SPATIO-TEMPORAL ANALYSIS OF MAXIMUM AND MINIMUM TEMPERATURES OVER LEVANT REGION (1987-2017)

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ABSTRACT
This study aims to analyze the spatial and temporal variability of the annual and seasonal maximum (T_{max}) and minimum (T_{min}) temperatures, along with the diurnal temperature range (DTR) over the entire Levant region for the period 1987-2017. The temporal trends for these three variables were calculated at the annual and seasonal scales by using the non-parametric Mann-Kendall test. Furthermore, the difference of the means between the two periods (1987-2000 and 2001-2017) were assessed by using the non-parametric Mann-Whitney U test.
During 1987-2017, the Levant region suffered a significant warming for the annual maximum and minimum temperatures around 0.33 and 0.30˚C\decade, respectively. In addition, spring showed very strong and significant warming trend (around 0.53˚C/decade for T_{max} and 0.51˚C/decade for T_{min}) compared with the other seasons. The annual, spring and summer means of T_{max} and T_{min} have significantly increased over the Levant region during 2001-2017 compared with the period 1987-2000. Spatially, the decreasing trends showed very isolated and random patterns compared with the broad, intensive and coherent warming trends at annual and seasonal time scales. The warming over Jordan was generally the highest.

Key words: Maximum and Minimum temperatures, Trend, Levant region, Mann-Kendall

RESUMEN
El objetivo de este estudio es analizar los cambios espaciales y temporales en los promedios anuales y estacionales de las temperaturas máxima y mínima en la región del Levante durante 1987-2017. Estos promedios se calcularon a partir de datos diarios para cada estación y para toda la región de Levante. Las tendencias espaciales y temporales para tres variables se calcularon utilizando la prueba no paramétrica de Mann-Kendall. Además, la diferencia de medias anuales y estacionales entre los dos períodos 1987-2000 y 2001-2011 se evaluó mediante el uso de la prueba U no paramétrica de Mann-Whitney.
Durante 1987-2017, la región de Levante fue testigo de un calentamiento significativo en las temperaturas máximas y mínimas anuales de 0.33 y 0.30 ˚C/década, respectivamente. Además, la primavera mostró una tendencia al calentamiento muy fuerte y significativa en comparación con otras estaciones en 0.53 ˚C/ década para la temperatura máxima y en 0.51 ˚C/década para la temperatura mínima. La temperatura

máxima y mínima anual, de primavera y verano han aumentado significativamente en esta región durante 2001-2017 en comparación con el período 1987-2000. Las tendencias decrecientes mostraron un patrón muy aislado y aleatorio en comparación con las tendencias de calentamiento amplias, intensivas y coherentes en los promedios anuales y estacionales de la temperatura máxima y mínima. Las tasas de calentamiento en Jordania fueron generalmente las más altas.
Palabras clave: Levante, temperatura máxima y mínima, Tendencia, Mann-Kendall

1. INTRODUCTION

Climate change has been an issue of special interest globally because it involves serious environmental, economic and social implications. According to the studies of Intergovernmental Panel on Climate Change (IPCC), the rate of warming in southern and eastern Mediterranean over this century will be larger than global average warming (IPCC, 2013). The Mediterranean region is more vulnerable to climate change, especially with the existing water resources shortage, weakness of existing infrastructure, low adaptive capacity and frequent drought periods. Additionally, all these factors are escalated by the political conflicts and the rapid population growth (Terink et al., 2013; Mathbout 2016). Moreover, the Mediterranean region is under sever anthropogenic pressures: overfishing, habitat destruction, alteration of rivers inflow and pollution (Ballesteros, 2006). The Mediterranean experienced a downward precipitation trend through the second half of the twentieth century (Xoplaki et al., 2003), and this trend is expected to continue, with a decrease of up to 20% in total annual precipitation by the year 2050 (Black, 2009). The IPCC's scenarios for the eastern Mediterranean indicate: Summer temperatures will gradually increase 0.5–0.9˚C per decade over much of the region, and the number of warm days could increase by 50–60 additional days/year by the end of the 21^{st} century (Lelieveld et al., 2012).

There are very few previous studies assessing the changes in temperature across the Levant region as a whole (Syria, Lebanon, Jordan, Palestine and Israel). Donat et al., 2014 analyzed changes in extreme temperature and precipitation in the Arab region during 1980-2010, but only 4 stations were from Levant region. Zhang et al. 2005 analyzed changes in climate extreme indices over the Middle East region using data from 52 stations of 12 countries, but only 11 stations were from Levant. On the other hand, the changes in temperature were well documented in many other countries in the Middle East and North Africa (e.g., Toros, 2012; Soltani et al, 2016).

The present study has two objectives. Firstly, it tries to fill the gap in the climatic studies over the Levant region as a whole. Secondly, it contributes to provide a comprehensive temporal and spatial analysis of maximum (T_{max}), minimum (T_{min}) and diurnal temperature range (DTR) at annual and seasonal scales, analyzing the long-term trends during 1987-2017.

2. METHODS

2.1. Study area and Data

The geographical domain of this study extends over the Levant region, between the latitudes 34ºN-42ºN and longitudes 29ºE-37ºE, with an area of about 311974 km² and elevation ranges from 459 m below the sea level to 3093 m above the sea level (Fig. 1b). According to the Köppen classification, 85% of the area is classified as warm and cold arid-semiarid climate zones (BWh, BWk, BSh and BSk), which extends over the whole Eastern Plateau regions, whereas the warm Mediterranean climate zones (Csa) conform only 15% of the area and cover the western coastal regions (Fig. 1a). Mean annual T_{max} and T_{min} over the study area vary from 16.2 to 31.7ºC and from 5.4 to 22.6ºC respectively, depending on elevation and distance from the Mediterranean Sea. Daily temperatures were obtained from the Meteorological Departments of Syria, Palestine and Israel as well as from the National Oceanic and Atmospheric Administration (NOAA), International Center for Agricultural Research in the Dry Areas (ICARDA) and Lebanese Agricultural Research Institute (LARI). A data quality control (QC) of these data was carried out in order to identify systematic errors, missing data and outliers.

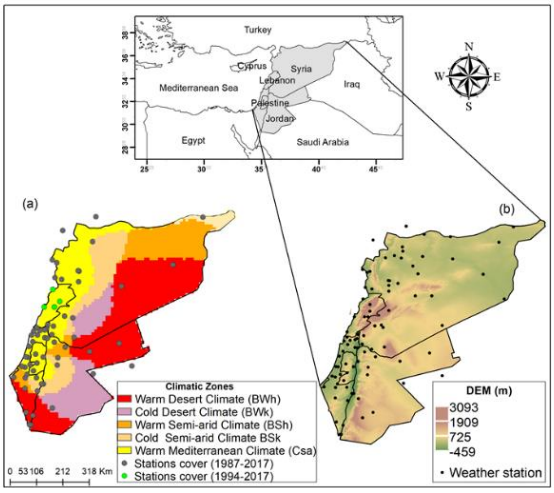

Fig. 1: Study area overview and spatial distribution of observed stations.

Time series were filtered based on two general criteria, the temporal continuity (at least 29 years) and coverage for the recent years (at least until 2015). The stations with shorter records were not used for the trend analysis, but they were still useful in assessing missing data and outliers. A total of 60 stations for 1987-2017 fulfilled the selected criterion. Fig. 1b shows all the available meteorological stations, and Fig. 1a shows the final stations used for this analysis.

In the second stage, time series were subjected to checking for any systematic errors, missing data and outliers. Missing data in one day were filled in by the averaged value of neighboring days (temporal interpolation). After that, the monthly averages of T_{max} and T_{min} were calculated for each station based on the daily data. All monthly averages calculated with 5 or less daily missing data were considered complete. Those calculated with 6 or more daily missing data (3.1%) from the whole dataset were spatially and temporally reevaluated. Furthermore, months with complete daily

missing data (0.6%) were filled in based on the neighboring stations (spatial interpolation) for distances < 80 km and with correlation r > 0.80.
The comparison with neighboring stations (spatial coherency) was also used to determine whether an outlier was the result of natural factors or systematic errors They were manually edited by replacing them with the monthly averages values.
In the third stage, monthly series of selected stations were tested for homogeneity. The method used follows the approach proposed by Wijngaard et al., (2003). Four absolute tests (Pettitt, standard normal homogeneity test (SNHT), Buishand and Von Neumann ratio tests) were applied at 5% significance level using RStudio V. 3.4.3. At end of this stage, all non-climatic change points were fitted before the change points by using software package AnClim v5.025.

2.2 Trend detection in the annual and seasonal averages

The annual and seasonal averages of T_{max}, T_{min} and DTR were derived from the monthly averages for each station. Furthermore, they were calculated for the whole study area during the period 1987-2017. The trends were calculated by the Mann-Kendall non-parametric test (MK test) and Sen's slope estimator. Mann-Kendall test is less sensitive to the non-normality of a distribution and less affected by outliers in the series (Zhang et al., 2000). The presence of serial correlation was examined prior to the application of MK test, and the pre-whitening approach was used to remove the correlation (von Storch, 1995). The statistical significance of the trends was assessed at the 0.1, 0.05, 0.01 and 0.001 levels.
The temporal averages calculated for annual and seasonal scales were plotted. They were also fitted by using the non-parametric Lowess smoothing technique to moderate the temperature variability during the period (Cleveland, 1979). The significant differences of the means between the periods 1987-2000 and 2001-2017 were also analyzed by using the non-parametric Mann-Whitney U test for two samples.

3. RESULTS

3.1 Temporal behaviour for annual and seasonal averages during 1987-2017

Figure 3 shows the temporal behavior for the annual and seasonal averages of T_{max}, T_{min} and DTR over the Levant region. The long-term annual averages reached 25.5°C for T_{max}, 13.9°C for T_{min} and 11.6°C for DTR. In winter\summer, they reached 16.1\33.7°C for T_{max}, 6.7\20.7°C for T_{min} and 9.4\12.9°C for DTR. The long-term autumn averages of T_{max} and T_{min} are higher than those for spring by 3–3.5°C, where they ranged for spring\autumn by 24.6\27.6°C for T_{max}, 12.2\15.7°C for T_{min} and 12.4\11.9°C for DTR. The analysis at stations revealed that the highest annual average was in 2010 at Elat (southernmost of Palestine, elevation:12m) with 33.6°C for T_{max}, and at Sedom Man (southern east of Negev desert) in 2010 with 23.7°C for T_{min}.
During 1987-2017, the warmest\coldest annual averages were in 2010\1992, respectively, with values of 27.5\23.6°C for T_{max} and by 15.5\12.4°C for T_{min}. At the global scale, the warmest year was also in 2010 (WMO, 2011) as well as at regional scales in Saudi Arabia (Nazrul Islam et al., 2015), Egyptian Mediterranean coast (Tonbol et al., 2018) and Turkey (Hadi et al., 2018). Furthermore, the world was also

cold during 1991\1992 probably due to the eruption of Mt. Pinatubo (Jones, 1994) and years 2010\1992 were the warmest\coldest in Iran (Ghasemi, 2015).
Annual, spring and autumn averages of T_{max} and T_{min} have generally passed three major stages: an increase below their long-term averages since 1987 until 2000. After that, they showed a decrease near their long-term averages during 2000-2006, and then, they began to increase above their long-term averages since 2006 onward. The general trends for winter and summer averages followed a similar pattern, except in the period 1987-1992 when the averages decreased below their long-term means. The annual and seasonal T_{max} and T_{min} tended to increase over the study area during the last decade of the 20th century. Such tendency was also found in Turkey, Saudi Arabia, Egypt and Spain (Türkeş et al., 2002; Almazroui et al., 2012; Domroes et al., 2005; Gonzalez-Hidalgo et al., 2016).
Difference of the means and their significance for the annual and seasonal averages of T_{max}, T_{min} and DTR during the two periods 1987-2000 and 2001-2017 are listed in Table 2. The results show a warming trend during 2001-2016 at annual and seasonal scales. For T_{max}, the study area shows a high and significant ($\alpha \leq 0.05$) increase in its mean for spring and winter during the second period (2001-2017) by 0.9 and 1.1°C, respectively. For T_{min}, a strong and significant increase was in the means of spring and summer by 1.1 and 1.1°C, respectively. The results also indicated that winter showed non-significant increase in its mean of DTR by 0.6 °C, whereas the means of summer and autumn displayed non-significant decreases by -0.3 and -0.2 °C, respectively.

3.2 Trends for the annual and seasonal averages during 1987-2017

All seasons showed significant warming trends for T_{max} and T_{min}, with the warming in the T_{max} is slightly stronger than that for the T_{min}, except for autumn (Table 3). The analyzed region witnessed significant warming at 0.001 level for the annual T_{max} and T_{min} averages, with values of 0.33 and 0.30˚C\decade, respectively. The annual DTR average showed very weak and non-significant decreasing trend.

It is also interesting to note that spring showed very strong and significant warming trend compared with the other seasons by 0.53˚C/decade for T_{max} and 0.51˚C/decade for T_{min}. Winter showed strong warming in T_{max} by 0.50˚C/decade, whereas it showed low significance for T_{min}. Autumn exhibited strong warming in T_{min} by 0.52˚C/decade, whereas it showed low significance for T_{max}.

3.3 Spatial trends at annual and seasonal scales

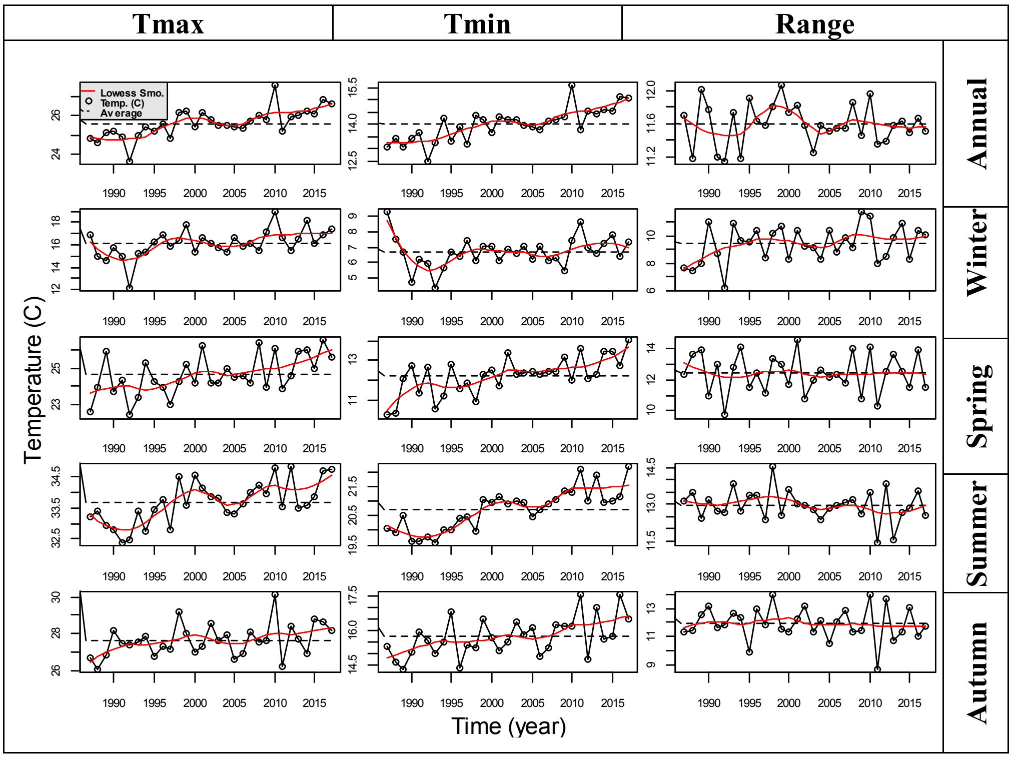

Fig. 2: Temporal behavior for the annual and seasonal T_{max}, T_{min} and DTR averaged over the study area. Red lines indicate the Lowess smoothing, dashed lines the long-term averages for the whole period 1987-2017.

Level	Tmax		Diff.	Tmin		Diff.	DTR		Diff.
	P1	P2		P1	P2		P1	P2	
Annual	25.1	25.9	0.8***	13.4	14.3	0.9***	11.6	11.6	0
Winter	15.6	16.5	0.9*	6.5	6.8	0.3	9.1	9.7	0.6
Spring	24	25.1	1.1***	11.6	12.7	1.1***	12.4	12.4	0
Summer	33.3	34	0.7***	20.1	21.2	1.1***	13.1	12.8	-0.3
Autumn	27.4	27.9	0.5	15.4	16	0.6*	12	11.8	-0.2

*Table 1: Means difference in the annual and seasonal averages of T_{max}, T_{min} and DTR and their significance level over the study area during the period 1 (P1, 1987-2000) and period 2 (P2, 2001-2017). *** indicate significant difference at α = 0.001 level, **at α = 0.01 level, * at α = 0.05 level, and + at α = 0.1 level.*

Level	T_{max} (˚C/year)	T_{min} (˚C/year)	DTR (˚C/year)
Annual	0.033***	0.030***	-0.003
Winter	0.050**	0.027+	0.030
Spring	0.053**	0.051**	-0.007
Summer	0.034**	0.029***	-0.021
Autumn	0.036*	0.052***	-0.027

*Table 2: Trends for the annual and seasonal averages during 1987-2017. *** indicate significant difference at α = 0.001 level, **at α = 0.01 level, * at α = 0.05 level, and + at α = 0.1 level.*

3.3.1 Maximum temperature

The results provide strong evidences for significant warming trends throughout the entire Levant region (Fig. 4). The decreasing trends showed very isolated and random pattern compared with the broad, intensive and coherent trends of warming. Only one station in Lebanon (Houche oumar) exhibited significant decreasing trends in summer and autumn by -0.38 and -0.42°C\decade, respectively. A total of 85%, 65%, 73%, 70% and 43% of stations (60 stations) exhibited significant warming trends in the annual, winter, spring, summer and autumn averages of T_{max}, respectively. It is interesting to note that the strong warming trends (0.45-0.65°C\decade) spatially occurred in winter and spring. Summer and autumn exhibited less significant warming trends (with values lower than 0.44°C\decade) for all areas. The strong warming trends generally covered the entire Jordan mainly, central and southern areas of West bank (Jerusalem and Hebron) and the southern areas of Syria. In spring, the strong warming also extended to cover the Eastern Plateau as well as the north-western areas of Syria (Fig. 4). The warm and cold arid/semi-arid climate zones (Fig. 1a) were affected by strong warming trends in winter, spring and summer compared with the warm Mediterranean climate zones (Fig. 4). Generally, the southern countries (Palestine and Jordan) showed strong warming trends compared with the northern countries (Syria and Lebanon). The rates of warming over Jordan were 0.36, 0.51, 0.58, 0.44 and 0.30°C\decade for annual, winter, spring, summer and autumn, respectively. Over Palestine, they were 0.31, 0.44, 0.52, 0.34 and 0.30°C\decade, respectively, while over Syria, they reached 0.28, 0.40, 0.46, 0.30 and 0.30°C\decade, respectively.

3.3.2 Minimum temperature

The results showed that the areas affected by significant warming trends at annual and seasonal scales for T_{min} were less than those for the T_{max}, except in spring and autumn. In this context, a total of 83%, 32%, 80%, 65% and 62% of stations exhibited significant warming trends at annual, winter, spring, summer and autumn, respectively (Fig. 4). The spatial analysis indicated that the rates of warming are generally lower than those for T_{max}, except for autumn and at annual scale in Syria and Lebanon. Over Jordan, the rates of warming were 0.30, 0.22, 0.46, 0.40 and 0.39°C/decade at annual, winter, spring, summer and autumn, respectively. Over Syria, they were 0.30, 0.36, 0.38, 0.24 and 0.45°C/decade, respectively. For Palestine, they reached 0.25, 0.29, 0.41, 0.28 and 0.34°C/decade, respectively. The strong warming trends (0.45-0.70°C/decade) occurred in autumn and spring, whereas winter and summer exhibited less significant warming (less than 0.39°C/decade) for all areas in Levant. In autumn, they covered the central and northern district of Syria, Tripoli and Beirut from Lebanon and the northern parts of Saudi Arabia. In spring, the same region is affected by strong warming as well as the eastern and northern of Jordan and the southern of West bank (Hebron and Arad).

3.3.3 Diurnal temperature range

The decreasing trends gradually covered large areas with moving from winter to autumn. A total of 42%, 20%, 40%, 65%, and 68% of stations exhibited decreasing trends at annual, winter, spring, summer and autumn, respectively (Fig. 4). In summer and autumn, all the areas were affected by decreasing trends, except in a few and isolated areas. The strong decreasing trends (from -0.25 to -0.50 °C\decade) occurred in autumn, mainly in Syria, in Lebanon and in some coastal areas of Palestine. The same areas were affected by significant decreasing trends by lower rates (from -0.14 to -0.32°C\decade) during summer and spring. In winter, the averages showed warming trends for the most regions, except Damascus, Maze airport and Keferdan districts in Syria and Lebanon. It is also noticed that the northern areas of Jordan as well as some areas in the north of Palestine were affected by significant positive trends by 0.26-0.44°C\decade in winter.

4. **CONCLUSIONS AND DISCUSSION**

In this work, the recent trends of maximum and minimum temperatures (at annual and seasonal scales) during the period 1987-2017 over the Levant region, in the Middle East region, have been evaluated. Previous of this analysis, a rigorous and detailed study of the quality of the daily temperature records has been performed. This study has allowed using more than 60-time series from several stations across the study regions.

The main conclusion of this analysis is that the Levant region suffered intensive and coherent warming trends at annual and seasonal time scales during 1987-2017. This significant warming is around 0.33 and 0.30˚C/decade, respectively for the annual maximum and minimum temperatures. In addition, spring showed very strong and significant warming trend compared with the other seasons, although for all the region, minimum temperatures present a high rate of increase in autumn.

These results are consistent with those studies from many regions around the Levant. Ghasemi (2015) found for Iran during the period 1961-2010, a strong and significant warming by 0.42 °C\decade for spring T_{max}. Soltani et al. (2016) found significant increasing trends in the annual T_{max} and T_{min} averages over Iran by 0.031 and 0.059 ˚C\year, respectively. Toros (2012) found in Turkey during 1961-2008, that 69% and 66% of the stations show positive trends in the annual T_{max} and T_{min}, respectively. AlSarmi et al. (2011), for the Arabian Peninsula during 1980-2008, found that the annual T_{max} and T_{min} significantly increased at a rate 0.32 and 0.55°C\decade, respectively, and autumn exhibited very strong warming trends in T_{min} (0.70

°C\decade). Kenawy et al. (2009) found a significant warming trend in the annual T_{min} and DTR averages over Libya (0.23°C\decade and –0.28°C\decade, respectively), and

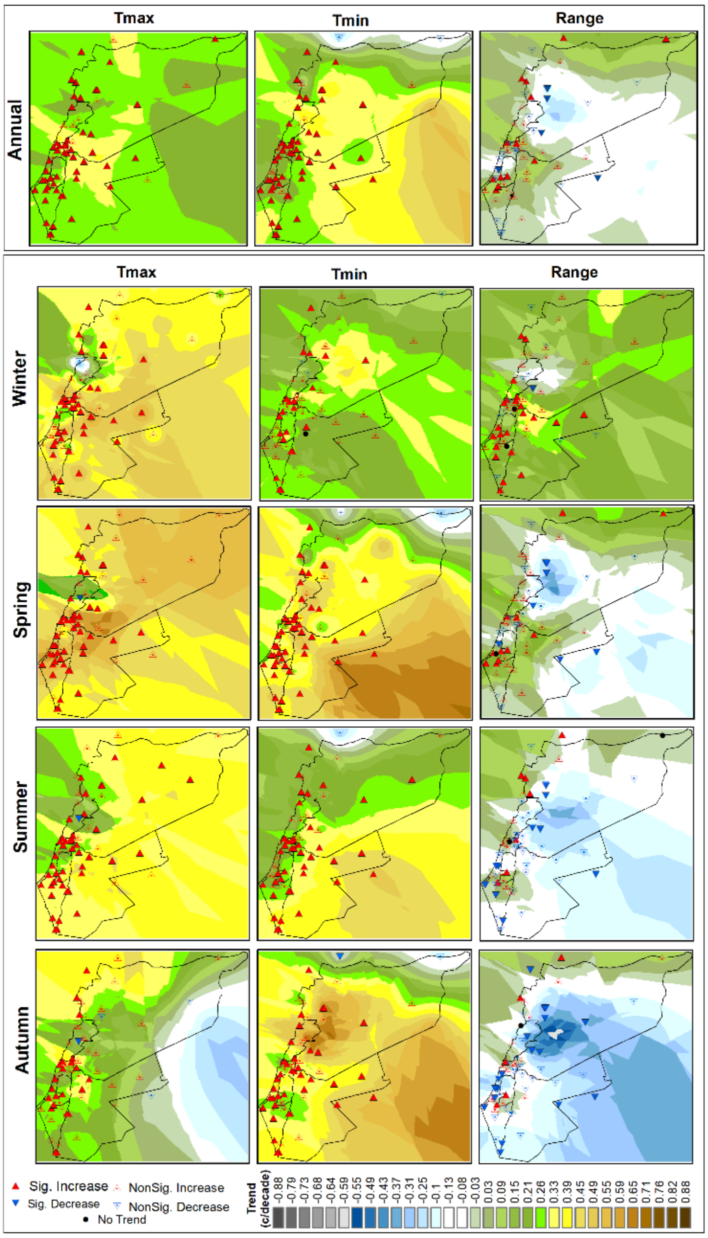

Fig. 4: Spatial trends at annual and seasonal scales during 1987-2017. Trends for Lebanon stations were calculated using the period 1994-2017.

spring exhibited the highest significant warming trend with a value of 0.29°C\decade for T_{min}.

In addition, the T_{max} and T_{min} means of the annual, spring and summer have significantly increased over the study area in the period 2001-2017 compared with the

period 1987-2000. These increases are coincident with those at global scale, where an increase of 0.21°C in the global mean of decadal temperature from 1991–2000 to 2001–2010 is larger than the increase from 1981–1990 to 1991–2000, and larger than for any other two successive decades since the beginning of instrumental records (WMO, 2013).
Under climate change conditions, it could expect an intensification of these trends, with important impacts in a region with severe problems in different socio-economic aspects.

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