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Temperature and precipitation variability over Euro-near East Asia

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Abstract

The main objective of this study was to present trends in different indices of daily and monthly extreme temperature and precipitation and comparison of mean temperature and precipitation variations for selected meteorological stations in Turkey (Kandilli and Bursa) and Saudi Arabia (Medina and Dhahran). The effects of Saudi Arabia climate change and the North Atlantic Oscillation (NAO) on the variation of these parameters were analysed. In recent years, there have been numerous studies of trends in extreme temperature, heat island effects and precipitation and temperature indices from around the world. This study presents a long-term analysis of air temperature and precipitation in Turkey and Saudi Arabia. One dimensional continuous wavelet and discrete wavelet packets were used to study variations in air temperature and precipitation within the study areas for the sub-period 1983-1998. The temperature indices were computed from daily and monthly maximum, minimum and mean air temperature values for selected stations in Turkey and Saudi Arabia. A set of eight temperature indices was selected for this study. The precipitation indices were computed from daily and monthly rainfall rate for all stations in the two countries. Two precipitation indices were selected to analyse the effects of micro-, meso- and large-scale fluctuations. Indices change significantly as the climatic dynamics change from one season to another. Wavelet techniques are capable of revealing various aspects of data that allow investigation of climate dynamics and global warming. In conclusion, some similarities were defined between seasonal temperature values in Kandilli and Medina, and the negative role of positive NAO values on air temperature variations.

Key words: Temperature-precipitation indices, NAO, wavelet.

Introduction

The variations in precipitation and surface air temperature observed over an area are important factors in assessing water availability and evaporation, which play an important role in agriculture, industry and related human activities [1-4].

Regression and wavelet analysis have been employed to trace and to quantify temporal variations in eastern Ontario. Possible links between observed climate change of these stations and possible natural and anthropogenic drivers were also investigated. The ARIMA model was used to study potential future changes in temperature and precipitation in the South-east Anatolia Project [5-13]. A probabilistic forecast is produced by merging the statistics of internal, ocean-driven North American climate with scenario-driven forced responses, assuming linearity and equal probability for each internal decadal state over the period 2011-2020 [14, 15].

Wavelet analysis permits the identification of intermittency and its statistical characterization in natural time series, it may provide valuable information about the dynamics underlying the series. Wavelet transforms have been successfully applied to different time series in order to understand their temporal scales of variability [2-6]. This methodology was applied in the present study, to determine and compare variations in temperature and precipitation in Turkey and Saudi Arabia.

Analysis of temperature indices indicates the occurrence of fewer cold nights, cold days and frost days, and, conversely, more warm nights and warm days across Canada [13]. No consistent changes were found in most of the indices of extreme precipitation. This paper discusses time series, frequency and index analyses of some meteorological variables based on the surface observatory data from two stations (pilot regions) in each country. The results of this study, focusing on the variations in these meteorological variables may be utilized to define their role in environmental and ecological problems. Therefore, the first objective of this study is to define the temporal and spatial distributions of these variables; a further objective is to explain the variability of observed climate variability at these stations. The results may assist in developing measures to mitigate the effects of climate change, currently experienced in many important economic sectors [15-19].

Material and Methods

Study area: Fig. 1a-b presents two maps showing the locations of the study areas and meteorological stations. Two study areas and four stations were selected to analyse data in Turkey and Saudi Arabia. The observatories are in the north-western part of Turkey, in Marmara Region, Istanbul (Kandilli; 40°55' N, 29°05' E, h 114 m above mean sea level, AMSL) and Bursa (Uludağ; 40°07' N, 29°07' E, h 1877 m AMSL). The Turkish data are compared with recordings from two stations in Saudi Arabia, Medina (24.5° N, 39.6° E, h 926 m AMSL) and Dhahran (26°06' N, 50°10' E, h 22 m AMSL).

a

b

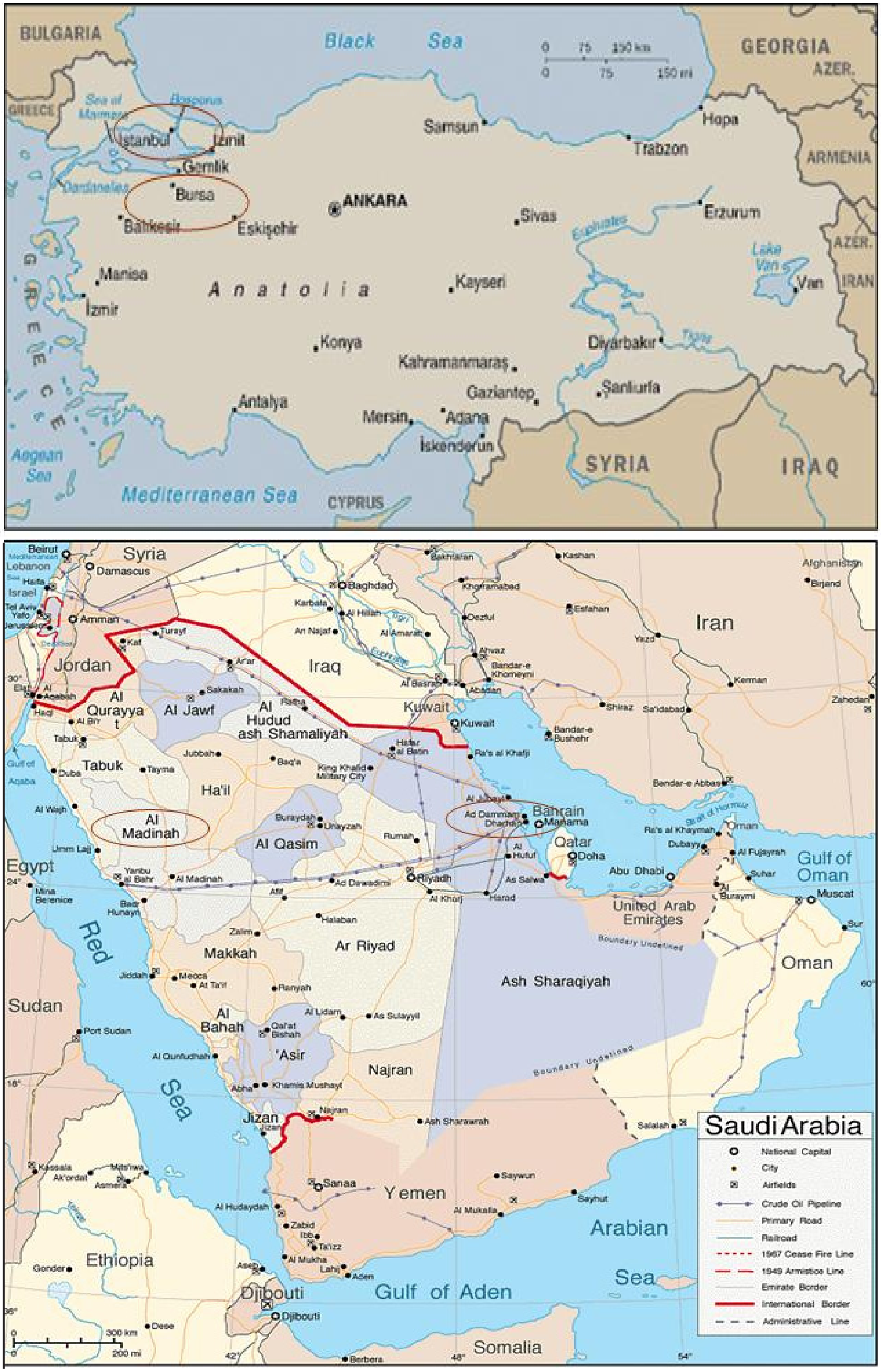


Figure 1. Maps showing location of the study areas and location of the meteorological stations in Turkey (a) and in Saudi Arabia (b).

Description of study areas in Turkey: Turkey is bounded by the Black Sea on the north, the Aegean Sea on the west and the Mediterranean Sea on the south. Although Turkey is situated in a relatively temperate climate zone, the diverse nature of the landscape and the existence in particular of mountains that run parallel to the coasts, result in significant climate variability from one region to another. In Istanbul and around the Sea of Marmara (Marmara Region), the climate is moderate and the temperature can drop below zero in winter. The two pilot areas (Kandilli and Uludağ) selected for case studies are shown in Fig. 1a. Kandilli is under the effect of air-sea interactions; Uludağ is one of the higher mountainous areas of Turkey.

Description of study areas in Saudi Arabia: Saudi Arabia is a country situated in South-west Asia, the largest country of Arabia, bordering the Persian Gulf and the Red Sea, north of Yemen [1]. The Hijaz Plateau and the Najd Plateau are on the north of the Arabian Peninsula. In winter, its climate is controlled by the interaction o Siberian high pressure, Mediterranean lows and the Sudan trough. Mediterranean cyclones, which migrate from west to east in association with upper troughs and active phases of subtropical and polar jets, are considered the main rain-producing synoptic systems. In summer, the entire circulation pattern is altered; so, mid-latitude extra-tropical disturbances do not affect the region. Saudi Arabia's climate is governed by a thermal low, which is an extension of the Indian monsoon low, centred over Asia. The whole area of the country can be classified as having a hot desert climate. The south-western region is an exception, where a mild steppe climate prevails. In this region, rain is more frequent in winter and spring than in summer and autumn. The two pilot areas selected for case studies (Medina and Dhahran) are located in this region (Fig. 1b).

Data: This study discusses daily mean air temperature and daily total rainfall in addition to temperature and precipitation indices of four stations in two countries during the period 1983-1998. Data are based on measurements of daily mean air temperature and daily total rainfall rate values for the periods 1901-2003 in Turkey and 1990-2006 in Saudi Arabia, respectively (Table 1).

Methods: Statistical methods SPSS and MATLAB (wavelet menu) programs were used for spatial and temporal analysis of monthly and annual mean, maximum and minimum air temperatures, rainfall and the effects of the North Atlantic Oscillation on these variations.

Wavelet menu: The MATLAB Wavelet Toolbox contains graphical tools and command line functions. It is possible to examine and explore characteristics of individual wavelet packets, to perform wavelet packet analysis of one- and two-dimensional data [12]. Wavelet packets compress and remove noise from signals and images. Due to the inherent complexity of packing and unpacking complete wavelet packet decomposition tree structures, the Wavelet Packet 1D and Wavelet Packet 2D graphical tools are recommended for performing exploratory analysis in many different interdisciplinary fields, from medicine to environmental problems[7, 8, 10, 11].

Basics of wavelet analysis: In this section we shall give some basic definitions about wavelet transform. A wavelet is a family of small waves generated from a single functions f(t), called a mother wavelet. A sufficient condition for a function f(t) to qualify as a mother wavelet is discussed by Siddiqi *et al.*[11].

One problem with performing the wavelet transform in Fourier space is that this assumes the time series as periodic ones. The result is that signals in the wavelet transform at one end of the time series will get wrapped around to the other end. This effect is more pronounced at larger scales as the influence of each wavelet extends further in time. Principles of wavelet transforms are listed as follows: 1) split up the signal by frequency ranges, 2) representing the same signal, but all corresponding to different frequency bands and 3) only providing what frequency bands exists at what time intervals.

Recent developments have provided an opportunity to determine inter-annual and inter-decadal oscillations in climate variables using different techniques (Table 2). The wavelet transform is a useful tool for data analysis in atmospheric science[7]. The power of wavelet analyses is that frequency and time deposition of data are possible. In contrast, traditional Fourier analysis produces only frequency decomposition. Wavelet analysis allows one to locate power variations within a discrete time series at a range of scales. Wavelet transform relates window width to the frequency of base function, forming a flexible time window to overcome the limitations of Fourier transform techniques. Wavelet analysis has been applied to various oceanic and meteorological fields, including daily atmospheric pressure, dispersion of Yanai waves, satellite infrared radiance and sea surface temperature [6, 11, 12]. Signal f(t) represents one of the variables as given in Equation 1a.

$$\int_{-\infty}^{\infty} |f(t)|^2 dt \quad < \infty \tag{1a}$$

The Fourier transform F of f(t) is defined as:

$$F(\omega) = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt \tag{1b}$$

$$\int_{-\infty}^{\infty} |W_f(a,b)|^2 db = W(a) \tag{2}$$

which is called the wavelet variance or wavelet spectrum. It may be observed that the scalogram can be represented either as a three-dimensional plot or as a two-dimensional grey scale image. Here, parameters *a* and *b* represent the scaling factor and the location in time, respectively [6, 11]. In this paper, f(t) was considered as daily total rainfall, daily mean air temperature and NAO values.

Table 1. Description of data.

Station	Data	Period
Kandilli and Uludağ	Daily mean air temperature and daily total rainfall rate	1901-2003
Medina and Dhahran	Daily mean air temperature and daily total rainfall rate	1990-2006
Kandilli, Uludağ, Medina and Dhahran	Daily temperature and precipitation indices	1983-1998

Analyses: Climate variability is defined in different six scales, as shown in Table 2. Climate variability will be explained as inter-monthly, semi-annual, residual annual, inter-annual, sub-

Table 2. Climate variability.

Climate variability	Time scale
Inter-monthly fluctuations	2.0-3.1 months
Semi-annual cycle	4.7-7.4 months
Residual annual cycle	1.3-16.0 months
Inter-annual variations	2.2-3.5 years
Sub-decadal variations	5.3-8.3 years
Decadal to centennial changes	10.6-110.7 years

decadal or decadal to centennial changes by considering the time scales of variables.

Statistical analysis: Four seasonal variations of daily mean temperature values in Kandilli show different intervals, as shown in Fig. 2a. In spring, there is a decreasing trend in temperature variations, whereas a slightly increasing trend was observed in other seasons. The highest increasing trend is observed in summer. Seasonal variation of daily mean temperature values in Uludağ is presented in Fig. 2b. An increasing trend is observed in summer, beginning from the 1990's. In spring, autumn and winter, there are some decreasing trends in temperature values. The largest decreasing trend is observed in spring.

As shown in Fig. 2c-d, seasonal temperature trends are positive at both the Medina and Dhahran Saudi Arabian stations. In Dhahran, the higher increasing trends of temperature variation are observed in winter and autumn. Similarly, in Medina, higher increasing air temperature trends are observed in autumn and winter, respectively.

In general, the increasing trend in temperature observed in Kandilli is higher than values recorded in Uludağ. Similarly, higher positive temperature trends are observed in Medina than Dhahran in three seasons (except winter) in recent years. Increasing values would be associated with urbanization and heat island effects at all stations, beginning from the 1990's.

Results

Temperature and precipitation indices: Descriptive statistics of daily temperature and rainfall rate (R) values are presented in Table 3. Daily mean air temperature values are 13.6°C and 5.1°C; rainfall rates are 5.9 and 10.2 mm in Kandilli and Uludağ, respectively. Daily total rainfall rate is almost two times higher in Uludağ than the values observed in Kandilli. The standard deviations of rainfall are also higher in Uludağ than in Kandilli. The standard deviations of temperatures do not show significant differences between the two stations. Trends of precipitation indices are positive, with a small increasing ratio in Uludağ. Daily total precipitation values show a slightly decreasing trend in Kandilli. Daily maximum precipitation is almost two times more in Dhahran than in Medina.

Table 3. Statistical description of daily mean air temperature and total rainfall rate values in Turkey (Kandilli and Uludağ) between 1983-1999.

Statistical parameter	Kandilli		Uludağ	
	T mean (°C)	R (mm)	T mean (°C)	R (mm)
N	5843	2451	5844	2182
Mean	13.6	5.9	5.1	10.2
Std. error of mean	0.1	0.2	0.1	0.3
Median	13.7	2.2	5.1	5.2
Mode	19.0	0.0	0.0	0.0
Std. deviation	7.3	10.0	8.1	14.0
Variance	53.2	100.2	66.1	196.7
Skewness	-0.1	4.7	-0.1	3.9
Std. error of skewness	0.0	0.0	0.0	0.1
Kurtosis	-1.1	36.0	-0.7	28.3
Std. error of kurtosis	0.1	0.1	0.1	0.1
Range	35.0	123.0	47.0	187.0
Minimum	-6.0	0.0	-20.0	0.0
Maximum	29.0	123.0	27.0	187.0
Percentiles (10)	3.80	0.10	-5.4	0.4
90	23.00	16.50	15.8	25.4
95	24.10	23.50	17.8	36.5

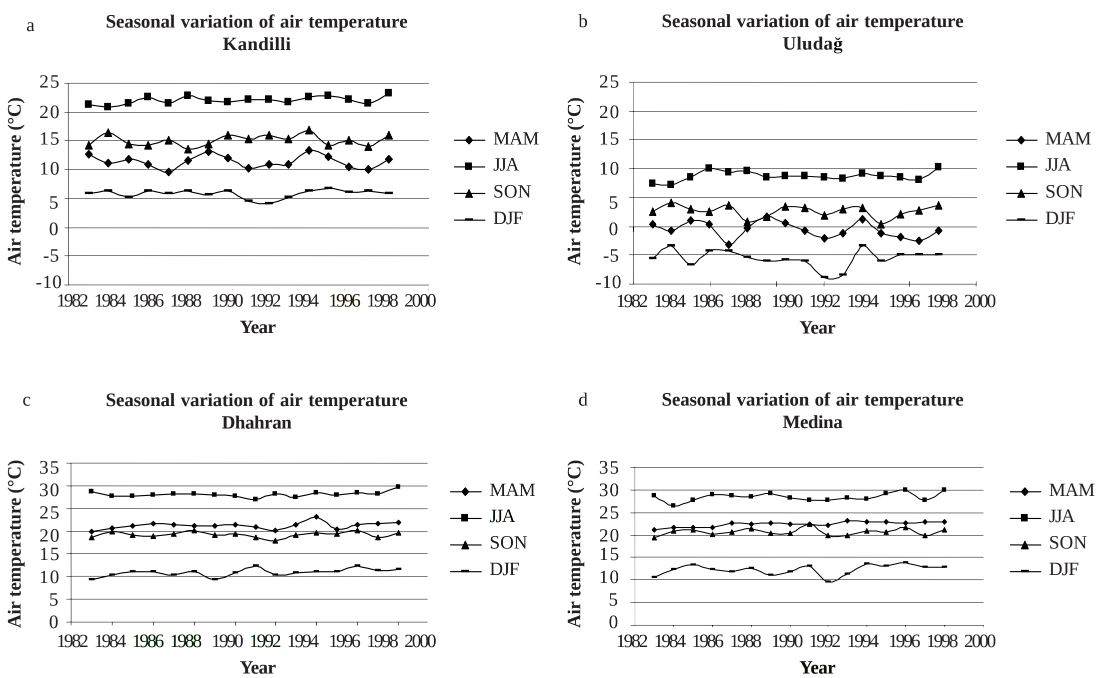


Figure 2. Seasonal mean air temperature variation in Kandilli (a), Uludağ (b), Dhahran (c) and Medina (d), (1983-1998).

Table 4. Temperature indices in Kandilli and Uludağ, Turkey (1983-1998).

Temperature indices	Definitions	Units	Kandilli	Uludağ
Frost days	Number of days with $T_{min} < 0°C$	days	106	2431 (n=5844)
Cold days	Number of days with $T_{max} < 10^{th}$ percentile	days	-	565
Cold nights	Number of days with $T_{min} < 10^{th}$ percentile	days	616	587
Summer days	Number of days with $T_{max} > 25°C$	days	137	106
Warm days	Number of days with $T_{max} > 90^{th}$ percentile	days	602	567
Warm nights	Number of days with $T_{min} > 90^{th}$ percentile	days	-	578
Diurnal temperature range	Mean of the difference between T_{max} and T_{min}	°C	34.9	7.5
Standard deviation of mean	Standard deviation of daily mean temperature from T_{mean} normal	°C	7.3	8.1

Temperature indices for the two stations in Turkey are presented in Table 4. The number of frost days is higher in Uludağ (2431 days in whole period) than in Kandilli (106 days in whole period).

If we compare air temperature averages in the two stations in Saudi Arabia, mean temperature values are 26.1°C in Dhahran and 28.3°C in Medina (Table 5). Maximum and median values of temperatures are higher in Medina, slightly warmer than in Dhahran. In contrast, higher minimum air temperature is observed in Dhahran than in Medina. Daily mean total rainfall rate is slightly higher in Dhahran than in Medina. Precipitation trends are positive, both in Dhahran and Medina.

Standard deviations of air temperature values are almost the same in Medina and Dhahran. Daily maximum precipitation in Dhahran is two times higher than the value observed in Medina. There were not observed frost days in Dhahran or Medina (Table 6).

Table 5. Statistical description of daily mean air temperature and total rainfall rate values in Saudi Arabia (Dhahran and Medina) (1983-1998).

Statistical parameter	Dhahran		Medina	
	T mean (°C)	Rainfall rate (mm)	T mean (°C)	Rainfall rate (mm)
N	12896	12498	12505	12427
Mean	26.1	0.3	28.3	0.2
Std. error of mean	0.1	0.0	0.1	0.0
Median	26.9	0.0	29.1	0.0
Mode	35.0	0.0	36.0	0.0
Std. deviation	7.6	2.5	7.3	1.7
Variance	57.9	6.1	53.3	3.0
Skewness	-0.2	21.9	-0.3	16.7
Std. error of skewness	0.0	0.0	0.0	0.0
Kurtosis	-1.3	736.0	-1.1	343.2
Std. error of kurtosis	0.0	0.0	0.0	0.0
Range	34.0	125.0	39.0	52.0
Minimum	7.0	0.0	3.0	0.0
Maximum	41.0	125.0	42.0	52.0
Percentiles (10)	15.5	0.0	18.0	0.0
90	35.4	0.0	37.1	0.0
95	36.3	0.1	38.1	0.0

Precipitation indices for Turkey and Saudi Arabia are presented in Tables 7 and 8, respectively. As shown in Table 7, the number of days with rain is higher in Uludağ (2812 days) than in Kandilli (2275 days). The maximum number of consecutive dry days is approximately two times higher in Uludağ than in Kandilli. The number of days with rain is higher in Dhahran (667 days) than in Medina (427 days) (Table 8). Simple day rain intensity is almost the same for both stations. The maximum number of consecutive dry days is approximately three times higher in Dhahran than in Medina.

Linear correlation coefficients between Kandilli and Uludağ for seasonal mean air temperature values are positive, change is within range of 0.76 and 0.92 (Table 9). The same coefficients between Kandilli and Dhahran are positive for mean air temperature values, varying within the range of 0.84 and 0.86. Linear correlation coefficients between Kandilli and Medina for mean air temperature values are positive, varying within the range of 0.83 and 0.85. These coefficients between Uludağ and Dhahran for mean air temperature values are positive, within the range of 0.77 and 0.81. Between Uludağ and Medina, coefficient for mean air temperature values is positive, within the range of 0.77 to 0.80. Linear correlation coefficients for seasonal mean air temperature in Dhahran and Medina are positive, varying between 0.91 and 0.95. Seasonal variations in air temperature values at Kandilli are more similar to the variations in Dhahran than those recorded at Medina. There is a sufficient evidence of this relationship, $\alpha = 0.05$. Linear correlation coefficients between all four stations for total rainfall values vary between 0.02 and 0.24.

Wavelet techniques: Fig. 3a shows 1D wavelet analysis of air temperature values in Kandilli. In the second part of the study

Table 6. Temperature indices in Dhahran and Medina, Saudi Arabia (1990-2006).

Temperature indices	Definitions	Units	Dhahran	Medina
Frost days	Number of days with $T_{min} < 0°C$	days	0	0
Cold days	Number of days with $T_{max} < 10^{th}$ percentile	days	1164	1159
Cold nights	Number of days with $T_{min} < 10^{th}$ percentile	days	1177	1204
Summer days	Number of days with $T_{max} > 25°C$	days	9596	10783
Warm days	Number of days with $T_{max} > 90^{th}$ percentile	days	1287	1241
Warm nights	Number of days with $T_{min} > 90^{th}$ percentile	days	737	1247
Diurnal temperature range	Mean of the difference between T_{max} and T_{min}	°C	12.8	13.5
Standard deviation of mean	Standard deviation of daily mean temperature from T_{mean} normal	°C	7.6	7.3

Table 7. Precipitation indices in Kandilli and Uludağ, Turkey (1983-1998).

Precipitation indices	Definitions	Units	Kandilli	Uludağ
Days with rain	Number of days with rain > trace	days	2275	2812
Simple day intensity index of R	Annual total rain / number of days with rain > trace	mm/d^{-1}	10.5	0.49
Max no of consecutive dry days of P	Max no of consecutive dry days (trace days are excluded)	days	56	109
Highest 5-day precipitation amount	Maximum precipitation sum for 5-day interval.	mm	260.7	119.8
Very wet days (> = 95th percentile)	Number of days with precipitation (> = 95th percentile)	days	121	23
Heavy P days (> = 10mm)	Number of days with precipitation (> = 10 mm)	days	449	744

Table 8. Precipitation indices in Dhahran and Medina, Saudi Arabia (1990-2006).

Precipitation indices	Definitions	Units	Dhahran	Medina
Days with rain	Number of days with rain > trace	days	657	427
Simple day intensity index of R	Annual total rain/number of days with rain > trace	mm/d^{-1}	4.8	4.9
Max no of consecutive dry days of P	Max no of consecutive dry days (trace days are excluded)	days	2132	642
Highest 5-day precipitation amount	Maximum precipitation sum for 5-day interval.	mm	75	-
Very wet days (> = 95th percentile)	Number of days with precipitation (> = 95th percentile)	days	12	10
Heavy P days (> = 10mm)	Number of days with precipitation (> = 10 mm)	days	77	64

Table 9. Linear correlation coefficients between seasonal air temperature values in study areas.

Correlation coefficient	Kandilli	Uludağ	Dhahran	Medina
Kandilli	1	0.76-0.92	0.84-0.86	0.83-0.85
Uludağ		1	0.77-0.81	0.77-0.80
Dhahran			1	0.91-0.95
Medina				1

period, minimum air temperature values show a slightly greater increasing trend than the first part of the period. Total rainfall values show an increasing trend in Kandilli (Fig. 3b). Standard deviations of rainfall values decrease in the second part of the study period. In Fig. 3c, at the first part of graphic, small-scale (with approximately 17 days periodicity) inter-monthly fluctuations, residual annual cycles and semi-annual cycles (with 40-55 days periodicity) effects on daily mean air temperature variations have been observed.

Wavelet decompositions of air temperature and precipitation values in Medina are presented in Fig. 4a-b. Slightly higher values were recorded in the second part of the period. Fig. 4c shows continuous wavelet analysis of daily mean air temperature values and detection of self similarity in Medina with Morlet function between the years 1983 and 1998. Only residual annual cycle and inter-monthly variability are associated with temporal variations of daily air temperature in Medina.

Analysis of the North Atlantic Oscillation effects: Wavelet analysis of North Atlantic Oscillation is presented in Fig. 5a-b. Beginning from 1984, residual and annual cycles were observed with a 20-36 months range scale (Fig. 5c). Inter-annual, sub-decadal and decadal to centennial changes were recorded with 50-65 months periodicity.

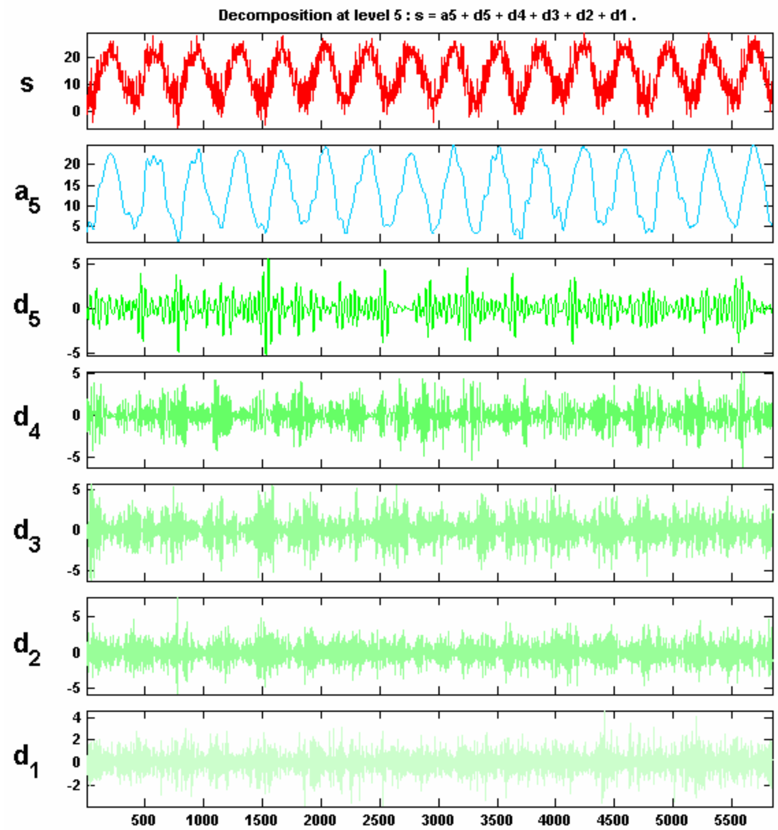
The North Atlantic Oscillation (NAO) is temporal variations of Sea Surface Temperature (SST) values (Fig. 5a-b). Positive NAO variations are associated with higher temperature values and reduced rainfall. These effects are more dominant in Kandilli. Increasing ratio of daily mean air temperature values and decreasing trend of rainfall rate values are associated with positive NAO values in Kandilli. Positive NAO values associated with increasing temperature trends have also been observed in other stations.

Discussion and Conclusions

This paper focuses on climatic variability of air temperature and precipitation indices and the application of wavelet methods to detect small-large scale effects on precipitation and temperature indices. For this purpose, daily, monthly and annual mean air temperature and rainfall values were analysed. Time series analysis shows trends in these data and the role of effects observed at different scales.

Extreme indices from station data were analysed in a simple format by considering input data as precipitation; maximum, minimum and mean air temperature values. The main aim of this paper was to define seasonal variations in the temperature and precipitation indices. The change in indices was investigated for study areas in Turkey and Saudi Arabia. The three main factors that influence precipitation are temperature, pressure and geographical differences.

Analysis of residual inter-annual cycles of variability shows semi-annual, inter-monthly and residual annual cycles and their role on air temperature values in Kandilli. Similar analyses for a



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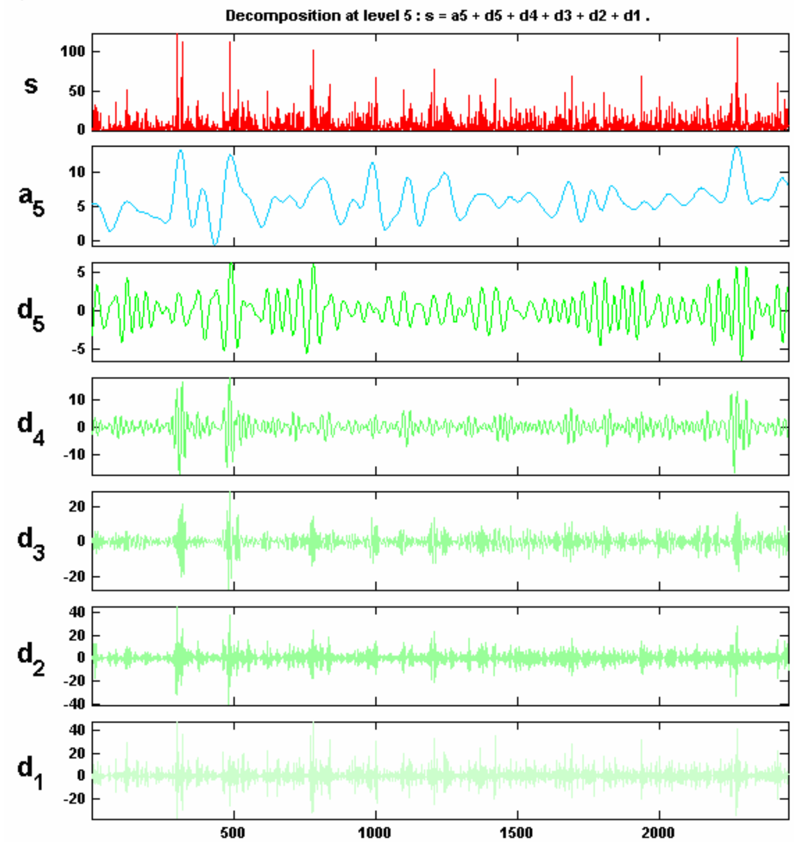

Figure 3a, b. 1D Wavelet analysis (decomposition) of daily mean air temperature values (a) and daily total rainfall rate values (b) in Kandilli, dMeyer with 5 levels, (1983-1998).

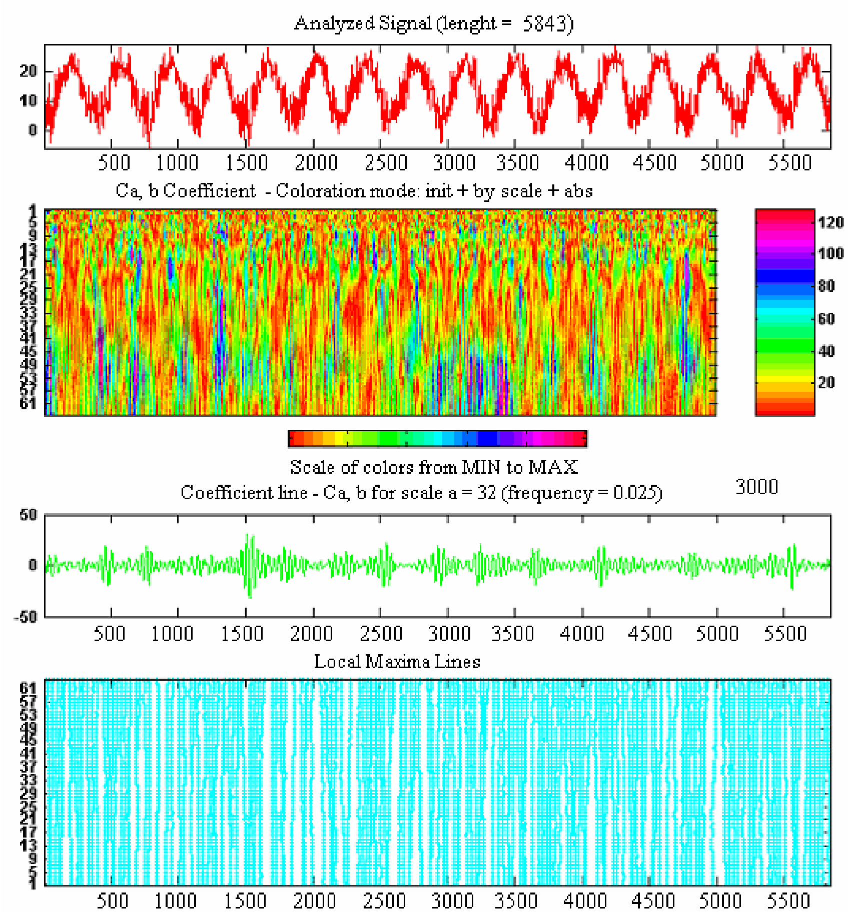

Figure 3c. 1D Continuous wavelet (detection of self-similarity) analysis of daily mean air temperature values in Kandilli, Morlet, sampling period: 1, (1983-1998).

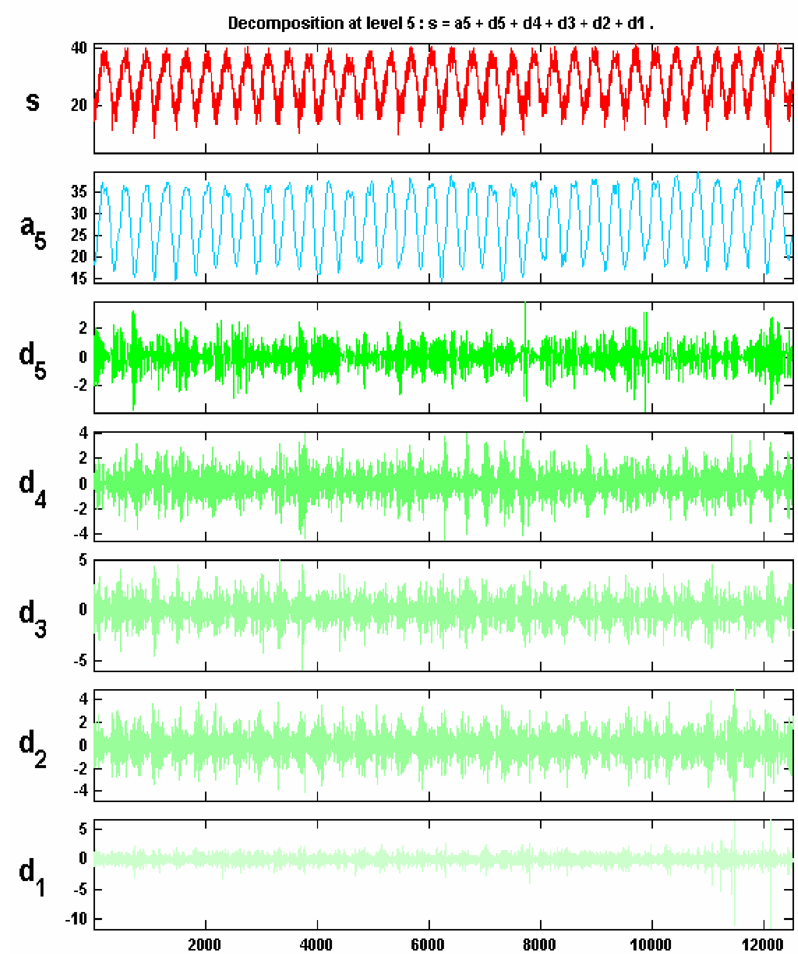

Figure 4a. 1D Wavelet analysis (decomposition) of daily mean air temperature values using dMeyer with 5 levels in Medina, (1983-1998).

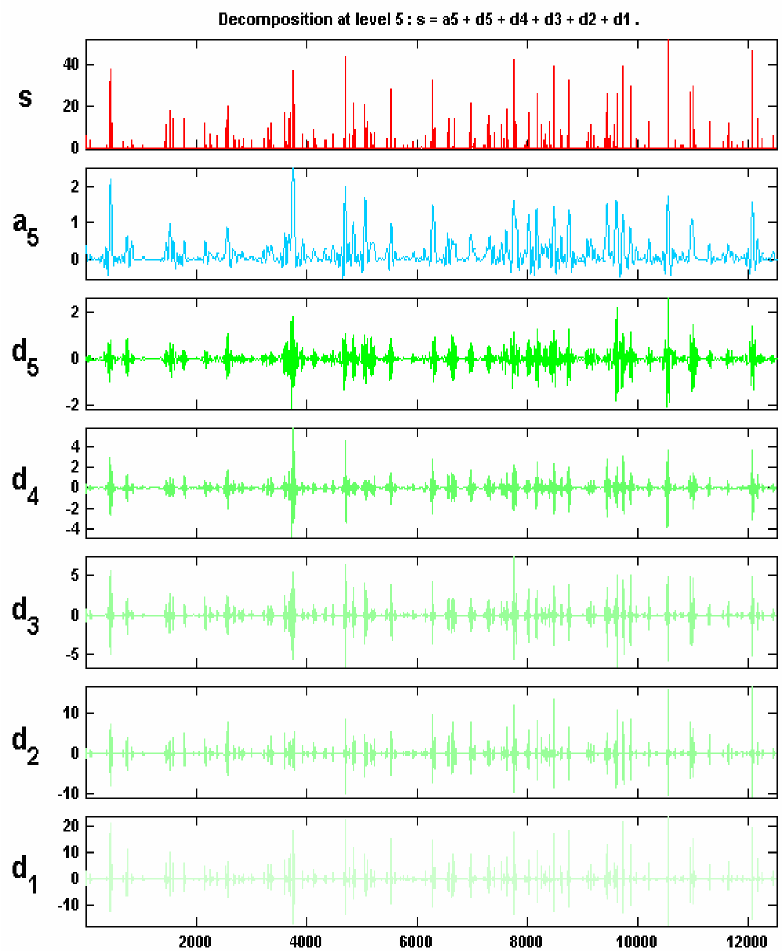

Figure 4b. 1D Wavelet analysis (decomposition) of daily total rainfall rate values using dMeyer with 5 levels in Medina, (1983-1998).

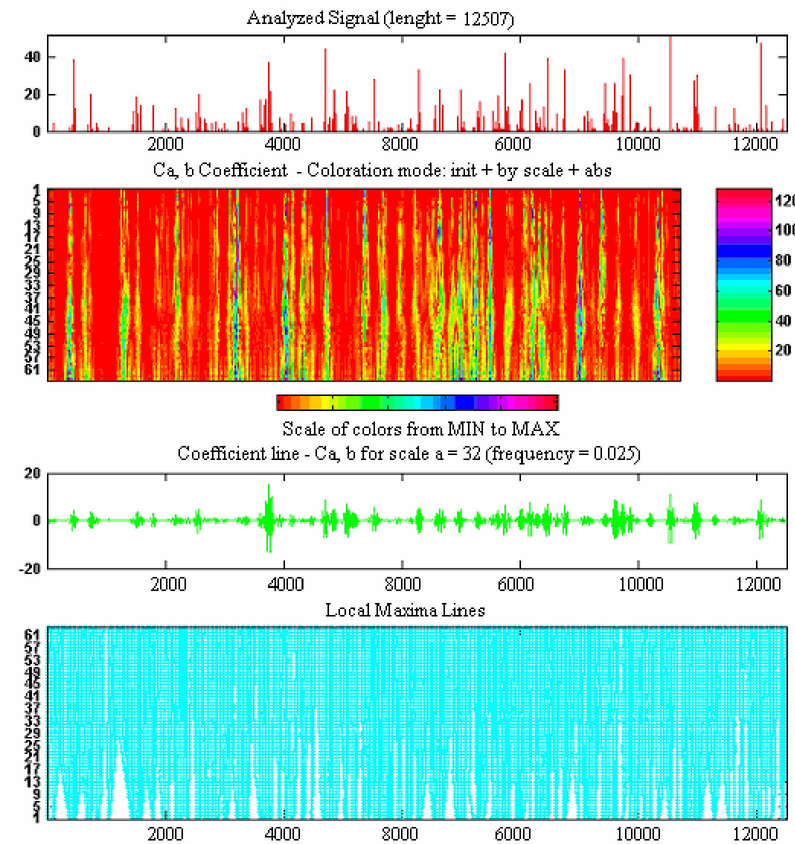

Figure 4c. 1D Continuous wavelet (detection of self similarity) Analysis of daily mean air temperature values with Morlet, sampling period: 1, in Medina (1983-1998).

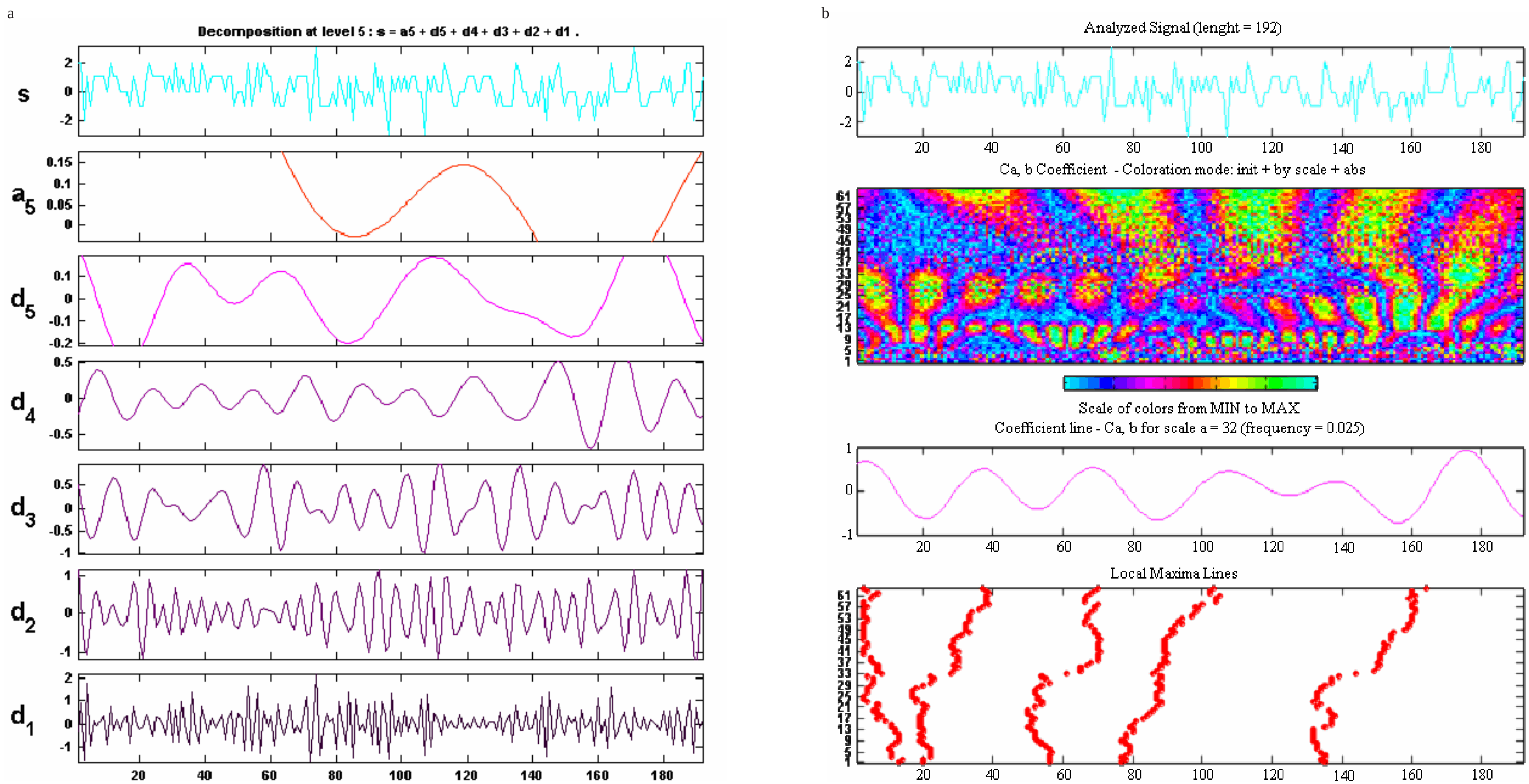

Figure 5. 1D Wavelet (monthly decomposition) NAO z-score, using Dmeyer with 5 levels (a); 1D Continuous wavelet (detection of self similarity) NAO Z-scores, DMeyer, sampling period 1 (b), (1986-2004) .

Medina explain the combined effects of only residual cycles and inter-monthly variability on temperature values at this location, but semi-annual cycles are not observed. The inter-annual variability shows that rainfall distribution over the south-western region in Saudi Arabia is not uniform. There are many factors affecting its irregularity; such as elevation, topographic configuration and orientation [1]. Moreover, Medina is characterized by the lowest rainfall variability compared with the other regions in the study area.

It is concluded that indices change significantly as the climatic dynamics change from one season to another. In climatological prediction models, the trends in time series of climatic variables and the correlations between them can help identify the model. This study may prove useful in other areas.

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