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The Role of Teleconnection Patterns on Wind Speed of Iraqi-Kurdistan Region

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ABSTRACT

Changes in the wind speed of the Iraqi-Kurdistan region are associated with many types of teleconnection patterns. Daily wind speed datasets for eight meteorological stations in Iraqi-Kurdistan region were gathered from Sulaymaniya, Penjwen, Hallabja, Kalar, Erbil, Sallahadin, Zakho, and Duhok weather stations. spectral comparability between the daily wind speed of the eight sites and prominent atmospheric indices was implemented for the North Atlantic Oscillation (NAO), Southern oscillation (SO), Mediterranean Oscillation (MO), and Arctic Oscillation (AO), using multi-taper method (MTM) for spectral analysis to find the source of the wind speed cycle of the cites for the study area. It was found that the common cycles for the eight stations are 2.22, 2.5, 3.33, 3.7, 4.35, 5.56, 7.14, 10, and 14.29 cycles. It is obvious that there are common cycles between each of the NAO, SO, MO, and AO indices and the cycles of daily wind speed of the eight stations. The results of this study will allow us to understand the relation between the regional daily wind speeds patterns fluctuations and the global teleconnection patterns and also to forecast the behavior of daily regional wind speed.

KEYWORDS: Iraqi-Kurdistan region, North Atlantic Oscillation (NAO), Southern oscillation (SO), Mediterranean Oscillation (MO), Arctic Oscillation (MO), Multi-Taper Method (MTM), teleconnection patterns.

الخلاصة

التغيرات التي تحصل في سرعة الرياح في إقليم كردستان-العراق، تصاحب عدة أنواع من أنماط الإتصال البعيدة المدى. تم الحصول على قيم السرعة اليومية للرياح من ثماني محطات أنوائية في الأقليم وهي محطات السليمانية، بنجوين، حلبجة، كلار، أربيل، صلاح الدين، زاخو ودهوك. تم إجراء مقارنة طيفية بين سرعة الرياح اليومية للمحطات الثمانية وبيانات معامل ذبذبة شمال الاطلسي، معامل ذبذبة الجنوبية، معامل ذبذبة المتوسط، معامل ذبذبة القطبية بإستخدام تقنية التحليل الطيفي الإحصائي (MTM) والهدف هوايجاد مصدر نشوء دورات الرياح في مواقع منطقة الدراسة. وجد أنَّ الدورات المشتركة بين دورات الرياح للمواقع الثمانية المختارة ٢,٢٢، ٢,٥، ٣,٣٣، ٣,٧، ٤,٣٥، ٥,٥٦، ٧,١٤، ١٠ و١٤,٢٩ دورة. كان واضحاً أنه توجد دوران مشتركة بين كل من ذبذبة شمال الاطلسي، الذبذبة الجنوبية، ذبذبة المتوسط والذبذبة القطبية مع دورات الرياح اليومية للمواقع الثمان المختارة. نتائج هذا البحث تساعدنا على فهم العلاقة بين دورات الرياح اليومية والتغيرات في أنماط الإتصال البعيدة المدى مما يسهم في التنبؤ بسرعة الرياح اليومية في المنطقة.

INTRODUCTION

Wind speed is a significant element in weather and climatic. It is easier for people to use the environment and successfully control wind energy when they are aware of how wind regimes vary. Therefore, the wind is significant in agriculture, urbanization, air transport, energy supply, and many other aspects. Analysis of the temporal-spatial patterns of wind variations is essential to get the most benefits of wind [1]. The wide spread of weather variations and climate at a distance create a large climate patterns and weather indices. According to certain descriptions, climate patterns and indices lead to identification to evaluate the temporal and spatial variations in wind patterns. Teleconnection is a term used to describe the significant link and connection between two long-distance circulation systems or patterns' temporal variations [2]. Teleconnections link weather and climate across enormous distances. Teleconnections also, attract attention because they last longer than most other atmospheric phenomena. This suggests that the atmosphere may be in a state that makes it more feasible to use weather predictions over a length of time that is considerably longer than a regular weather forecast when teleconnections are functioning [3]. The biggest climatic teleconnections are divided into four groups based on where they originate: ENSO (El Nino-Southern Oscillation) occurs in the Pacific Ocean, NAO (North Atlantic Oscillation) happens in the Atlantic Ocean, AO (Arctic Oscillation) appears in the North Polar Region and MO (Mediterranean Oscillation) takes place in the Mediterranean basin [4]. Studying large-scale atmospheric oscillation patterns, such as the Southern Oscillation (SO) and the North Atlantic Oscillation (NAO), as has been done more and more frequently over the past two decades, may have some of this potential. It is commonly recognized that the El Nino and La Nina events, which represent the extreme periods of SO, have a significant influence on the world's climate. The relationship between climatic variables (such as precipitation, wind, temperature, and drought index patterns) and SO has been well established in several studies since the 1980s. NAO is another well-known large-scale oscillation of atmospheric mass occurs between the core of the subtropical high surface pressure, which situated around the Azores, and the subpolar low surface pressure, which is located near Iceland, it has a meridional pattern [5]. SO is a cyclical pattern of disturbances in sea level pressure between the eastern Pacific and the Maritime Continent. It is connected to the El Nino (Indonesia and surrounding region). Tahiti, for example, has abnormally low pressure during an El Nino, whereas Darwin, for example, experiences unusually high sea-level pressure. The eastern Pacific Ocean is warmer than typical during an El Nino [6]. MO is defined as a dipolar tendency of the atmosphere between the Western and Eastern Mediterranean. Since then, several scientists have ascribed this pattern to the variations in significant atmospheric and oceanic characteristics between the two basins. Algiers and Cairo height difference anomalies were used as the primary definition for the index quantifying the intensity of the dipole [7].

AO is a major climatic fluctuation in the region. AO index depends on changes in atmospheric pressure between the central Arctic northward of 20° N and two lesser centers at around 45° N across the Atlantic and Pacific basins. The Northern Hemisphere's atmospheric phenomena and the AO have a strong correlation [8]. Numerous studies drew attention to crucial global/regional action-related elements, such as ENSO, NAO, AO, and others. Some world locations climates are extremely affected due to teleconnections [9]. AO is nearly equivalent to NAO, when compared to the North Atlantic oscillation pressure phenomena at sea level, the Arctic oscillation pressure phenomena at sea level work more jointly. These two oscillations combine in a time series [10]. In this study, utilizing spectral techniques, such as multi-taper method (MTM) used to search into any existent periodicities in wind speed series NAOI, AOI, MOI, and ENSOI. It is crucial to understand how the NAO, AO, MO, and ENSO relate to the cycles in wind speed in the cities of Sulaymaniya, Penjwen, Hallabja, Kalar, Erbil, Sallahadin, Zakho, and Duhok. The latitude, longitude and height of Sulaymaniya, Penjwen, Hallabja, Kalar, Erbil, Sallahadin, Zakho and Duhok cities are illustrated in Table 1 [11]. In this paper, for spectral analysis of the time series of daily wind speed, we employ the non - parametric multi-taper method (MTM) [12]. The purpose of this study is to ascertain how each of these teleconnection patterns affects the average daily wind speed in the Iraqi-Kurdistan region.

Review of Teleconnection Studies

Teleconnection patterns, or generally "teleconnections," describe large-scale, persistent, recurrent patterns of climatic anomalies that cover a lot of regions. Since 1935, the phrase "teleconnection" has begun to emerge in literature. However, During the 1960s, much of the work and implementation of it has been done [13]. Through teleconnections, dynamic circulation of climate indexes in one remote area can be correlate to variations in the climatological variables in another. Therefore, SO, NAO, AO, and MO are examples of these dynamic circulations. Teleconnections have been shown that large-scale climatic oscillations have an impact on wind direction and speed [7, 14].

Shen, *et al.* (2021) [15] looked at the ENSO and other large-scale ocean-atmosphere circulations' potential effects on the variation in near surface wind speed across China. In the meanwhile, the links between near surface wind speed and significant ocean-atmosphere circulations are indicated using a forward stepwise regression approach. Azorin-Molina, *et al.* (2018) [16]

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Disclosed NAO which has positive effect on yearly wind speed, and the SO, which has a substantial negative link with winds in winter, spring, and fall, are both important factors in understanding the unpredictability of Saudi Arabia's winds. Kurtuluş and Zahide (2021) [10] after examining the connections between Turkey's wind speed and climatic oscillations, one may come to the conclusion that NAO and AO are the climatic oscillation indices that best characterize wind frequency across the country. Alizadeh, *et al.* (2018) [17] demonstrated that ENSO cycle affects Iran's yearly atmospheric variations, He showed that the annual mean sea level pressure, wind speed and direction across Iran have a rather significant ENSO fingerprint.

Naizghe and Ouarda (2017) [14] determined the impact of ENSO and NAO on wind speeds over the United Arab Emirates, regression and wavelet analysis were utilized. According to wavelet coherence analysis, ENSO and NAO are mostly responsible for the wind speed in the United Arab Emirates. While NAO indices have an impact on winter and fall wind speeds. SOI simultaneously modifies wind speed in the summer.

Palani (2020) [18] examined the impact of variations in the El Nino and La Nina events on the climate data values at Sulaymaniya station in the Iraqi-Kurdistan region from 2008 to 2018. Karabörk, *et al.* (2005) [5] made a sequence of cross-correlation analysis to reveal the link between the Turkish climatic variables and each of NAO and SO. Few researches have been conducted to study the teleconnections of wind speed with the climate indices, despite the fact that several studies on the circulation patterns of hydro-climatological variations with climate indices have been conducted in this region.

Dataset Description

Two sets of data were used in this work. Data of daily wind speed were included in the first dataset from eight ground stations. Climate indices data are included in the second dataset.

1. Region of Study and Ground Station Data

Four governorates make up the Kurdistan region, which sometimes referred to as Northern Iraq: Erbil, Sulaymaniya, Hallabja and Duhok. It also occupies 73,618 km^2 of the country's total land area (nearly 17% of the whole area of Iraq) [19]. The Iraqi-Kurdistan region, between 42.33^o and 46.58^o E longitudes and 34.5^o and 37.37^o N latitudes is the location for this study. The area is surrounded by Iran from the east, Turkey from the north and Syria from the west. Figure 1 depicts the region under considerations, which has a range in elevation from 3601 meters above the average sea level of the northeast to 134 meters above average sea level of the southwest. The Iraqi-Kurdistan region experiences hot, winters with heavy rain and dry summers. compared to summer and winter, spring and autumn have shorter seasons [11]. As indicated in Table 1 and Figure 2, the climatological information utilized in the research relates to daily wind speed measurements gathered from 8 meteorological sites.

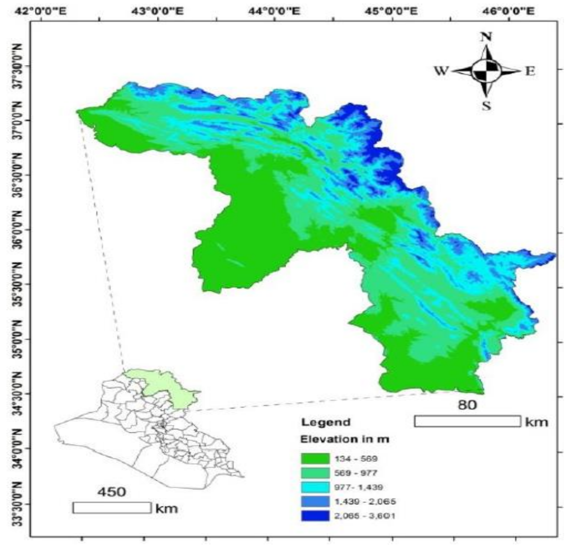

Figure 1. Study area (Iraqi-Kurdistan region).

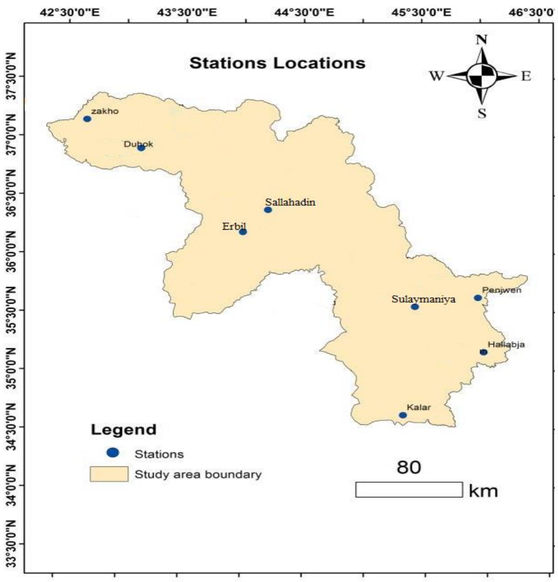

Figure 2. Locations of meteorological stations

Table 1. Meteorological stations and their characteristics.

No.	Stations	Latitude	Longitude	Elevation in (m) above mean sea level	Years
		N	E		
1	Sulaymaniya	35.559	45.4298	884.8	2017-2021
2	Penjwen	35.6327	45.9531	1309	2017-2021
3	Hallabja	35.166	45.9943	621	2017-2021
4	Kalar	34.63	45.3272	200	2017-2021
5	Erbil	36.1966	44	470	2017-2021
6	Sallahadin	36.3881	44.2076	1088	2017-2021
7	Duhok	36.8686	42.9538	569	2017-2021
8	Zakho	37.1459	42.6736	440	2017-2021

2. Climate Oscillation Data

Climate oscillations are large-scale, dynamic oceans and atmospheric circulations that produce climate patterns defined by cyclical swings in the global or regional climate across periods ranging from a few hours to many decades. The parameters are used to calculate the magnitudes of these oscillations are called climate indices. In order to identify how large global climatic oscillations, affect the wind speed in the Iraqi-Kurdistan region and eventually utilize them as potential predictors, the present work examines some of these oscillations. These oscillations' various periodicities allow for both short and long-term interpretations of the variables affecting the climate and wind speed in the study area. Each climate index's data period and references to the data source are included in Table 2.

Table 2. Related global climate indices and the data source used in the current study.

Climate oscillation	Short name	Period	Source of data
North Atlantic Oscillation	NAO	2017-21	https://psl.noaa.gov/data/timeseries/daily/NAO/
Southern Oscillation Index	SOI	2017-21	https://www.longpaddock.qld.gov.au/soi/soi-data-files/
Mediterranean Oscillation	MOI	2017-21	https://crudata.uea.ac.uk/cru/data/moi/
Arctic Oscillation	AO	2017-21	https://ftp.cpc.ncep.noaa.gov/cwlinks/

Spectral Analysis Technique

SSA-MTM Toolkit, which was installed on Manjaro (Linux), has been used extensively in time series research because to its strength in analysis and signal-to-noise determination [20]. In climate data, time series analysis finds patterns. Spectrum analysis, which has several variations, is one of the practical approaches for analyzing time series and obtaining its information. The Multi-Taper Method (MTM) is a type of spectrum analysis technique that is frequently used to solve hydrological signal analysis issues, such as those involving studies of atmospheric and oceanic datasets [21]. We can extract statistical significance periodicities in wind speeds time series using the approaches. Cross-coherency analysis is use to determine the correlation between two signals in the frequency domain. In essence, spectral analysis is a variation of Fourier analysis that makes it acceptable for stochastic rather than deterministic functions of time. It is the separating of a signal into various frequency components [22].

Multi Taper Method (MTM)

MTM is ideal for observing the relevant patterns in such different fluctuations because it has lowest error, excellent spectral and precise statistical evidence for the identified spectral peak position [23]. MTM is a new technique for spectral analysis and signals recovery of time series whose frequency may include both wideband and line elements. This technique involves multiplying the data sequence under analysis by a set of tapers. After that the output is processed by Fourier using FFT. Squared and used to determine the predicted frequency spectrum. The spectral leakage is reduced by these tapers (power leakage is artificially high-power estimates at frequencies away from the true peaks frequencies). This approach makes use of a limited number of tapers to try to decrease the variation of spectral estimations outside of a frequency with a bandwidth [22].

Both the line parts and the continuous background of the spectrum may be estimate-using MTM. The overall power spectrum S_x may be calculated once the tapers $w_k(t)$ for a certain frequency bandwidth have been determined by combining the separate spectra provided by each tapered version of the set of data. We call $\hat{S}(f) \equiv |Y_k(f)|^2$ the k the Eigen spectrum, where Y_k is the discrete Fourier transform (DFT) of $\{X(t)\, w_k(t)$: $t = 1,., N\}$.

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The high-resolution multi-taper spectrum is a weighted sum of the "K" Eigen spectra,

$$S_r(f) = \frac{\sum_{k=1}^{k} \mu_k \, |Y_k\,(f)|^2}{\sum_{k=1}^{k} \mu_k} \qquad (1)$$

The relative weights on the contributions from each of the "K" Eigen spectra can be adjusted further to obtain a more leakage-resistant spectral estimate, termed the adaptively weighted multi-taper spectrum:

$$S_w(f) = \frac{\sum_{k=1}^{k} b_k^2\,(f)\,\mu_k |Y_k\,(f)|^2}{\sum_{k=1}^{k} b_k^2\,(f)\,\mu_k} \qquad (2)$$

The selection of weights μk and other information, is explained in detail by Ghil *et al.* [24]. In any MTM application where p is a carefully selected integer, the number k of taper utilized should be fewer than 2p-1. MTM has been used to solve several geophysical signal analysis issues, including those involving the interpretation of observational data on the atmosphere and ocean. This approach has several distinct advantages: a high resolution and a level of statistical reliability unrelated of spectral power. Where p is the time-frequency bandwidth parameter, only the first S=2p-1 tapers are functionally resistant to spectral leakage. The selection of P=2 and K=3 in the context of climate research offers a fair compromise between the resolution needed to resolve climatic signals and the variance of the spectral measurement [25].

RESULTS AND DISCUSSION

1. Wind Speed Cycles

Multi-taper Spectral analysis was applied on daily wind speed time series to detect the existed periodicities in the wind speeds of Sulaymaniya, Penjwen, Hallabja, Kalar, Erbil, Sallahadin, Zakho, and Duhok cities. It is obvious from the power spectra of Sulaymaniya daily wind speed as in Figure 3. there are nine cycles above 99% significant level (2.08, 3.33, 3.7, 4, 4.35, 4.76, 5, 7.14, and 9.09 cycles), nine cycles above 95% significant level (2.17, 2.38, 2.56, 2.63, 4.55, 5.56, 8.33, 10, and 16.67 cycles) and ten cycles above 90% significant level (2.22, 2.33, 2.5, 2.7, 2.86, 5.88, 6.67, 12.5, 14.29, and 50 cycles) as Table 3. All the cycles are obtained by choosing the method's parameters P=2 and K=3 of multi-taper method. Each obtained cycle is a result of teleconnection pattern type.

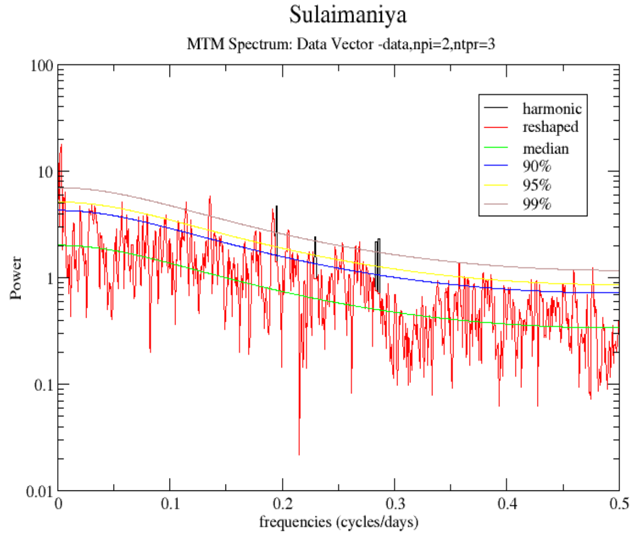

Figure 3. Power spectra of Sulaymaniya wind speed series using multi-taper method.

Table 3. Sulaymaniya daily wind speeds cycles obtained by MTM spectral analysis.

significant level	Periodicities (days)				
above 99%	2.08	3.33	3.7	4	4.35
	4.76	5	7.14	9.09	
above 95%	2.17	2.38	2.56	2.63	4.55
	5.56	8.33	10	16.67	
above 90%	2.22	2.33	2.5	2.7	2.86
	5.88	6.67	12.5	14.29	50

Figure 4 shows the spectral analysis (periodogram) of Penjwen wind speed series using multi-taper method. We obtained 4 cycles above 99% significant level, 15 cycles above 95% significant level and 9 cycles above 90% significant level as illustrate in Table 4. The number of daily periodicities above 95% is more than the number of daily periodicities above 99% and 90%.

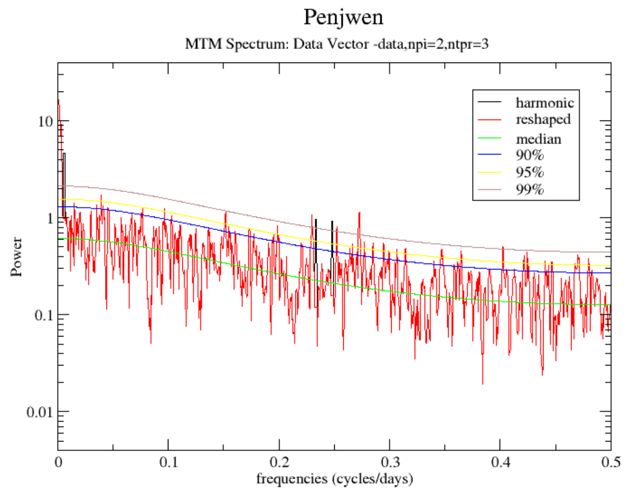

Figure 4. Power spectra of Penjwen wind speed series using multi-taper method.

Table 4. Penjwen daily wind speeds cycles by MTM spectral analysis.

significant level	Periodicities (days)
above 99%	2.50 3.70 4.00 4.35
above 95%	2.08 2.13 2.22 2.27 2.38 2.78 2.86 3.23 3.33 3.45 3.57 5.00 7.14 10.00 25.00
above 90%	2.44 2.94 3.85 4.55 5.56 5.88 6.25 14.29 50.00

Figure 5 shows the spectral analysis (periodogram) of Hallabja wind speed series using multi-taper method. We get number of daily periodicities above the significant level of 99% are eight cycles, the number of daily periodicities above the significant level of 95% are sixteen cycles and the number of daily periodicity cycles above 90% are nine cycles. The number of daily periodicities above 95% is more than the number of daily periodicities above 99% and 90%. Daily periodicities are illustrated in Table 5.

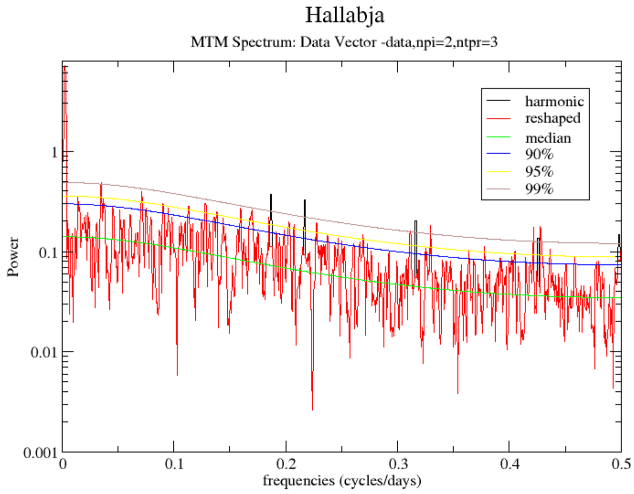

Figure 5. Power spectra of Hallabja wind speed series using multi-taper method

Table 5. Hallabja daily wind speeds cycles by MTM spectral analysis.

significant level	Periodicities (days)
above 99%	2.33 2.38 3.03 3.13 3.33 4.55 5.26 25.00
above 95%	2.22 2.44 2.63 2.78 3.70 4.17 4.35 4.76 5.00 5.56 6.25 7.14 7.69 9.09 11.11 14.29
above 90%	2.08 2.17 2.50 2.56 3.85 4.00 10.00 12.50 100.00

Figure 6 shows the spectral analysis (periodogram) of Kalar wind speed series using multi-taper method. Twenty cycles were collected above 99% significant level, seventeen cycles above 95% significant level and four cycles above 90% significant level. The number of daily cycles above 99% is more than the number of daily cycles above 95% and 90%.

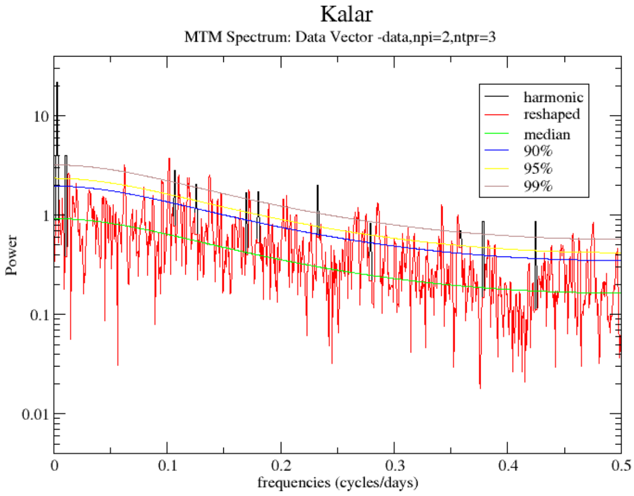

Figure 6. Power spectra of Kalar wind speed series using multi-taper method.

Table 6. Kalar daily wind speeds cycles by MTM spectral analysis.

significant level	Periodicities (days)
above 99%	2.08 2.17 2.33 2.63 2.78 2.94 3.45 3.57 3.7 4.35 4.76 5 5.56 5.88 7.14 7.69 8.33 9.09 10 14.29
above 95%	2 2.13 2.22 2.27 2.5 2.86 3.03 3.13 3.23 3.45 3.85 4.17 5.26 6.25 6.67 12.5 100
above 90%	2.72 3.33 11.49 50

Figure 7 shows the spectral analysis (periodogram) of Erbil wind speed series using multi-taper method. We obtained 10 cycles above 99% significant level, 6 cycles above 95% significant level and for the above 90% significant level are 12 cycles as illustrate in Table 7. The number of daily cycles above 90% is more than the number of daily cycles above 99% and 95%.

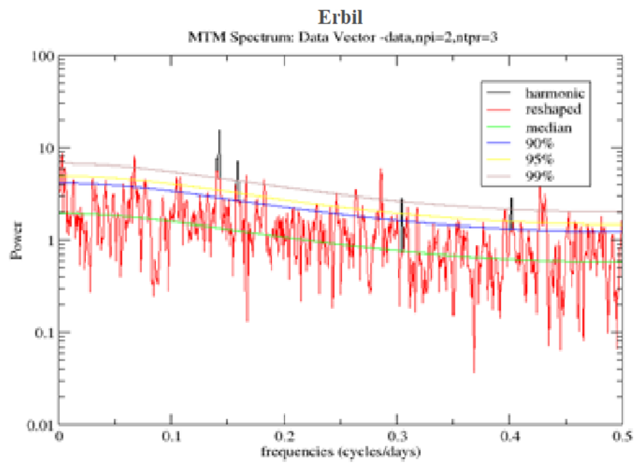

Figure 7. Power spectra of Erbil wind speed series using multi-taper method.

Table 7. Erbil daily wind speeds cycles by MTM spectral analysis.

Significant level	Periodicities (days)						
above 99%	2.33	2.50	3.33	3.45	3.85	5.56	5.88
	6.25	7.14	14.29				
above 95%	2.08	2.22	3.13	3.23	3.7	9.09	
above 90%		2.17	2.44	2.63	2.86	3.57	4.35
	4.76	7.69	16.67	25.00	33.33	100.00	

Figure 8 shows the spectral analysis (periodogram) of Sallahadin wind speed series using multi-taper method. 9 cycles are obtained above 99% significant level, the daily periodicities above 99% is equal to daily periodicities above 90%, and the daily periodicities above 95% are eleven cycles. The daily periodicities above 95% are more than the daily periodicities above 99% and 90% as illustrated in Table 8.

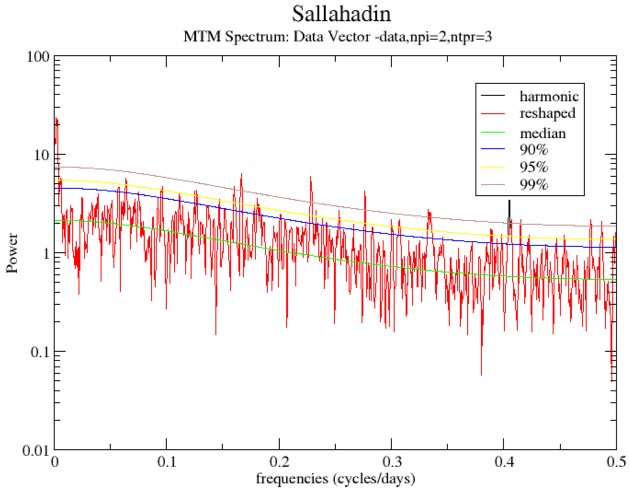

Figure 8. Power spectra of Sallahadin wind speed series using multi-taper method.

Table 8. Sallahadin daily wind speeds cycles by MTM spectral analysis.

Significant level	Periodicities (days)					
above 99%	2.04	2.08	2.44	2.50	3.03	3.57
	4.35	5.88	6.25			
above 95%	2	2.22	2.38	2.56	3.23	3.33
	4	5.56	7.14	10	16.67	
above 90%	2.27	2.56	2.86	3.70	4.17	5.00
	6.67	9.09	14.29			

Figure 9 shows the spectral analysis (periodogram) of Duhok wind speed series using multi-taper method. We acquired seven cycles above 99% significant level, nine cycles above 95% significant level and eleven cycles above 90% significant level. The daily cycles above 90% is more than the daily cycles above 99% and 95%. All daily cycles are illustrated in Table 9.

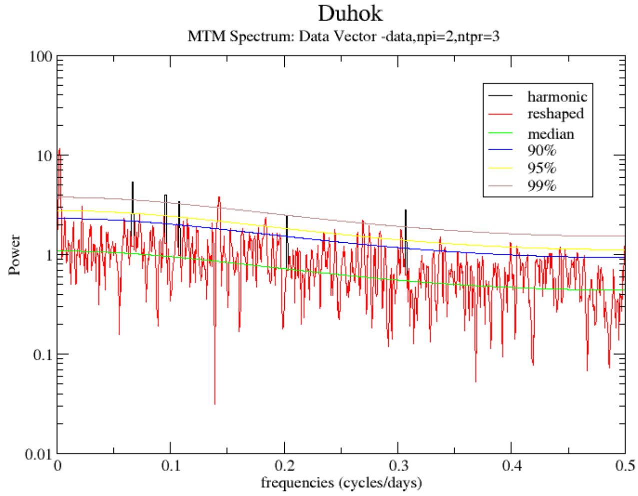

Figure 9. Power spectra of Duhok wind speed series using multi-taper method.

Table 9. Duhok daily wind speeds cycles by MTM spectral analysis.

Significant level	Periodicities (days)					
above 99%	3.23	3.70	5.56	7.14	9.09	10.00
	14.29					
above 95%	2.27	2.44	2.5	2.94	3.33	3.57
	3.85	4.35	50			
above 90%	2.17	2.22	2.33	5.00	5.26	5.88
	6.25	6.67	7.14	8.33	16.67	

Figure 10 shows the spectral analysis (periodogram) of Zakho wind speed series using multi-taper method. The obtained daily periodicities above the significant level of 99% are 14 cycles. The daily periodicities above the significant level of 95% are 5 cycles and the daily periodicities above 90% are 11 cycles. The daily cycles above 99% are more than the daily cycles above 95% and 90% as illustrate in Table 3. The common cycles for the eight stations 2.22, 2.5, 3.33, 3.7, 4.35, 5.56, 7.14, 10 and 14.29 days. Although there are variances in certain cycles and spectral resolution. It is clear from the spectrum of the spectral approach for each site that there is a general agreement in the periodicities and the shape among them. The daily wind speed is a very variable climatic factor both geographically and temporally at different scales, thus there are some variations in the periodicities across the spectra of the eight locations.

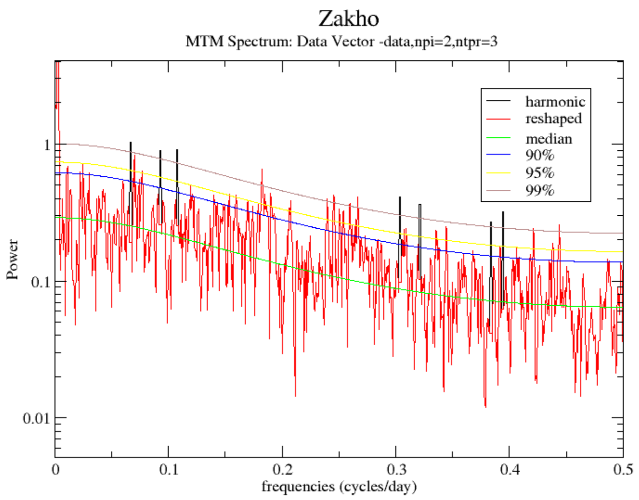

Figure 10. Power spectra of Zakho wind speed series using multi-taper method.

Table 10. Zakho daily wind speeds cycles by MTM spectral analysis.

Significant level	Periodicities (days)						
above 99%	2.22	2.38	2.50	2.63	3.13	3.33	3.70
	3.85	4.00	4.35	5.56	9.09	11.11	14.29
above 95%	2.94	4.76	5.26	6.25	12.5		
above 90%	2.04	2.44	2.70	3.57	5.88	6.67	7.14
	8.33	33.33	50.00	100.00			

2. Teleconnection Patterns Cycles

To know the genesis of the wind cycles of each cite for the study area, MTM spectral analysis method is also applied on the daily NAO index, SO index, MO index, and AO index for the same five years of the daily wind speed time series. MTM spectral technique is subjected on daily NAO index choosing the method's parameters p=2 and k=3, the obtained power spectra is more complicated than the previous power spectra of wind cites. We get 33 cycles in general for the significant levels 99%, 95% and 90% as in Figure 11 and Table 11. From Figure 12, which contain all periodicities of SOI by applying MTM for the given series 23 cycles are selected and shown in Table 12.

MTM applied on MOI, the spectral analysis result is show in Figure 13. The obtained periodicities are summaries in Table 13, where 24 significant cycles are selected from the periodogram. From Figure 14 the general periodicities of the spectral analysis method for the Arctic Oscillation Index (AOI), are obvious all harmonic periodicity in the Table 14, where 32 significant cycles are selected in general for all significant levels. The common cycles for the four-teleconnection patterns NAOI, SOI, MOI and AOI are 2.22, 2.5, 2.86, 3.33, 3.7, 4, 4.35, 5.56, 5.88, 6.67, 7.14, 8.33, 10, 12.5 and 14.29 cycles.

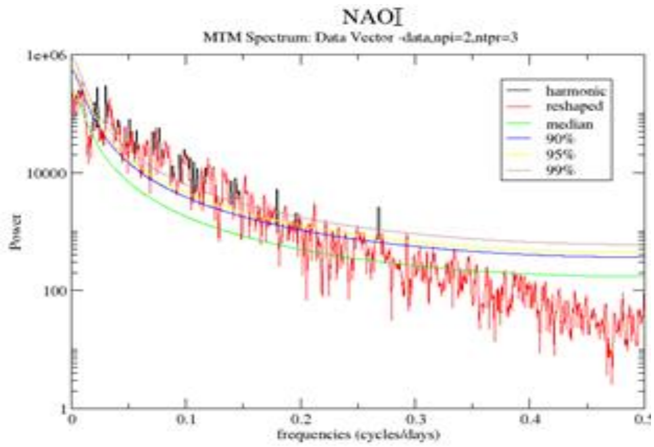

Figure 11. Power spectra of NAOI series using multi-taper method.

Table 11. NAOI daily periodicities

2.04	2.08	2.17	2.22	2.27	2.33	2.38	2.50
2.86	2.94	3.03	3.13	3.33	3.7	4	4.35
4.55	5.00	5.26	5.56	5.88	6.67	7.14	7.69
8.33	10.00	12.50	14.29	16.67	20.00	25.00	33.00
100.00							

Table 12. SOI daily periodicities

2.08	2.22	2.50	2.70	2.27	3.33	3.70	4.00
2.86	4.35	5.00	5.26	5.56	5.88	6.67	7.14
4.55	8.33	9.09	10.00	12.50	14.29	50.00	

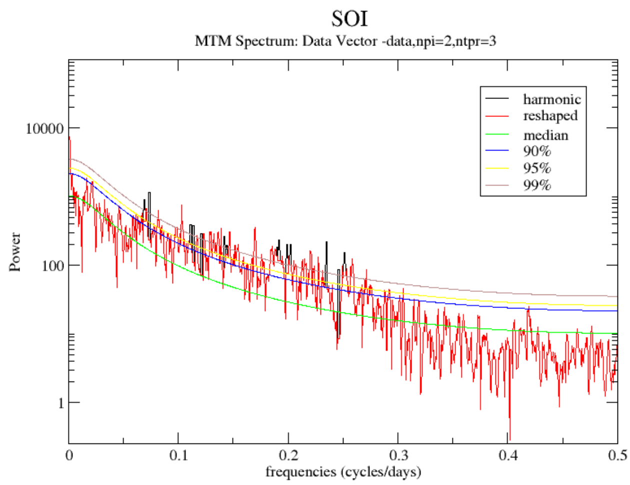

Figure 12. Power spectra of SOI series using multi-taper method.

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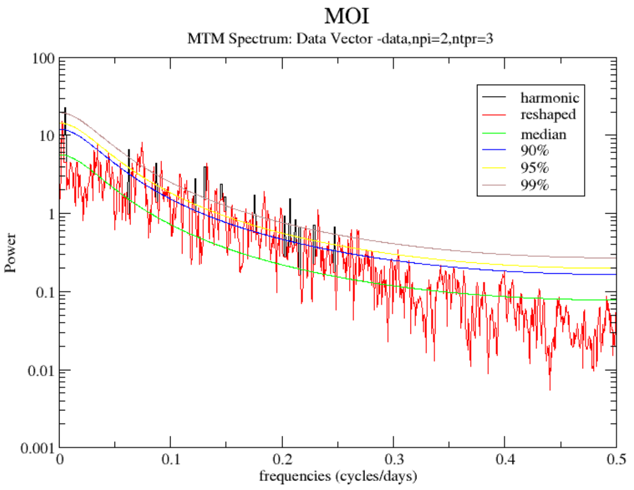

Figure 13. Power spectra of MOI series using multi-taper method.

Table 13. MOI daily periodicities

2.04	2.13	2.22	2.33	2.5	2.78	2.86	2.94
3.23	3.33	3.7	4	4.35	4.76	5.56	5.88
6.67	7.14	8.33	10	12.5	14.29	25	100

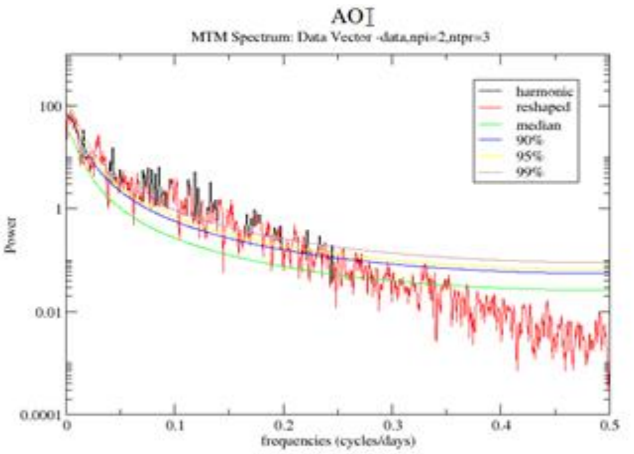

Figure 14. Power spectra of AOI series using multi-taper method.

Table 14. AOI daily periodicities

2.04	2.17	2.22	2.33	2.5	2.56	2.63	2.86
3.03	3.33	3.7	3.85	4	4.35	4.55	5
5.26	5.56	5.88	6.67	7.14	7.69	8.33	9.09
10.00	11.11	12.50	14.29	20.00	25.00	33.33	50.00

CONCLUSIONS

From MTM spectral analysis of daily wind speed of Sulaymaniya, Penjwen, Hallabja, Kalar, Erbil, Sallahadin, Zakho and Duhok cities, the periodogram of large-scale teleconnection patterns of NAO, ENSO, MO and AO, it can be concluded that:

1. The common cycles of daily wind speed for the eight stations in Iraqi-Kurdistan region are 2.22, 2.5, 3.33, 3.7, 4.35, 5.56, 7.14, 10 and 14.29 cycles. Each of eight stations has its own cycles slightly different from the others.
2. The spectral analysis of NAO index series shows 33 significant cycles which used to determine the impact of NAO on the wind of study region. The common cycle between NAO and daily wind speed of the cites of study region are 21 cycles.
3. SO is important teleconnection pattern and effect on weather and climate of the study area. The significant detected periodicities of SO index series are 23 cycles, and that to detect the influence of SO on the study area. There are 17 synchronized cycles between SO and the wind speed of the study area.
4. MO index series is spectrally analyzed, and several cycles are found, these periodicity cycles affect Iraqi-Kurdistan region daily wind speed through 24 significant cycles. MO effect on the wind speed of the study area through 17 cycles.
5. AO is another important atmospheric circulation effect on the study area. The detected periodicities in AO index series are 32 significant cycles. The wind speed of the study area is affected by AO through 21 cycles.
6. The statistically substantial relationships between the daily wind speed for the eight cities and NAOI, SOI, MOI, and AOI demonstrate that atmospheric circulation variability is an important reason for the daily wind variability in the studied region.
7. The common cycles for the four-teleconnection patterns NAOI, SOI, MOI and AO are 2.22, 2.5, 2.86, 3.33, 3.7, 4, 4.35, 5.56, 5.88, 6.67, 7.14, 8.33, 10, 12.5 and 14.29 cycles.

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