Temperature Variability over Saudi Arabia and its Association with Global Climate Indices

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Abstract. This paper investigates the effect of large-scale forcings on the variability of the mean air temperature of Saudi Arabia, using the observed data and the National Centers for Environmental Prediction (NCEP) reanalysis gridded datasets for the period 1978-2010. The analysis shows that the seasonal mean temperature variability is high in the northern and central regions compared to the southern. Moreover, the temperature variability is highest (~30%) in the winter season and lowest (~2 %) in the summer. Following global warming indications, the interannual variability of the mean air temperature of Saudi Arabia indicates a warming phase that started in the late 1990s.

The analysis reveals that the strong variability in temperature over Saudi Arabia is closely associated with the North Atlantic Oscillation (NAO) index for all seasons except the autumn; however, the relationship is most prominent during the winter season. The study indicates that the winter season temperature is also influenced by the Arctic Oscillation (AO) index, whereas the spring season temperature is influenced by the El Niño Southern Oscillation (ENSO). This research concludes that the negative phases of ENSO, AO and NAO all play a major role in the temperature increase over most parts of Saudi Arabia.

Keywords: Temperature, Saudi Arabia, ENSO, NAO, AO.
**Introduction**

Temperature is one of the most important climatic parameters, and it can seriously impact the socio-economic condition of a region. Temperature is intimately related to agriculture, drought, water resources, power generation, human health, urbanization, and cold- and heat-wave extremes. For example, rising temperature has a direct effect on crop yields as well as indirect effects on the availability of irrigation water (Nelson et al., 2009). Cueto et al. (2009) found that the minimum temperatures within the urban area of Mexicali city are increasing at a faster rate than in the surrounding rural area, they found an intimate relationship between urbanization and local temperature. Ultimately, the increase in temperatures in the urban climate has negative implications for energy, water consumption and human health.

In the present era of global warming and climate change, understanding the exact climatic situation, especially information relating to temperature extremes, is critical. The average global surface air temperature has increased by about 0.6 ± 0.2 °C since the late nineteenth century (Folland et al., 2001), where the rate of warming in the global surface air temperature during the last half century (1956-2005) was 0.128°C/decade (IPCC, 2007). However, the temperature of a region varies with topographic characteristics such as high and low elevations, land coverage and land types. In addition, temperature falls with increase in altitude, whilst the warmness of a region also depends on surface terrestrial albedo, which is high over sandy areas like the Rub Al-Khali desert in Saudi Arabia.

Saudi Arabia is situated in the southwest of Asia at the junction of Africa and Asia and is the largest country (occupying 80% of area) in the Arabian Peninsula (CSD, 2010). The country has mountain ranges in the western region, situated parallel to the coast of the Red Sea. The Rub Al-Khali is the world’s largest sand desert, which covers almost the entire south-eastern region of Saudi Arabia (Atlas, 1984; Edgell, 2006; and Bishop, 2010). The climate of Saudi Arabia is extremely hot and dry (Almazroui, 1998; and Ragab and Prudhomme, 2000). The rainfall climatology, as studied by Almazroui (2011), is such that the country receives large amounts of rainfall in the northern, central-northern and south-western regions, whereas the south-eastern region is almost entirely dry. The south-western region of Saudi Arabia receives rainfall
in almost all months of the year, whereas the northern region receives most of its rainfall during the winter and spring seasons (Almazroui, 2011; Abdullah and Almazroui, 1998; and Al-Jerash, 1985). In the northern region of the country, the climate parameters are associated with westerly disturbances, the Sudan trough and the storms of the Mediterranean region, whereas the southern climate is influenced by the Indian Ocean monsoon circulation (Sen and Al-Suba’i, 2002).

A few studies have been conducted in the Arabian region to understand the behaviour of its temperature climatology: For the whole of the Middle East, (Bou-Zeid and El-Fadel, 2002); for Saudi Arabia, (El-Nesr et al., 2010); for Kuwait, (Nasrallah and Balling, 1995); and for Jordan (Smadi, 2006). However, most of these studies mainly addressed the temperature trends and their relationship with water resource management. Furthermore, these studies used the available surface observation data, which are very sparse in this region.

Of further significance is the fact that ENSO, NAO and AO are also major drivers of the climate of the northern hemisphere, as discussed in several studies, and it is therefore of vital importance to examine the effects of these external forces (NAO and AO) on the region’s climate. However, in the past, very little research has been conducted to address the relationship between the temperature and the large-scale forcings in the study region. For example, Almazroui (2006) studied the mean temperature of only four stations over Saudi Arabia and their relationship with ENSO phenomena. Unfortunately, no attempt has been made so far to detect the impact of NAO and AO on the seasonal temperatures of Saudi Arabia. This work is thus the first attempt at investigating the effects of these large-scale forcings on the temperature over Saudi Arabia. Specifically, the current study investigates the relationship between the mean temperatures in Saudi Arabia with the large-scale forcings, using the available observed data (from 27 stations) and the gridded reanalysis datasets. It is envisaged that the research will be useful in understanding how ENSO, AO and NAO affect the temperature climatology of the study area.

**Data and Methodology**

The daily temperature data of 27 stations from the years 1978-2010 were acquired from the Presidency of Meteorology and Environment
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(PME), Saudi Arabia. The National Centers for Environmental Prediction (NCEP) surface mean air temperature (Kalnay et al., 1996) gridded data are also utilized. The station details, together with mean temperatures (averaged over 1978-2010) on the annual and seasonal timescales in Saudi Arabia, are given in Table 1. The station acronyms from this table are used for the rest of the study. The large-scale features, such as Niño3.4, AO and NAO data, are utilized to identify their effects on the temperature of Saudi Arabia. These large-scale monthly time series data were obtained from the Climate Prediction Center (CPC) at the National Oceanic and Atmospheric Administration (NOAA) website (http://www.cpc.ncep.noaa.gov/).

Table 1. The observation station details, with mean temperature (°C) on annual and seasonal scales in Saudi Arabia, averaged over 1978-2010.

<table>
<thead>
<tr>
<th>Station Information</th>
<th>Temperature (°C)</th>
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<tbody>
<tr>
<td>Name</td>
<td>Acronym</td>
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<td>Turaif</td>
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<td>Arar</td>
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<td>Al Qaysumah</td>
<td>S7</td>
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<tr>
<td>Hafer Alhaden</td>
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<td>Hail</td>
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<td>Gassim</td>
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<td>Wejh</td>
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<td>Ahsa</td>
<td>S13</td>
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<tr>
<td>Riyadh New</td>
<td>S14</td>
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<td>Riyadh Old</td>
<td>S15</td>
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<tr>
<td>Madinah</td>
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<td>Yenbo</td>
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<td>Jeddah</td>
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<td>Taif</td>
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<td>Makkah</td>
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<td>Al Baha</td>
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<td>Bisha</td>
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<td>Khamis Mushait</td>
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<td>Najran</td>
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<td>Sharurah</td>
<td>S26</td>
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<tr>
<td>Jazan (Gizan)</td>
<td>S27</td>
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The spatial and temporal analyses of temperature on the annual and seasonal scales are performed using standard statistical methods. The annual cycle, mean and standard deviation of temperature are obtained from the observed seasonal dataset. The temperature climatology is obtained from the NCEP data on the monthly, seasonal and annual timescales. The interannual variability of temperature obtained from the NCEP dataset for an area confined between 35°-60°E and 12°-22°N is compared with the observed country average data across Saudi Arabia. The coefficient of variation (CV) is used to obtain the mean temperature variability over the region. The effects of the large-scale natural forcings, such as ENSO, NAO, and AO, on the mean seasonal temperature over Saudi Arabia are studied using both the observed station and the gridded datasets. The Student’s t-test is used to assess the significance of the relationship of these forcings with the seasonal mean temperatures over the region under study.

Results and Discussion

Figure 1 shows the topography of the study region and its surroundings because the temperature varies with the elevation and other topographic factors such as land characteristics and vegetation. It is apparent in Fig. 1 that there is a flat, low-elevation (<500m) north-south inclined strip located in eastern Saudi Arabia. This relatively low-elevation belt is narrower in the north and wider in the south. To the west of this low-elevation belt, another north-south inclined belt is located with relatively high elevation. In this belt, most of the land is under 1000m, with the exception of a very few locations where elevation reaches up to 1500m. The elevation of this mountain range, however, reaches over 2000m in southwestern Yemen. The temperature over Saudi Arabia varies with this topographic variation.

The surface observation stations are mostly located in the western and northern parts of the country. The low-dense network of observation stations in the north is not able to reflect the exact characteristics of the spatial temperature distribution. In addition, no observational facilities are available in the southeast of the country, where the Rub Al-Khali is situated.
Fig. 1. The topography in and around Saudi Arabia. The acronyms of the surface observation stations (see Table 1) and their locations (red dots) are also shown.

Temperature Variability

Seasonal Variability

At first, the temperature variability at seasonal scale obtained from the observed data is discussed followed by the NCEP data explanation.

The mean and one sigma deviation of the observed temperature from 27 stations over Saudi Arabia are shown in Fig. 2. The horizontal axis shows the station acronym from north to south of Saudi Arabia according to Table 1. In each graph the center point (dot mark) is the mean of the temperature at a particular station for the study period (1978-2010) and the dispersion is the one sigma standard deviation. In general, relatively low temperature is observed for the northern stations during winter season, whilst the temperature of the southern stations are low in other (spring, summer and autumn) seasons. The seasonal temperature
variability for the stations located in the north and the central areas of Saudi Arabia is high compared to the stations situated in the south (also see Table 1). There is a gradient of high variability in the north to the low variability in the south.

For example, the mean temperature at the extreme north station (S1) ranges from 8.57°–28.32°C in different seasons, however at the southern station (S27) it ranges from 26.68°–33.97°C (see Table 1). This infers a large seasonal cycle in the northern region compared to the southern. Overall, during the winter season this gradient of temperature variability seems to be high and it is almost stagnant during the summer. This happened because the northern and central regions of Saudi Arabia are under the influence of westerly disturbances from the Mediterranean Sea during the winter season.

The low-density network of surface observation stations across Saudi Arabia means that we are unable to infer the temperature distribution in the country with a sufficiently high degree of accuracy. Thus, the NCEP gridded data were considered for assessing the level of accuracy of the temperatures obtained from the observed data.

The Coefficient of Variability (CV) obtained from the NCEP data during winter, spring, summer and autumn seasons are shown in Fig. 3. In general, the temperature variability is high in the northern region of Saudi Arabia, compared to the southern region of the country, for all seasons; the gradient of this temperature variability is again from the northern region (high) to the southern region (low). The variability gradient is more prominent during the winter season, compared to the other seasons. These results are fully consistent with the results of the observed data discussed earlier (see Fig. 2). In the northern region, the CV reached about 30% during the winter season, whilst during the summer it was much less pronounced, reaching only about 2%.

**Interannual Variability**

The interannual variability of the seasonal temperature anomaly obtained from the observed and the NCEP data is shown in Fig. 4. The anomalies are obtained for all seasons, considering the reference period from 1978 to 2010. The observed temperature is averaged from all 27 stations used, whereas the NCEP temperature is the areal averaged over the region between 35°-60°E and 12°-22°N.
Fig. 2. The temperature variability in Saudi Arabia obtained from the observed station data for the (a) Winter (b) Spring (c) Summer, and (d) Autumn seasons averaged over 1978-2010.

Figure 4 shows that the interannual variability of the observed seasonal temperature is apparent in both the warm (positive) and cold (negative) phases. Since the late 1990s, all seasons have shown a warming phase over Saudi Arabia, although four cold phases were observed during the winter season. This could be linked with the increase in temperature over the study region due to global warming. The NCEP data captured well the interannual variability in almost all seasons. Importantly, the NCEP data clearly identifies the warm phase from the late 1990s. During the winter season, the correlation between the observed and the NCEP data is 0.94, which is statistically significant at the 95% level according to the Student’s t-test.
According to the One Sigma standard deviation (0.97°C) during the winter season, the observed dataset identified ten extreme temperature years (1983, 1989, 1992, 1993, 1994, 1999, 2002, 2004, 2006 and 2010) over the country (Fig. 5a). It is interesting to note that the years 1983, 1989, 1992 and 1993 are the cold years, according to the One Sigma standard deviation criterion; however, since 1994 all the extreme years are found to be extremely hot, relative to the ‘normal’ years. The year 2010 is the warmest (2.22°C w.r.t. 1978-2010 average reference period) among all the extreme years, whereas 1983 is the coldest (-2.25°C w.r.t. 1978-2010 average reference period).
1978-2010 average reference period) among all the cold years. It was also noted that after 1995, the temperature shows an increasing trend during the winter season. The NCEP data also capture the extreme years quite well but with some underestimation of temperature compared to the observed data.

During the spring season, the correlation between the two datasets is found to be 0.83, which is statistically significant at the 95% level (Fig. 4b). According to the One Sigma standard deviation criterion (0.86°C), the observed data identified nine extreme temperature years (1982, 1983, 1992, 1997, 2001, 2003, 2007, 2008 and 2010) in Saudi Arabia. Except for the year 1982, all the extreme years are captured well by the NCEP data. In the spring season, 1983 is the extreme coldest year (-1.84°C w.r.t. 1978-2010 average reference period), whereas 2010 is the extreme warmest year (1.95°C w.r.t. 1978-2010 average reference period).

The correlation between the observed and the NCEP data is 0.88 during the summer season, which is statistically significant at the 95% level (Fig. 4c). According to the One Sigma standard deviation criterion (0.95°C), the observed data identified nine extreme temperature years (1978, 1982, 1984, 1998, 2000, 2006, 2008, 2009 and 2010) in Saudi Arabia. Except for the years 1978, 1982, 1984, 1998 and 2009, all the extreme years were captured well by the NCEP data. In the summer season, 1984 is the extreme coldest year (-1.81°C) whereas 2010 is the extreme warmest year (2.1°C).

During the autumn season, the correlation between the two datasets is 0.89, which is 95% statistically significant (Fig. 4d). According to the One Sigma standard deviation criterion (0.75°C), the observed data identified eleven extreme temperature years (1978, 1981, 1982, 1983, 1984, 1998, 1999, 2002, 2007, 2009 and 2010) in Saudi Arabia. All of the extreme years are captured well by the NCEP data, with some underestimated values compared to the observed data. In the autumn season, 1978 is the extreme coldest year (-1.54°C), whereas 2010 is the extreme warmest year (1.6°C). Overall, the results show that 2010 was the warmest year in Saudi Arabia during the study period, observed during all four seasons.
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(a) Winter (DJF)  
(b) Spring (MAM)  
(c) Summer (JJA)  
(d) Autumn (SON)

Fig. 4. Area averaged mean temperature anomalies obtained from the observed and the NCEP data for the (a) Winter, (b) Spring, (c) Summer and (d) Autumn seasons. The anomaly is taken with respect to the reference period 1978-2010.

Temperature Climatology

The ability of the NCEP data to capture the overall temperature profiles over Saudi Arabia encouraged us to further utilize them to obtain the spatial distribution of the temperature climatology over the country, which is not possible from the direct use of the observed station values.

Seasonal and Annual Temperature Climatology

The seasonal mean temperature climatology averaged over 1978-2010 is shown in Fig. 5. The results show that the temperature in the south-eastern region of Saudi Arabia is high, compared to the other regions of the country. The reason for the relatively high temperatures (reaching above 50°C and not shown in the color bar) in this south-eastern region is due to the presence of the world’s largest sand desert, the Rub Al-Khali (Empty Quarter).

During the winter season, the temperature distribution over the country is in three distinct areas: the northwest is below 10°C, the center is 10°-15°C, and the east and the western coastal areas are 15°-20°C (Fig. 5a). As the northern region of the study area is under the influence of
western disturbances originating from the Mediterranean, it is colder than the southern region, which is under the influence of the tropics and hence is considerably warmer in this season. During the spring season, the temperatures increase all over the country, ranging between 20° and 35°C (Fig. 5b), climbing more quickly in the north, whilst in the summer season, the whole country is warm, with temperatures reaching above 30°C (Fig. 5c). In the summer season, the highest temperatures are observed in the south-eastern region, where the mean is above 35°C. During autumn, moderate temperatures are observed over the country, which range between 25° and 30°C, except in the northwest where they are below 25°C (Fig. 5d). However, in the south-eastern tip of the country, high temperatures are observed during this season.

Fig. 5. The spatial distribution of seasonal mean temperature (°C) climatology obtained from the NCEP data for the (a) Winter, (b) Spring, (c) Summer, and (d) Autumn seasons averaged over 1978-2010.
The spatial distribution of annual mean temperature obtained from the NCEP data averaged over 1978-2010 is displayed in Fig. 6. Generally, there are two temperature zones over the country: one covers the central-to-northwestern region, with temperature ranging between 20° and 25°C, whilst the other is central-to-eastern and southern and western areas, having temperatures ranging between 25° and 30°C. It is interesting to note that the lowest temperature (<20°C) is observed in a small part of the north-western region, whilst the highest temperature (>35°C) is observed in two small pockets of the Rub Al-Khali area. On the annual scale, the temperature gradient is from the southeast to the northwest of the country.

Effects of large-scale forcings on temperatures over Saudi Arabia

This section discusses the effects of large-scale features such as ENSO, AO and NAO on the temperature of the Saudi Arabia, obtained for both the observed and the NCEP datasets.

Effect of the ENSO Index

The correlations between the observed mean temperatures from the station dataset and the Niño3.4 index during different seasons are shown in Fig. 7. Overall, a negative correlation is found between the Niño3.4 index and the observed mean seasonal temperature of the region for most
of the stations. In addition, the correlations for stations S17 and S18 are negative and are statically significant at the 95% level, however for the stations S25 and S26, the correlations are positive and statistically significant at the 95% level during the winter season. During the spring season, all the stations show a negative correlation except for S25, which shows a weak positive correlation. The stations in northern, central (except S13 and S14) and S18 and S20 in south-western Saudi Arabia show strong negative correlation (95% statistically significant). In summer, only S2, S6 and S8 show a negative statistically significant correlation, whereas in autumn, none of the stations has a statistically significant relationship with the Niño3.4 index.

Fig. 7. The correlation of Niño 3.4 SSTs and the mean temperatures obtained from the observed data for the winter, spring, summer, and autumn seasons averaged over 1978-2010.

The spatial distribution of the correlation of the Niño3.4 index with the NCEP mean temperature for different seasons is shown in Fig. 8. The shaded areas indicate the correlations with a 95% statistical significance according to Student’s t-test. During the winter season, weak correlation is found with the NCEP data over Saudi Arabia except for a small area in the south-western region. During the spring season, the mean temperatures over most parts of Saudi Arabia are under the influence of the Niño3.4 region. In the summer and autumn seasons, no statistically significant correlation is found over the country. These results are consistent with the results obtained from the observed data as discussed earlier (see Fig. 7).
The negative correlation indicates that when there is a positive phase (El Niño) of ENSO temperatures over Saudi Arabia tend to fall; however, for the negative phase (La Niña) of ENSO, temperatures tend to rise across the country. Accordingly, the spring temperatures of Saudi Arabia are found to be affected by ENSO, which reduces the temperature mostly from the central to the northern parts of the country.

**Effects of the AO Index**

The correlation between the AO index and the observed mean temperature in different seasons for the period 1978-2010 is shown in Fig. 9. During the winter season, all stations show a negative correlation, except S23. In this season, all stations show strong negative correlation with a 95% statistical significance, except for the southern stations (S22, S23, S24, S25, S26 and S27). The highest correlation is obtained for the
northern station S2 (-0.79). In other seasons, there is no statistically significant correlation between the AO index and the mean temperature, except for S18 during the spring (-0.37) and the autumn (-0.35).

The correlation of the AO index with the NCEP temperature for the period 1978–2010 is shown in Fig. 10. The shaded areas indicate the statistically significant correlation at the 95% level according to Student’s t-test. The AO affects the winter season mean temperature of Saudi Arabia, except for the southern areas of the country. The negative correlation is evident from Fig. 10 for other seasons, however no statistically significant relationship is found except over the Red Sea during the autumn. These results are consistent with the results obtained from the observed data as discussed earlier.

As discussed earlier the variability in winter season temperature is high in the northern and the central areas of the country (see Fig. 3a). This high variability is associated with the AO, and so it could be used as an indicator for predicting the winter mean temperature in the study region.

![Correlation AO and NCEP temperature](image_url)

**Fig. 9.** The correlation of AO and the mean temperature obtained from the observed data for the winter, spring, summer, and autumn seasons averaged over 1978-2010. (see Fig. 12). The strong negative correlation indicates that the mean temperature during the winter season over this region is strongly associated with AO phenomena. This indicates that during the negative phase of AO, the temperature in the region tends to increase, and vice versa.
Effect of the NAO Index

The correlation between the NAO index and the observed mean temperature for the period 1978-2010 in the four seasons is shown in Fig. 11. During the winter season, all stations show negative correlation, except for S23 (0.11). Out of the 27 stations, 18 stations show strong correlation (95% statistically significant). Similarly, during the other seasons, negative correlation is found between the observed mean temperature and the NAO index for all stations, except for S27 (0.07), where a positive correlation is found in the autumn season. During the spring and summer seasons, most of the stations show a statistically significant relationship among the temperatures and NAO index, however significant relationships are few during the autumn season. This
indicates that the mean temperature over Saudi Arabia is heavily affected by the NAO phenomena during the winter, spring and summer seasons.

![Graph showing the correlation of NAO and temperature](image)

**Fig. 11.** The correlation of NAO and the mean temperature obtained from the observed data for the winter, spring, summer, and autumn seasons averaged over 1978-2010.

The spatial distribution of the correlation between the NAO index and the NCEP temperature over the period 1978–2010 is shown in Fig. 12. The negative correlation with 95% statistically significance is prominent during the winter, spring and summer seasons. There is no significant correlation over Saudi Arabia during the autumn except at the central coast line of the Red Sea. These results are consistent with the results obtained from the observed data (Fig. 11). The negative correlation indicates that during the negative phase of the NAO, the temperature over Saudi Arabia tends to increase, whilst for the positive phase of the NAO, the mean temperature tends to decrease over the region.

Consequently, the seasonal mean temperature of Saudi Arabia is closely related to the variability of ENSO, the AO and the NAO. These large-scale features show clear indication about the control of seasonal-mean temperature over Saudi Arabia, which is quite significant in diagnosis of the climate over the region.
Fig. 12. The correlation of the NAO index and the mean temperature obtained from the NCEP data for (a) Winter, (b) Spring, (c) Summer, and (d) Autumn seasons averaged over 1978-2010.

Conclusions

The monthly, seasonal and annual temperature obtained from the surface observations at 27 stations over Saudi Arabia and the NCEP data are analyzed for the period 1978-2010. The effects of large-scale forcings, specifically ENSO, AO and NAO, on the mean temperatures over the country are also investigated. The results show that the variability in seasonal mean temperature in northern and central Saudi Arabia is high compared to the southern region of the country. The temperature gradient is found to be from the south to the north of Saudi
Arabia; however the temperature variability gradient is from the northern and central region to the southern region. During the winter and autumn seasons, the gradient in mean temperature variability is high, compared to the spring and summer seasons. During the summer season, the temperature variability is low over Saudi Arabia. It is found that the high variability in the temperature over Saudi Arabia is closely associated with the large-scale forcings, for instance, the NAO index is strongly related to the temperature with a 95% statistically significant negative correlation in all seasons except autumn; however this relationship is more prominent during the winter season. The AO phenomenon also influences the winter season temperature over Saudi Arabia, whereas ENSO events affect the spring temperature. The strong and positive phase of El Niño has a strong negative correlation with the temperature of Saudi Arabia; it reduces temperatures across this region. With the positive (negative) phase of AO, the temperature of Saudi Arabia tends to decrease (increase). Similarly, during the negative phase of NAO, the temperature over Saudi Arabia tends to increase, and vice versa. As a subsequent study, this analysis may be extended to the utilization of global and regional climate model outputs, in the diagnosis as well as the projection of temperature effects in this region, which could result in significant socio-economic benefits.

**Acknowledgements**

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**References**


تغير درجات الحرارة على المملكة العربية السعودية وعلاقتها بمؤشرات المناخ العالمية

منصور المزروعي
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المستخلص: يهتم هذا البحث بدراسة تأثير القوى الواسعة النطاق على تغير وتباين درجات الحرارة المتوسطة في المملكة العربية السعودية باستخدام البيانات المقاسة وكذلك البيانات الشبكية للمركز الدولي للتنبؤ البيئي (NCEP) خلال الفترة من 1978-2010م. وقد بينت دراسة التغيرات البيئية سنوية لدرجة الحرارة المتوسطة وجود ارتفاع في درجة الحرارة منذ نهاية تسعينات القرن الماضي، حيث تكون درجة الحرارة عالية في المناطق الشمالية والوسطى للملكة بالمقارنة مع المنطقة الجنوبية. وعلاوة على ذلك فإن القيم لهذا التباين تظهر في فصل الشتاء (≈ 30%) بينما أقل قيم تظهر في الصيف (≈ 2%). وقد أوضحت الدراسة أن هذا التباين الشديد في درجة الحرارة فوق المملكة العربية السعودية مرتبط بشكل كبير بظاهرة تذبذب الشمال الأطلسي (NAO) بنسبة تراقب عكسية ذات دالة إحصائية تصل إلى 95% لجميع الفصول باستثناء فصل الخريف. وتكون أكثر وضوحًا خلال فصل الشتاء. إضافة إلى ذلك فإن درجة حرارة فصل الشتاء تتأثر أيضاً بملامح ذنبية القطب الشمالي (AO)
في حين تتأثر درجة حرارة المملكة في فصل الربيع بظاهرة النوسان الجنوبي (ENSO). ويخلص هذا البحث إلى أن الطور السلبي لكل من النوسان الجنوبي (ENSO) وذبذبة القطب الشمالي (AO)، وتذبذب الشمال الأطلسي (NAO) تلعب دوراً رئيسياً في ارتفاع درجات الحرارة على المملكة العربية السعودية.