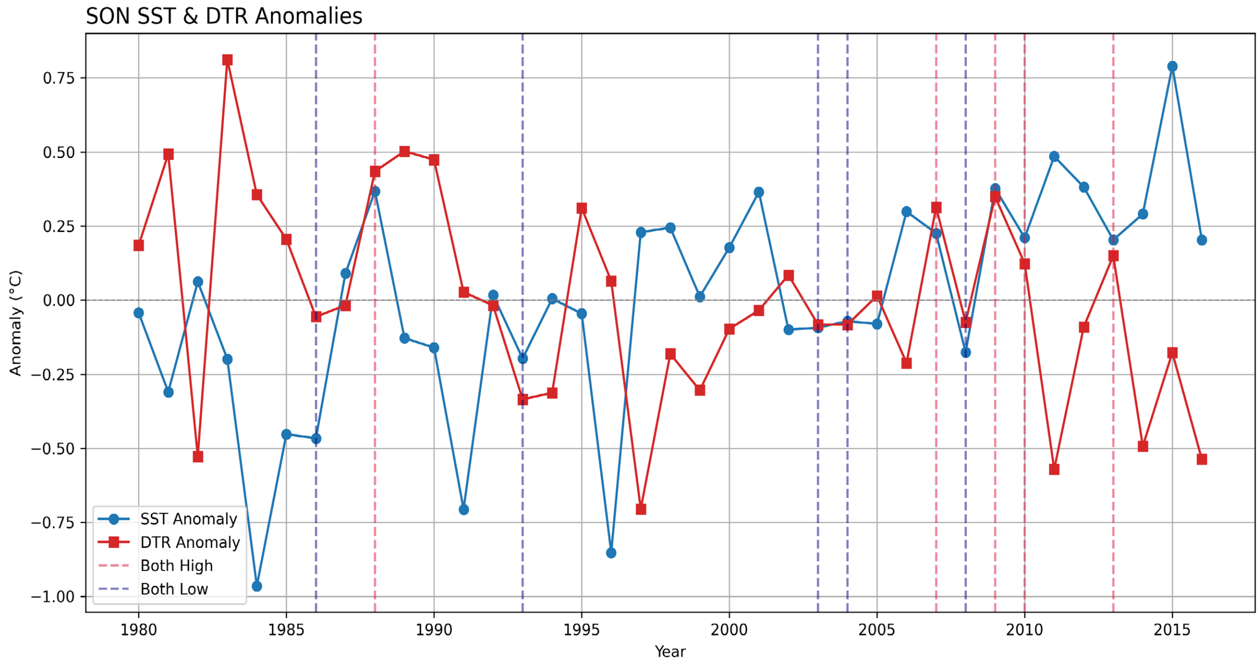

Figure 25. SON time series of SST and DTR anomalies. Reduced DTR observed during high SST years like 1994, 2010, and 2015.

The research connects with previous reports by Ionita et al. (2012) and Babaousmail et al. (2023) since these scholars emphasized the value of anomaly study at seasonal transitions when significant atmospheric interactions obscure the fundamental processes linking heat transfer to boundary-layer clouds and topographic elements.

Weak statistical correlations between sea surface temperature anomalies and diurnal temperature range do not affect the validity of discovered results. Physical evidence including elevated T_{min} levels caused by residual cloud cover remains consistent with SST-related effects even through complicated nonlinear mechanisms. Observations from the region and additional evidence from worldwide literature reveal powerful DTR variations even though direct statistical relationships prove limited. The study maintains robust findings through the unified analysis of statistical, physical and conceptual evidence.

4. Conclusion

Using SST anomaly data from the Indian Ocean, the researchers analyzed DTR variations across Pakistan throughout spring (MAM) and autumn (SON) seasons from 1980 to 2016. The research combines high-resolution climate data with cloud observations to identify the spatial as well as temporal and atmospheric factors that influence DTR fluctuations during transition seasons.

DTR data in Pakistan exist as patterns that exhibit significant varying distribution across geographic regions. Higher DTR readings were noticed in southern and central Pakistan including Sindh and southern Punjab and eastern Baluchistan during MAM and SON, primarily because of dry atmospheric conditions and intense surface heating together with restricted cloud cover. The northern mountainous locations experienced reduced DTR values because of weather patterns that created cloud cover and snow accumulation while high elevations made temperatures decrease.

During MAM, there existed a powerful negative connection between DTR and Indian Ocean SST anomalies which spread across the region in a consistent manner. The relationship between SST and DTR produced a negative correlation coefficient of $r \approx -0.035$ throughout southern Pakistan while the regression slope surpassed $-1.2^{\circ}C$ per $1^{\circ}C$ increase in SST. The relationship found strong support through widespread significant statistical areas which spanned Sindh province to southern Punjab province and eastern Baluchistan province where warmer SSTs led to increased humidity levels and cloud cover, thus reducing daytime heating and daily temperature range. SST patterns in spring showed both steady increases and corresponding decreases in DTR throughout the 1998, 2005 and 2010 seasons. Ocean-atmosphere interactions display a close tie to spring DTR fluctuations because of their robust cloud dependability ($r = -0.72$). The spring DTR variance could be explained through airflow-driven and surface-radiation processes which accounted for 45.5%, so MAM represented the season with the strongest DTR-SST connection.

The DTR variability patterns during the autumn season (SON) exhibited complicated behavior patterns. The SST-DTR correlation maintained a weak relation ($r \approx 0.011$) but showed moderate negative influence that originated from central Indian Ocean near the Maldives and Seychelles regions. The moisture effect from SST resulted in delayed seasonal cloud maintenance together with higher nighttime heat levels across central Punjab and upper Sindh and western Baluchistan during autumn seasons. The correlation value remained weak, but three years including 1994, 2010 and 2015, clearly demonstrated SST-DTR suppression patterns. The seasonal relationship between clouds and DTR remained weak ($r = -0.14$) because the surface-atmosphere recovery occurred at a slower pace in this season than in the spring season. The main drivers of SON DTR variability originate from local land-atmosphere feedbacks which SST influences moderately through a secondary effect.

Indian Ocean SST anomalies from the Arabian Sea and western equatorial belt demonstrate essential influence on Pakistan's transitional season climate because of their significant statistical connection with diurnal temperature range in spring season. The anomalies affect cloud formation patterns while steering upper-air circulation as well as surface heat interactions that eventually produce seasonal changes in daytime-to-nighttime temperatures. Such robust spring coupling enables the utilization of oceanic signals for warning systems and climate prediction in agricultural areas which need thermal management for crop development and water conservation.

The research proves that Indian Ocean Surface Temperature anomalies create a significant impact on temperatures across Pakistan during the transitional season periods. National climate models should incorporate SST monitoring because DTR variability affects agricultural production and water resources and health systems in the country. Climate resilience planning in Pakistan's vulnerable regions needs SST-based surface thermal regime predictions because of growing ocean warming caused by climate change.

Authors' Contributions

The study was conceived, designed, and executed by A.F., who conducted the data analysis, visualization, and manuscript writing. I.Z., H.F., A.D.D., H.H., M.A.F., and K.A. provided guidance, conceptual input, and relevant datasets that supported the research. All authors reviewed the manuscript and approved its final version.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Babaousmail, H., Ayugi, B. O., Ojara, M., Ngoma, H., Oduro, C., Mumo, R. et al. (2023). Evaluation of CMIP6 Models for Simulations of Diurnal Temperature Range over Africa. *Journal of African Earth Sciences, 202,* Article ID: 104944. https://doi.org/10.1016/j.jafrearsci.2023.104944

Braganza, K., Karoly, D. J., & Arblaster, J. M. (2004). Diurnal Temperature Range as an Index of Global Climate Change during the Twentieth Century. *Geophysical Research Letters, 31,* L13217. https://doi.org/10.1029/2004gl019998

Cao, J., Wen, D., Yang, R., & Zhu, Y. (2022). Impact of Indian and East Asian Summer Monsoons on the Diurnal Temperature Range of the Low-Latitude Highlands of China in the Rainy Season. *Journal of Climate, 35,* 2161-2172. https://doi.org/10.1175/jcli-d-21-0189.1

Haider, A., Mobeen, M., Rehman, M. S., Mohsin, M., Rafique, A., Naheed, N., Khan, M. D., & Rehman, A. (2021). Diurnal Temperature Range (DTR) Assessment in Major Cities of Punjab, Pakistan. *Pakistan Journal of Science, 73*, 446-454.

Haider, A., Shafiq-ur-Rehman, M. M., Ahmad, M. M., Raza, M. A., Nawaz, N., Mahmood, D. N., & Rana, K. A. R. (2014). Diurnal Temperature Range (DTR) Assessment in Major Cities of Punjab, Pakistan. *Pakistan Journal of Meteorology, 10,* 49-62.

Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS Monthly High-Resolution Gridded Multivariate Climate Dataset. *Scientific Data, 7,* Article No. 109. https://doi.org/10.1038/s41597-020-0453-3

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J. et al. (2020). The ERA5 Global Reanalysis. *Quarterly Journal of the Royal Meteorological Society, 146,* 1999-2049. https://doi.org/10.1002/qj.3803

Hussain, A., Cao, J., Hussain, I., Begum, S., Akhtar, M., Wu, X. et al. (2021). Observed Trends and Variability of Temperature and Precipitation and Their Global Teleconnections in the Upper Indus Basin, Hindukush-Karakoram-Himalaya. *Atmosphere, 12,* Article No. 973. https://doi.org/10.3390/atmos12080973

Hussain, A., Hussain, I., Ali, S., Ullah, W., Khan, F., Ullah, S. et al. (2023). Spatiotemporal Temperature Trends over Homogenous Climatic Regions of Pakistan during 1961-2017. *Theoretical and Applied Climatology, 153,* 397-415. https://doi.org/10.1007/s00704-023-04484-3

Ionita, M., Lohmann, G., Rimbu, N., & Scholz, P. (2012). Dominant Modes of Diurnal Temperature Range Variability over Europe and Their Relationships with Large-Scale Atmospheric Circulation and Sea Surface Temperature Anomaly Patterns. *Journal of Geophysical Research: Atmospheres, 117,* D15111. https://doi.org/10.1029/2011jd016669

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L. et al. (1996). The NCEP/NCAR 40-Year Reanalysis Project. *Bulletin of the American Meteorological Society, 77,* 437-471. https://doi.org/10.1175/1520-0477(1996)077<0437:tnyrp>2.0.co;2

Khan, N., Shahid, S., Ismail, T. B., & Wang, X. (2019b). Spatial Distribution of Unidirectional Trends in Temperature and Temperature Extremes in Pakistan. *Theoretical and Applied Climatology, 136,* 899-913. https://doi.org/10.1007/s00704-018-2520-7

Khan, N., Shahid, S., Ismail, T., Ahmed, K., & Nawaz, N. (2019a). Trends in Heat Wave Related Indices in Pakistan. *Stochastic Environmental Research and Risk Assessment, 33,* 287-302. https://doi.org/10.1007/s00477-018-1605-2

Lim, Y., Park, A. K., & Kim, H. (2012). Modifiers of Diurnal Temperature Range and Mortality Association in Six Korean Cities. *International Journal of Biometeorology, 56,* 33-42. https://doi.org/10.1007/s00484-010-0395-0

Liu, C., & Zeng, Y. (2004). Changes of Pan Evaporation in the Recent 40 Years in the Yellow River Basin. *Water International, 29*, 510-516. https://doi.org/10.1080/02508060408691814

Liu, L., Chen, W., Guo, J., Wu, R., Wang, L., Wang, S. et al. (2021). Large-Scale Pattern of the Wintertime Diurnal Temperature Range Variations over North America during 1979-2018. *Atmospheric Research, 257,* Article ID: 105614. https://doi.org/10.1016/j.atmosres.2021.105614

Liu, L., Li, Z., Yang, X., Gong, H., Li, C., & Xiong, A. (2016). The Long-Term Trend in the Diurnal Temperature Range over Asia and Its Natural and Anthropogenic Causes. *Journal of Geophysical Research: Atmospheres, 121,* 3519-3533. https://doi.org/10.1002/2015jd024549

Makowski, K., Wild, M., & Ohmura, A. (2008). Diurnal Temperature Range over Europe between 1950 and 2005. *Atmospheric Chemistry and Physics, 8,* 6483-6498. https://doi.org/10.5194/acp-8-6483-2008

Manatsa, D., Morioka, Y., Behera, S. K., Mushore, T. D., & Mugandani, R. (2015). Linking the Southern Annular Mode to the Diurnal Temperature Range Shifts over Southern Africa. *International Journal of Climatology, 35,* 4220-4236. https://doi.org/10.1002/joc.4281

Na, L., Na, R., Bao, Y., Zhang, J., Bao, Y., & Shan, Y. (2022). Diurnal Temperature Range Variability Driven by Cloud Cover and Precipitation in Mongolian Plateau under Global

Warming. *International Journal of Climatology, 42,* 8184-8200. https://doi.org/10.1002/joc.7702

Nawaz, Z., Li, X., Chen, Y., Guo, Y., Wang, X., & Nawaz, N. (2019). Temporal and Spatial Characteristics of Precipitation and Temperature in Punjab, Pakistan. *Water, 11,* Article No. 1916. https://doi.org/10.3390/w11091916

Nawaz, Z., Li, X., Chen, Y., Wang, X., Zhang, K., Nawaz, N. et al. (2020). Spatiotemporal Assessment of Temperature Data Products for the Detection of Warming Trends and Abrupt Transitions over the Largest Irrigated Area of Pakistan. *Advances in Meteorology, 2020,* Article ID: 3584030. https://doi.org/10.1155/2020/3584030

Sajjad, S. H., Blond, N., Mohsin, T., Shakrullah, K., & Clappier, A. (2022). Temperature Variability over Urban, Town, and Rural Areas: The Case of Pakistan. *International Journal of Climatology, 42,* 2881-2900. https://doi.org/10.1002/joc.7395

Shelton, S., Pushpawela, B., & Liyanage, G. (2022). The Long-Term Trend in the Diurnal Temperature Range over Sri Lanka from 1985 to 2017 and Its Association with Total Cloud Cover and Rainfall. *Journal of Atmospheric and Solar-Terrestrial Physics, 227,* Article ID: 105810. https://doi.org/10.1016/j.jastp.2021.105810

Shen, X., Liu, B., Li, G., Wu, Z., Jin, Y., Yu, P. et al. (2014). Spatiotemporal Change of Diurnal Temperature Range and Its Relationship with Sunshine Duration and Precipitation in China. *Journal of Geophysical Research: Atmospheres, 119,* 13,163-13,179. https://doi.org/10.1002/2014jd022326

Shenoi, S. S. C., Nasnodkar, N., Rajesh, G., Joseph, J., Suresh, I., & Almeida, A. M. (2009). *On the Diurnal Ranges of Sea Surface Temperature (SST) in the North Indian Ocean*.

Ullah, S., You, Q., Ullah, W., Hagan, D. F. T., Ali, A., Ali, G. et al. (2019). Daytime and Nighttime Heat Wave Characteristics Based on Multiple Indices over the China-Pakistan Economic Corridor. *Climate Dynamics, 53,* 6329-6349. https://doi.org/10.1007/s00382-019-04934-7

Vose, R. S., Easterling, D. R., & Gleason, B. (2005). Maximum and Minimum Temperature Trends for the Globe: An Update through 2004. *Geophysical Research Letters, 32,* L23822. https://doi.org/10.1029/2005gl024379

Wang, F., Zhang, C., Peng, Y., & Zhou, H. (2014). Diurnal Temperature Range Variation and Its Causes in a Semiarid Region from 1957 to 2006. *International Journal of Climatology, 34,* 343-354. https://doi.org/10.1002/joc.3690

Wang, K., & Clow, G. D. (2020). The Diurnal Temperature Range in CMIP6 Models: Climatology, Variability, and Evolution. *Journal of Climate, 33,* 8261-8279. https://doi.org/10.1175/jcli-d-19-0897.1

Xue, W., Guo, J., Zhang, Y., Zhou, S., Wang, Y., Miao, Y. et al. (2019). Declining Diurnal Temperature Range in the North China Plain Related to Environmental Changes. *Climate Dynamics, 52,* 6109-6119. https://doi.org/10.1007/s00382-018-4505-8

Yang, J., Liu, H., Ou, C., Lin, G., Zhou, Q., Shen, G. et al. (2013). Global Climate Change: Impact of Diurnal Temperature Range on Mortality in Guangzhou, China. *Environmental Pollution, 175,* 131-136. https://doi.org/10.1016/j.envpol.2012.12.021

Zhai, G., Zhang, J., Zhang, K., & Chai, G. (2022). Impact of Diurnal Temperature Range on Hospital Admissions for Cerebrovascular Disease among Farmers in Northwest China. *Scientific Reports, 12,* Article No. 15368. https://doi.org/10.1038/s41598-022-19507-8

Zhang, J., Wang, W., & Wu, L. (2009). Land-Atmosphere Coupling and Diurnal Temperature Range over the Contiguous United States. *Geophysical Research Letters, 36,* L06706. https://doi.org/10.1029/2009gl037505

Zhou, L., Dai, A., Dai, Y., Vose, R. S., Zou, C., Tian, Y. et al. (2009a). Spatial Dependence of Diurnal Temperature Range Trends on Precipitation from 1950 to 2004. *Climate Dynamics, 32,* 429-440. https://doi.org/10.1007/s00382-008-0387-5

Zhou, L., Dickinson, R. E., Dai, A., & Dirmeyer, P. (2010). Detection and Attribution of Anthropogenic Forcing to Diurnal Temperature Range Changes from 1950 to 1999: Comparing Multi-Model Simulations with Observations. *Climate Dynamics, 35,* 1289-1307. https://doi.org/10.1007/s00382-009-0644-2

Zhou, W., Chan, J. C. L., Chen, W., Ling, J., Pinto, J. G., & Shao, Y. (2009b). Synoptic-Scale Controls of Persistent Low Temperature and Icy Weather over Southern China in January 2008. *Monthly Weather Review, 137,* 3978-3991. https://doi.org/10.1175/2009mwr2952.1