Correlation Between Different Teleconnection Patterns and Temporal Climate Variation in the Litani Basin – Lebanon

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Abstract

This study examines the sensitivity of a mid-size basin's temperature and precipitation response to different global and regional climate circulation patterns. The Litani River Basin in Lebanon is the focus of this study. A methodology to generate a basin-scale, long-term monthly surface temperature and precipitation time series has been established using different statistical tests. The results show that some of the annual and seasonal temperature and precipitation variance can be partially associated with many atmospheric circulation patterns. This would give the opportunity to relate the natural climate variability with the watershed's hydro-climatology performance.

Keywords: Teleconnection, NAO, ENSO, Litani Basin, Watershed, Temperature, Precipitation, Mediterranean, Circulation patterns, climate change.

L'étude examine la sensibilité de réactiond'un bassin versant de dimensions moyennes, sur le plan de latempérature et des précipitations,à différents schémas mondiaux et régionaux de circulation atmosphérique. L'étude porte sur le bassin du Litani, au Liban. Une méthode utilisant différents tests statistiques a été établie afin de générer des séries chronologiques de température superficielle et de précipitations mensuelles à long terme, à l'échelle du bassin. Les résultats révèlent une association partielle entre certains des écarts dans les températures et les précipitations annuelles et saisonnières et divers schémas de circulation atmosphérique. Cela pourrait permettre de relier la variabilité climatique naturelle aux caractéristiques hydroclimatologiques du bassin versant.

Mots-clés: téléconnexion, NAO, ENSO, bassin du Litani, bassin versant, température, précipitation, Méditerranée, schémas de circulation, changements climatiques

1. Introduction

Changes in precipitation and temperature routine over a region would have significant implications on resource management and water availability, and consequently, on the balance of socio-economical, water and environmental systems. However, drawing a line between natural and human induced long term climate variability sources is also important to distinguish the effect of natural climate variability characterized by global and regional climate patterns change on watershed regime behavior. In addition, understanding the variability of local precipitation and temperature associated with the regional and global climate regime would improve climate forecasting and the identification of climate change features.

Long-term atmospheric circulation and variability can be manifested through climate patterns known as "teleconnection patterns". This term refers to the natural recurring of interannual and interdecadal oscillations, persistent pressure and circulation anomalies over a region, a continent or throughout the globe [1]. Teleconnection patterns are presented as numerical indices type and employed to determine the strength and implication of the patterns over a specific region or continent during a certain period of the year. Many authors investigated the physical behavior of these teleconnections in various regions of the globe [2, 3, 4]. Furthermore, numerous research projects and studies have been conducted correlating these indices to many climate variability factors mostly on the global and some regional scale. Glantz et al. [5] provided an extensive bibliography and a comprehensive review of many indices with yearly and seasonal teleconnections linking some regional weather variations to global climate anomalies.

The purpose of this study is to improve our knowledge of climatology and natural variability of the Litani Basin (Lebanon) in response to annual and seasonal time scales. The basin is located in the East Mediterranean region which currently is subjected to water scarcity. In order to enhance our understanding of the basin response, this contribution is realized through teleconnecting different global and regional natural climate patterns with the basin's temperature and precipitation anomalies using statistical methods. A statistical correlation approach is used which allows one to investigate the correlation between natural climate patterns and basin hydro-climatological variations. Teleconnection patterns are considered to be significant components of natural climate variability. Hence, this study will help to acknowledge the possible role of various global and regional climate circulations on a mid-sized local basin's temperature and precipitation which can be eventually linked, in a way or another to the basin's streamflow variations. Consequently, the dry and wet as well as warm and cool seasonal climatic variability of the basin maybe partially associated with the global and regional natural climate circulations. It is believed that the results from this study will assist decision makers acquire a better understanding of the climatological factors affecting the Litani Basin hydro-climatology performance and, hence, permit one to consider these factors in both the current and future planning and forecasting methods and procedures.

In this study, 12 teleconnection patterns have been chosen to be investigated in correlation with the Litani basin's temperature and precipitation variance; 10 of them are defined as Northern Hemispheric (NH) pattern by the Climate Prediction Center of the National Weather Services of the United States. The North Atlantic Oscillation (NAO) is based on the difference between the subtropical high in Ponta Delagada- Azores and subpolar low in Stykkisholmur – Iceland, and it is considered to be a measure of the strength of the westerlies [4]. The East Atlantic (EA) consists of a north-south dipole of anomaly centers [3] and crosses the entire North Atlantic Ocean and displaced towards the southeast relating to the NAO pattern. It is described by one positive center over the British Isles and two negative centers over central Atlantic and Eastern Europe. The East Atlantic/Western Russia (EA-WR) comprises two anomaly centers located over western Europe and the Caspian Sea in winter and three anomaly centers located over western-northwestern Russia, northwestern Europe and the Portuguese coast during spring and fall seasons. It is referred to as Eurasia-2 (EU2) by Barnston and Livezey [3]. Scandinavia (SCAND) consists of 3 circulation centers, where the main one is located over Scandinavia and a segment of the Arctic Ocean in Siberia. The other two centers are located over Western Europe and Western China (Magnolia). SCAND plays a considerable role on precipitation patterns in Europe and it affects the height anomalies over Scandinavia, Western Russia, the Iberian Peninsula and Northwestern Africa [3]. Polar/Eurasia (POL) contains one main center over the polar region, and separate centers of opposite sign over Europe and northeastern China [6]. Hence, it affects the changes of the mid latitude circulation that arise over a great fraction of Asia and Europe. The West Pacific (WP) pattern consists of a north-south dipole of anomalies. One center is situated over the Kamchatka Peninsula and a wide center of opposite sign covering a section of southeastern Asia and the lower latitudes of the farthest western North Pacific [2].

The spring, summer and fall East Pacific-North Pacific (EP-NP) pattern has three main anomaly centers where its center of action is located over the Pacific Ocean affecting mainly various North American regions [3]. Pacific/North American (PNA) illustrates the location, direction and potency of a low (trough) and high (ridge) pattern of air pressure on the Northern Pacific Ocean and North America [3]. The Tropical/Northern Hemisphere (TNH) is apparently a prominent mode during winter [6]. It contains one primary anomaly center over the Gulf of Alaska and a second anomaly center over Hudson Bay. The Pacific Transition (PT) pattern exists during August-September and has main centers of action located over the intermountain region of the United States and over the Labrador Sea and other weak anomaly centers with opposite signs over the Gulf of Alaska and over the eastern United States [6].

The two remaining teleconnection patterns selected for the studies are the following:
The El Niño Southern Oscillation (ENSO) which is regarded as the earth's dominant source of year-to-year climate variations and to have a continental to global hydro-climatological influence [7]; and one regional teleconnection pattern known as the Mediterranean Oscillation Index MOI-1 defined by Conte et al. [8] as the normalized pressure difference between Algiers (36.4°N, 3.1°E) and Cairo (30.1°N, 31.4°E). The Mediterranean Oscillation Index is described as a teleconnection pattern with opposite pressure and rainfall anomalies between the central-western and Eastern Mediterranean area.

2. Teleconnections and the Mediterranean

The Mediterranean is located in a region of great climate interest and challenge, because it is exposed to different climate patterns and includes accentuated orographic variation, complex land topography, and a wide ecological spectrum. These extensive disparities sometimes make the local physio-geographic aspects prevail over the global, continental and regional factors. The Mediterranean is located in the transitional zone between the subtropical high pressure arid zone (North African deserts) and the mid latitude (North Europe). It is exposed to the South Asian Monsoon in summer and Siberian high pressure system during winter. The Mediterranean climate is controlled by many geographical elements where the small scale process plays an important role [9].

In this study, the role of the main northern hemisphere climate patterns, such as North Atlantic Oscillation (NAO) and East Atlantic and West Russia Pattern (EA-WR) are considered. It is shown that these two patterns have an influence on the major inter-annual variability of the atmospheric circulation which is associated with climatological changes in the surface across the Eastern Mediterranean region [10]. However, the hydro-climatological correlations with other teleconnection patterns are studied as well to investigate the influence of ENSO, MOI and all other Northern Hemisphere teleconnection as defined by Smith et al. [11].

Relating climate patterns to the regional weather response and its various consequences in the Mediterranean area was the core of much research in the last decade. Ropelewski and Halpert [12], identify 17 global core regions that appear to have a clear ENSO-precipitation relationship. Hurrell [4] relates NAO behavior to the regional precipitation and temperature variability over Europe and the Mediterranean. Al-Fenadi [13] found a correlation between the North Libya Temperature index and ENSO. Kadioglu et al. [14] related the Turkish monthly total precipitation variation between 1931 and 1990 with El Niño events. Feliks et al. [15] studied the synchronization of the NAO with Eastern Mediterranean interannual and interdecadal climate variability including the Nile River flow. They realized the presence of a prominent oscillatory mode with a 7 to 8 yr period in the climatic indices studied synchronized with the NAO.
Mann [16] documented the domination of the NAO over large scale temperature variations in the Middle East.

Ulbrich and Christoph [17] conducted a couple of simulations showing that the climate change trend in winter precipitation relies significantly on the northward deviation of the storm track coupled with the shift and amplification of the NAO, which generate decreased and increased precipitation in the northwestern and southeastern Mediterranean regions, respectively.
Other studies were conducted to explore the effect of ENSO on different regions of the Mediterranean. Van Oldenborgh et al. [18] found a strong connection between warm winter El Niño and higher precipitation in spring for the area covering Southern England to Asia. Other findings in correlating temperature and precipitation variability in Europe and Africa with ENSO can be found in many other published papers [19].

The various effects of other atmospheric circulation patterns on the other hand have been investigated in the Mediterranean region. For example, Krichak and Alpert [20] correlated the positive trend of the East Atlantic–West Russia (EA–WR) teleconnection pattern with the precipitation decline over the East Mediterranean during the last couple of decades of the 20th century. Similarly, Krichak et al. [10] detected a relation between the East Mediterranean precipitation and the EA-WR teleconnection pattern. Gonzalez-Hidalgo et al. [21] demonstrated significant effect of the Mediterranean Oscillation Index (MOI) and the precipitation variability over the Mediterranean part of the Iberian Peninsula. For the same region, precipitation variability has been associated with the Eastern Atlantic pattern [22] and the Eurasian pattern [23] as well. Toreti et al. [24] showed a strong linear correlation between seasonal temperatures over Italy and the Eastern Atlantic (EA) pattern in all seasons except during autumn and a negative correlation between the Scandinavian (SCAND) pattern and summer temperatures. Krichak et al. [10] demonstrated a significant contribution of the EA pattern to the precipitation variations over the East Mediterranean.

3. Study area

The Litani Basin is located in Lebanon (Fig. 1), east of the Mediterranean Basin. The climate of this region is described in general by short, wet winters and long, dry summers. Lebanon is positioned between the subtropical aridity of Africa and the subtropical humidity of the eastern Mediterranean area. It is subject to many continental air masses and depressions such as the Siberian high pressure, Indian Monsoon and Cyprus depression [25]. In addition, the diverse orographic array alters the local climate conditions.

Lebanon’s average annual temperature in the coast is approximately 27ºC in summer and 14ºC in winter with a 3ºC decrease per 500 m elevation gain. Most of the rainfall takes place from November to March with an annual average of around 850 mm. The Mount Lebanon chain (west slopes) acts as a barrier between the Mediterranean Sea and the Beqaa Valley (inland). This causes the climate of the interior zone and mainly in the Beqaa Valley to vary from sub-humid in the south to arid in the north within less than 100 km strip. The orographic rainfall in the Mount Lebanon and Anti-Lebanon regions vary drastically in a short distance to reach as much as 1500 mm on the peak of the mountains which are covered by snow most of the year. In summer, however, most of the country is totally dry between June and August with almost zero precipitation.

The Litani Basin is considered the largest source of surface water in Lebanon, originating west of Baalbeck city which is located in the Beqaa Valley at an altitude of 1000 m with a drainage area of about 2,170 km^2. In 1959, the Litani River Authority completed the building of the Albert Naqash dam and the Qaraoun artificial lake at the Qaraoun village region located in the Beqaa Valley at an altitude of 800 m. The lake has the capacity of storing water up to 0.22 km^3. Practically, this lake divided the basin into two separate basins: The Upper Litani Basin (ULB), which is located in the Beqaa plain between the Lebanon and Anti-Lebanon slopes, covers 68.5% of the whole basin drainage area from 800 m altitude and up, and it drains toward the Qaraoun Lake. The Lower Litani Basin (LLB) covers the remaining part and it drains toward the Mediterranean. Hence, ULB is mostly dominated by mountainous features while LLB is mostly coastal falling from 500 m altitude to the sea level in a short distance of around 100 km length.
The average annual precipitation over the basin is around 700mm, where around 550mm fall in the area of river's origin and around 800 mm at the river's mouth. The discharge rate of the basin is approximately 0.5 km^3/yr for the ULB and 0.3 km^3/yr for the LLB.

The Litani River has a remarkable social, economic and environmental importance to Lebanon, especially to communities living in the neighborhood of the basin. River water used is related to the amount of annual precipitation on the basin vicinity. Portion of the water is invested in hydro-electric power generation and irrigation which makes the annual precipitation in the region crucial to the community's water needs. Hence, the importance of annual rainfall variations in relation to the river water management and to the socio-economical status of the region cannot be more emphasized. However, this river is a subject of serious water deficit due to many socio-economical strains and climate change.

4. Data and methodology

The present study aims to investigate the correlation between the precipitation and temperature variation over the Litani Basin region with different global and regional climate patterns known as teleconnections. The process starts with data collection, preparation and calibration. The geographical data of the Litani Basin area was gathered first by integrating ASTER Global Digital Elevation Map data [26] as shown in figure 1.

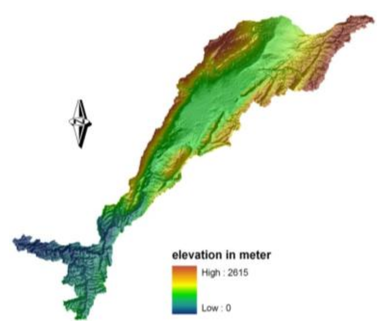

Figure 1. The Litany Basin's digital elevation model

The lack of reliable long term gauge data that cover the studied area imposes the burden of using quite different available resources. Consequently, monthly satellite data, global reanalysis global grid data and the available limited gauge data for couple of stations located in the region were used. Table 1 lists the sources of data used. The reanalysis gridded data consist of spatial interpolation of thousands of stations spread around the world, with 0.5ºx0.5º resolution adopted from 2 sources: University of Delaware data for Temperature and Precipitation, (UD-Temp and UD-prcp) between1900 and 2006 and University of East Anglia (CRU-TS and CRUTS-prcp) between 1901 to 2002 ; Satellite data include: Tropical Rainfall Measuring Mission (TRMM) covering the daily precipitation data between 1998 and 2008 with 0.25º resolution, and the Moderate Resolution Imaging Spectroradiometer for temperature (MODIS-Temp) with 0.05º resolution, (2000-2009); Local measured data include: Ksara Obsy station (1921 to 1960) located in the Beqaa Valley, North-East of Lebanon, for temperature data and Lebaa station (2001 to 2008) located in South Lebanon for gauged precipitation data.

Data type	**Periods**	**Resolution**	**Data source (visited 12/21/2010)**	**% of coverage**
UD-Temp [1]	1900~2006	0.5º	http://climate.geog.udel.edu/	100
CRU TS-Temp [1]	1901~2002	0.5º	http://www.cru.uea.ac.uk/	100
MODIS-Temp [2]	2000~2008	0.05º	http://edcdaac.usgs.gov/modis/	100
UD-Prcp [1]	1900~2006	0.5º	http://climate.geog.udel.edu/	100
TRMM [2]	1998~2008	0.25º	http://disc.sci.gsfc.nasa.gov	100
CRU TS-Prcp [1]	1901~2002	0.25	http://www.cru.uea.ac.uk/	100
Station - Ksara	1921-1960	/	http://data.giss.nasa.gov/gistemp/	33.8N, 35.9E
Station – Lebaa [3]	2001-2008	/	Ministry of Public Work - Lebanon	33.3N, 35.3E
ENSO	1950~2008	/	http://www.cpc.ncep.noaa.gov	/
MOI	1958~2007	/	http://www.cru.uea.ac.uk/cru/data/moi/	/
Northern Hemisphere Teleconnection	/	/	ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh	/

(1) Reanalysis data (2) Satellite data (3) Station data

Table 1. Data sources

In this study, various climate pattern indices were selected. The standardized north hemispheric teleconnection indices were chosen based on proximity to the Mediterranean basin and historical attempts studying these phenomena in relation to the Mediterranean climate variability. El Niño - Southern Oscillation (ENSO) index which is the standard SST index of El Niño - Southern Oscillation (ENSO) at Nino 3.4 region: 5ºN~5ºS, 120º-170ºW (ERSST.v3), and 10 other standardized northern hemisphere teleconnection indices were adapted from NOAA [11]. The Mediterranean Oscillation Index (MOI) was based on studies of the University of East Anglia UK [8].

The following methodology was employed to combine different reanalysis datasets, satellite data, and meteorological data in order to generate one set of gridded time series of monthly surface temperature and precipitation from 1900 to 2008. The geo-processing of the Litani Basin was achieved through the application of the Geographical Information System (GIS) for watershed delineation which is controlled mainly by the topography of the basin and river network. Subsequently, the gridded datasets of temperature and precipitation were spatially averaged over the basin and reducing the data to a single value varying over time. Two types of extrapolated time series for the period 2000-2008 were generated: a) a cell based time series which consists of extracted data from the grids where the used weather station are located (Ksara-Obsy and Lebaa) and b) a basin wide data averaging of the observations of satellite and the reanalysis of records. Satellite and weather stations data were employed to calibrate the reanalysis of gridded time series. In this paper, data generated between 1950 and 2008 were employed except for MOI index (Algiers and Cairo) that represents the 1958-2007 period. More detailed information regarding the methods used for dataset construction can be found in a related publication [27]. To investigate the correlation between the climatological factors and the selected climate patterns, the Pearson correlation coefficient, which is defined between two variables X and Y, is applied:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{(n-1)S_x S_y} \qquad (1)$$

where $\bar{X}$ and $\bar{Y}$ are the means of the variables, S_X and S_Y represents the standard deviations of X and Y variables, respectively.
Confirmatory data analysis procedures require statistical test(s) of significance to be used accordingly. Here, a *t*-test is applied in order to evaluate the significance of the determined correlation coefficients. Hence, the null hypothesis that correlation coefficient (r) = 0 is tested as:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \qquad (2)$$

where r is the Pearson's correlation coefficient, and n is the size of the sample. Based on the calculated standard t value, probability (p) can be found by using the t curve tail area table. If p < 5% (or 1%), the correlation is considered significant and the null hypothesis is rejected (i.e., there is a significant trend in the data series).

5. Results and discussion

The Litani Basin’s annual and interannual correlations of temperature and precipitation with teleconnection indices were examined. The highlighted results in Table 2 represent the significant linear correlations at 1% or 5% level between 1950 and 2008. The absence of such correlation does not mean necessarily a lack of dependence between the indices and the time series. On the contrary, as Pozo-Vasquez et al. [28] suggested, a non-linear complex relationship may be dominating which merits more attention in future studies.

Temperature variability over the Litani Basin shows an overall annual negative correlation with NAO index at 1% level. Meanwhile, mean temperature shows to be negatively correlated with NAO in all seasons except in spring. These results are in agreements with Wallace and Gutzler [2] relating the negative correlation between NAO and temperature variations over the eastern Mediterranean with the intensification of the westerlies [4]. This is emphasis as well the dominance of the regional climate over local weather characteristics. The high-pressure variance overshadowing the east Mediterranean region, especially in winter, is associated with the NAO. This favors an anticyclone flow of surface winds and directs the advection of cold air coming from southeastern Europe to the northern Red Sea [29]. However, no interannual significant linear correlation has been found between precipitation and NAO except in summer where precipitation in that area is nearly zero. This does not reveal necessarily the lack of any other type of non-linear correlation.

For the El Niño South Oscillation (ENSO), it is demonstrated that this phenomena that takes place mainly in the Pacific area has a global climatological variation impact [2]. The changes of pressure gradient across the Pacific are associated with changes in temperature and precipitation anomalies on the eastern and western Pacific coasts leading to worldwide climate variability [30]. During El Niño, the eastern Pacific warms up affecting the jet streams in the subtropics which become stronger leading to wetter (drier) winter conditions in the east (west). However, Pozo-Vasquez et al. [28] revealed numerous difficulties to relate El Niño to climate variability in Europe due mainly to the different types and potencies of El Niño episodes leading to various and inconsistent climatological responses.

	Climate Patterns	Spring	Summer	Fall	Winter	Wet	Dry	Annual	Tran
Temperature	NAO	-0.25	-0.39**	-0.32**	-0.44**	-0.5**	-0.42**	-0.38**	-0.27**
	EA	0.26**	0.43**	-0.16	0.11	-0.02	0.44**	0.33**	0.39**
	WP	-0.20	-0.22	0.16	0.04	-0.08	-0.12	0.13	-0.19
	EP-NP	-0.02	-0.27**	-0.10	-0.07	-0.07	-0.29**	-0.12	-0.04
	PNA	-0.04	0.04	0.00	0.06	-0.01	0.02	0.08	-0.08
	EA-WR	-0.10	-0.43**	-0.35**	-0.59**	-0.51**	-0.48**	-0.32**	-0.09
	SCAND	-0.08	-0.33**	0.05	0.07	0.19	-0.24	-0.17	-0.07
	TNH	N/A	N/A	N/A	-0.14	-0.07	N/A	N/A	N/A
	POL	-0.20	0.03	-0.20	0.02	-0.09	0.15	-0.20	-0.07
	PT	N/A	N/A	N/A	N/A	N/A	0.05	N/A	N/A
	MOI[1]	-0.20	0.03	-0.08	-0.52**	-0.48**	-0.15	-0.17	-0.21
	ENSO	-0.28**	0.03	0.01	-0.13	-0.21	0.04	-0.13	-0.18
Precipitation	NAO	-0.04	-0.26*	-0.07	-0.10	-0.16	-0.15	-0.02	0.04
	EA	-0.27*	0.14	0.21	-0.36**	-0.19	0.02	-0.09	-0.31*
	WP	0.16	-0.10	-0.01	-0.10	0.08	-0.14	-0.15	0.10
	EP-NP	-0.09	-0.04	-0.02	0.17	0.22	-0.10	0.07	-0.20
	PNA	0.01	0.15	-0.04	0.09	0.10	0.19	-0.01	0.04
	EA-WR	-0.20	-0.10	-0.07	0.18	0.19	-0.09	0.00	-0.17
	SCAND	0.16	-0.07	-0.29*	0.09	0.19	0.08	-0.01	0.08
	TNH	N/A	N/A	N/A	-0.3*	-0.34**	N/A	N/A	N/A
	POL	0.19	0.06	0.29*	0.21	0.41**	0.13	0.28*	0.10
	PT	N/A	N/A	N/A	N/A	N/A	0.01	N/A	N/A
	MOI[1]	0.06	-0.12	0.20	0.27*	0.19	-0.25	0.31*	0.06
	ENSO	0.16	0.06	0.24	0.24	0.32*	-0.03	0.17	-0.06

* significant at 5% level, ** significant at 1% level, N/A is not applicable

Spring occurs in the months from March to May, summer is from June to August, fall is from September to November, winter is from December to February, wet-season is from November to March, dry-season is from June to September, and the transitional (Trans) is from April to May. (1) MOI – Algiers and Cairo (1958 – 2007)

Table 2. Litani Basin's temperature and precipitation linear correlation with different Teleconnection indices between 1950 and 2008 (MOI is from 1958 to 2007).

For the Litani Basin (Table 2), the ENSO index does not show statistically significant relationships with the mean yearly air temperatures except for a negative correlation in spring. However, the mean precipitation in the wet season from November to March is positively correlated with the ENSO index at 1% level. These results are in agreement with the general conclusions of many authors [14 and 19] but are controversial when compared with other studies [31]. This inconsistency is due to the different spatial and temporal data investigated and the statistical analysis methods used.

The East Atlantic-Western Russia (EA-WR) pattern is shown to have no significant correlation with the Litani precipitation with all various temporal and spatial data used. However, the connection with temperature variation is evident. An annual negative correlation between the Litani's temperature and EA-WR pattern is detected. This is in addition to the seasonal correlation found throughout the year except in spring and transitional seasons. The temperature variability of the Litani Basin seems to be strongly associated with the two anomaly centers of the pattern located over the Caspian Sea and Western Europe. While more intense northern airflow is associated with the positive EA-WR, the negative phase is linked to positive height anomalies over the Caspian Sea and western Russia and negative height anomalies over northwestern Europe [20]. Thus, the EA-WR pattern is likely to convey amplified anomalous northeasterly or southeasterly circulation connected with temperature variations in the Eastern Mediterranean area including Lebanon. However, no evidence of its connection with precipitation patterns has been found. Correlations between winter temperature and EA-WR have been found for other areas in the East Mediterranean as shown by Hasanean [32] giving additional evidences on the influence of large scale oscillation on a local meteorological scale in mid latitude regions.

The Eastern Atlantic (EA) teleconnection pattern is shown to be negatively correlated with precipitation during spring, winter and transitional seasons. These results are in agreement with Hatzaki et al. [33] who demonstrated a significant correlation between East Mediterranean precipitation and EA pattern during the spring, winter and autumn seasons. For temperature, a positive correlation was found annually and during the summer, spring, dry and transitional seasons but no correlation was present during winter and wet seasons.

A negative correlation can be found between fall precipitation and the SCAND pattern which may be attributed to the dry air advection from Asia [34]. This pattern, which is portrayed by a strong anomaly located over the Scandinavian Peninsula, shows negative temperature correlation over the basin.

The Polar/Eurasia (POL) pattern shows significant positive correlation with annual precipitation anomalies. This is in addition to the correlation illustrated during the fall season. The stronger positive correlation between the POL pattern and precipitation is found during the wet season as this pattern is known to be mostly prominent between December and February. The positive precipitation correlation in the wet season seems to be due to the enhanced circumpolar vertex during the positive phase of the POL pattern. However, no significant linear correlation is found with temperature variability.

As stated by the Climate Prediction Center (USA), the positive phase of the East Pacific-North Pacific (EP-NP) pattern is linked with above-average surface temperatures over the eastern North Pacific; below-average temperatures over the central North Pacific and eastern North America; above-average precipitation over north of Hawaii; and below-average precipitation over southwestern Canada. The low and high pressure anomalies associated with this pattern are shown to produce a strong regional circulation in the Mediterranean vicinity [35]. For the Litani Basin, a negative correlation was found between EP-NP pattern and temperature changes during the summer and the dry season.

The Tropical/Northern Hemisphere pattern (TNH) connection with the Mediterranean meteorological variability has not yet been investigated. For the Litani Basin, no correlation is detected with temperature anomalies. However, negative correlation with precipitation is observed during wet and winter season.

Pacific / North American (PNA) pattern, which is associated with climate variability over North America, shows no linear correlations with precipitation and temperature anomalies over the basin. The same results are found for Pacific Transition (PT) and West Pacific (WP) patterns showing no impact on the climatological variation of the area under study. For these last three patterns, no evidence has been found in literature that shows any type of correlation with the East Mediterranean area. In fact, the PNA, WP and PT patterns behavior have not been studied in relation with the Mediterranean area climate variation.

The Litani basin shows a significant correlation of temperature with Mediterranean Oscillation Index – Algiers and Cairo during winter and wet seasons for the period 1958-2007. These results show similarity for each region of the Litani Basin. The strong positive geopotential height anomalies, which prevail over the western central basin of the Mediterranean during wintertime and extend toward Russia, drive cool air to the Eastern Basin dominated by lower height anomalies [36]. The results are in agreement with Nastos et al. [37] who found a statistically significant negative correlation between wintertime temperature and MOI over Greece for the period 1951-2007 and 1955-2001 respectively. In contrast, Elmallah and Elsharkawy [38] observed positive correlation with wintertime temperature anomalies over Egypt which confirms the importance of the distinct local characteristics of each zone in the Eastern Mediterranean region. For precipitation, annual and winter season positive correlation with MOI has been detected. Likewise, Gonzalez-Hidalgo et al. [21] noticed a positive correlation between precipitation and the Mediterranean Oscillation Index over the Iberian Peninsula during the rainy season for the second half of the 20th century.

6. Summary and Conclusions

The annual and interannual precipitation and temperature variations over the Litani Basin have been examined in connection with different global and regional circulation indices. The associated time series for monthly temperature and precipitation were related to annually and seasonally to thirteen teleconnection patterns. Pearson linear correlation coefficients were employed to describe the variance distribution of the series in connection with the selected indices. Based on data availability, twelve indices were used for the period 1950-2008.

Data for the study watershed was derived from different sources and was spatially averaged. Generally, moderate correlation values (i.e., ~0.26 to 0.6) with 1% to 5% significance have been found in select seasons between temperature variation and NAO (negative), EA (positive), EP-NP (negative), EA-WR (negative), SCAND (negative), MOI (negative) and ENSO (negative). Similarly, significant correlation values (i.e., ~0.26 to 0.4) have been found in select seasons between precipitation and NAO (negative), EA (negative), TNH (negative), POL (positive), MOI (positive) and ENSO (positive). However, PT, PNA and WP patterns showed no correlation with either measure. Although most of the results from this study were consistent with previous, similar studies of the East Mediterranean area, some findings highlight the uniqueness of the basin's geophysical characteristics and local weather implications. Some other teleconnections show various correlations almost throughout the year, such as NAO and EA-WR (with temperature).

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