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Phase Lag of Temperature behind Solar Radiation in Iraq

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ABSTRACT

Solar radiation is the ultimate source of energy to the Earth and its surrounded atmosphere. In the multitudes, the seasonal variations of solar radiation reaching the Earth's surface is almost sinusoidal resulting in nearly sinusoidal variations in air temperature. A phase lag exists between the two cycles due to the heat capacity of the Earth. The aim of this work is to determine this phase lag in four cities representing different climatic regions in Iraq. Monthly and daily data of all sky solar radiation incident on a horizontal surface (SW) and air temperature at 2m (T2m) were analyzed for the period 1990-2019. The results showed that SW peaks occurred in the last week of June while the T2m approached its peak sometime between mid-July and mid-Aug depending on the location of the city. The average phase lag for the entire 30 year's period was ~29 days in northern city of Mosul, 44 days in western town of Rutba and ~36 days in the central and southern cities of Baghdad and Basra respectively. Diurnal SW and T2m data during the equinoxes (spring and autumnal) and solstices (winter and summer) of 2019 were used to determine the diurnal phase lag. The finding of this paper indicated that SW peaked at 1 PM during all seasons and in all four cities and the phase lag was varying between 2 to 3 hours depending on the season and location.

KEYWORDS

Phase lag, air temperature, solar radiation.

INTRODUCTION

The solar radiation reaches the Earth's surface in the form of direct and diffuse radiation and warms both the surface of the earth and the atmospheric layer close to the surface. The amount of solar radiation reaching a given place is the key factor for determining the climatic features of that place [1]. The solar radiation is a shortwave radiation emitted by the sun in bands extending from X-rays to radio waves, but the irradiance of solar radiation peaks in the visible wavelengths. The Earth absorbs most of the solar radiation energy reaching its surface, 70% of the total incident solar radiation is absorbed by the Atmosphere and the Earth's surface, while approximately 30% is reflected back to space [2]. Outgoing radiation longwave radiation emitted from surface and part of this radiation is absorbed by the atmosphere which then radiate longwave in all directions including downwards and therefore warming the air close the earth surface [3]. The Northern Hemisphere receives the highest amount of incoming solar radiation when the Sun reaches its highest point in the sky on the summer solstice (Typically 21st June or 22nd June) while warmest temperature does not occur until a month later. This delay is called "seasonal lag" and its main reason is the high heat capacity of the Earth [4].

Annual changes in air temperature associated with seasons are much larger over the continental than over the coastal area. Air temperature lags behind the solar cycle by 30 days over the continental areas, compared with 40 days in maritime areas which examined by Seco et al. [5]. This is due to some facts which will present as follows. The specific heat of water is five times higher than that of land. The solar radiation penetrates the water to a depth of several meters but only a thin layer for the land. Therefore, the temperature of the sea does not rise as rapidly as that of the land surface during the day time. Also, the land becomes increasingly colder than the sea by loss of heat by radiation during the night time. By conduction, the air temperature adjacent to the land and sea surface subject to large extremes and very small variations between the day time and the night time respectively [6]. Another type of lag between solar radiation and air temperature occur on daylight times. The solar radiation increases from sunrise and reaches its maximum daily value at noon when the sun reaches its highest position and then decreases and reaching minimum at sunset. Air temperature also increases with increasing solar radiation but it peaks a time behind noon. This lag is called “daily lag”[7] .

Many studies were done to investigate the gap time between the phase lag incident solar radiation and air temperature that attracted objective research points. Among early works of this point were those conduct by [8] , [9] , [10], [11] studied the phase lag in Santiago in Chile and Salamanca in Spain and found that air temperature has a phase lag of 30 days behind global solar radiation in Santiago and a phase lag of 15 days in Salamanca [12]. El-hussainy et al., carried out a good correlation between solar radiation and averaged maximum and minimum air temperatures. Phase lag between them was more than 30 days for coastal station, while less than 30 day for stations surrounded by mountain in Egypt [5]. The number of days of the phase lag was found maximum when a good correlation between the minimum air temperature and the global solar radiation occurs and vice-versa in case of maximum air temperature. Investigated the response of earth’s surface temperature to the annual solar irradiance cycle using 60 years of data. Their developed model explained that both the resulting low sensitivity and time delay of 1-2 months requires negative feedback that may represent cloud effects or convective transport between zones. [13].

Unlike previous studies is this study that focus on the variability in the amplitude and phase of annual cycle of surface air temperature by using two different model, and studied changes in the phase of the seasonal cycle that have strong relationship with atmospheric circulation, but it was difficult to explain these trends due to the lack in the natural variability understanding [14]. Explored the projected changes in the seasonal cycle of surface temperature. They attributed the average phase delay of 5 days in the global mean ocean surface temperature during the twenty-first century to sea ice melt.[15]. Analyzed both observations and coupled climate models to study the seasonal cycle of atmospheric heating and temperature. They found that the seasonal heating of the troposphere is everywhere enhanced by increased shortwave absorption by water vapor[16]. Santer et al., (2018) studied the human influence on the seasonal cycle of tropospheric temperature. Their results suggested the changing seasonal cycle in tropospheric temperature provides strong evidence for an important human effect on Earth’s climate [17]. More over analyzed the temporal structure of the climatologically seasonal cycle in surface air temperature across the globe. They concluded that over large regions of Earth, the seasonal cycle of surface temperature departs from an annual harmonic and the duration of fall and spring differ by as much as 2 months[6]. The relation between the air temperature and incident solar radiation was diagnostic by focus on the phase lag for four selected stations in Iraq. The aim of this work is to understand the behavior of air temperature through to determine the phase lag of T2m behind SW for long time studied (1990-2019) years of monthly and daily data.

MATERIAL AND METHODS

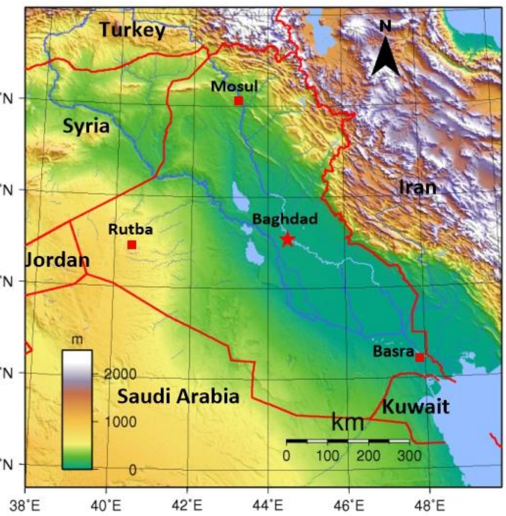


Figure 1. Geographical map of Iraq.

Iraq is a country located in the central of Middle East region between latitudes 29.08° and 37.37° N and longitudes 38.75° and 48.75° E (see Figure 1). It is bordered by Turkey from the north and Iran from the east, the Arabian Gulf to the southeast, Kuwait and Saudi Arabia and to the south, and Syria and Jordan to the west. The surface of Iraq is divided into three main sections, namely, the mountain range, the sedimentary plain, and the desert plateau. The mountain range extends from norther borders with Turkey to the northwestern. The alluvial plain is located between Tigris and Euphrates rivers and extends from northwest to southeast. The desert plateau covers the western and south western parts of the country [18]. The climate of Iraq is characterized by long, hot, dry summers and short, cool winters. During the summer a strong northwesterly winds called the Shamal (north in Arabic language) winds causes frequent dust storms, especially during June and July, and transport dust towards southeast and reach Kuwait, Saudi Arabia, Iran, and the Arabian Gulf. In Iraq, rain only falls during October to May and the highest rainfall occur over northeastern aream [19].

The data sources for this work, multi sets of data were used including daily and monthly means of all sky solar radiation incident on a horizontal surface (SW), downward longwave radiation (LW), and air temperature at 2m (T2m) for the period 1990-2019. All sets of data were acquired from the Prediction of Worldwide Energy Resources (POWER) project provided The National Aeronautics and Space Administration (NASA). The POWER project aimed at improving the renewable energy data set and creating new data sets from new satellite systems [20]. Data were obtained for four Iraqi cities representing northern, central, western, and southern parts of the country. The data analysis consisted essentially monthly time series of SW, LW, and T2m to assess the behavior of these variables during the 30 years' period. Then the long term means of monthly SW and T2m were used to estimate the long term phase lag between them in the four cities. To determine the phase lag on daily basis during the indicated time period, daily data of SW and T2M were analyzed. As an example, Figure 2 shows the time series of SW and T2m in Mosul. The time series were averaged over 5 years' period during 1990-2019. These 5 years averaged daily SW and T2m were plotted and used to determine the phase lag (in number of days) between SW and T2m for each 5 years' period. Finally, the diurnal phase lag was determined during the solstices and equinoxes in the four cities.

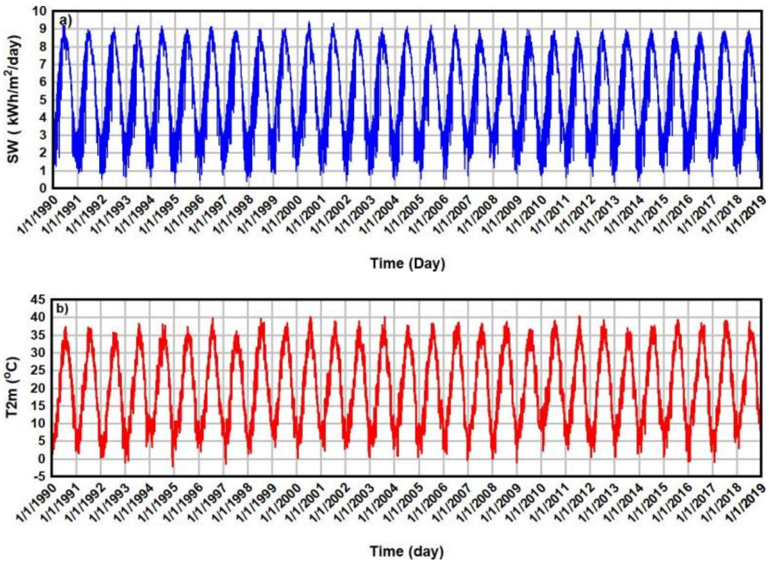


Figure 2: Mosul daily time series for a) SW and b) T2m during 1990-2019 as an example of the data used in this work.

RESULTS

The monthly variations of SW, LW, and T2m for Mosul, Baghdad, Rutba, and Basra during the period 1990-2019 as shown in Figure 3. It is seen that there is a small variation from one year to others in all three parameters and in all cities. This variation, which was attributed to the variation of the meteorological conditions, is more evident during the summer months (Jun-Aug) because all parameters approach their maximum values during this time. The LW shows an obvious increasing trend starting from 2004, especially in Mosul, Baghdad, and Basra. This is because these three cities are the most urbanized and populated cities in Iraq and emission of greenhouse gases has been increasing due to the continuous increase in the number of vehicles. Also the use of large number of diesel power generators by public to compensate for the shortage of electrical energy, supply. An increasing trend in T2m is also observed in all four cities.

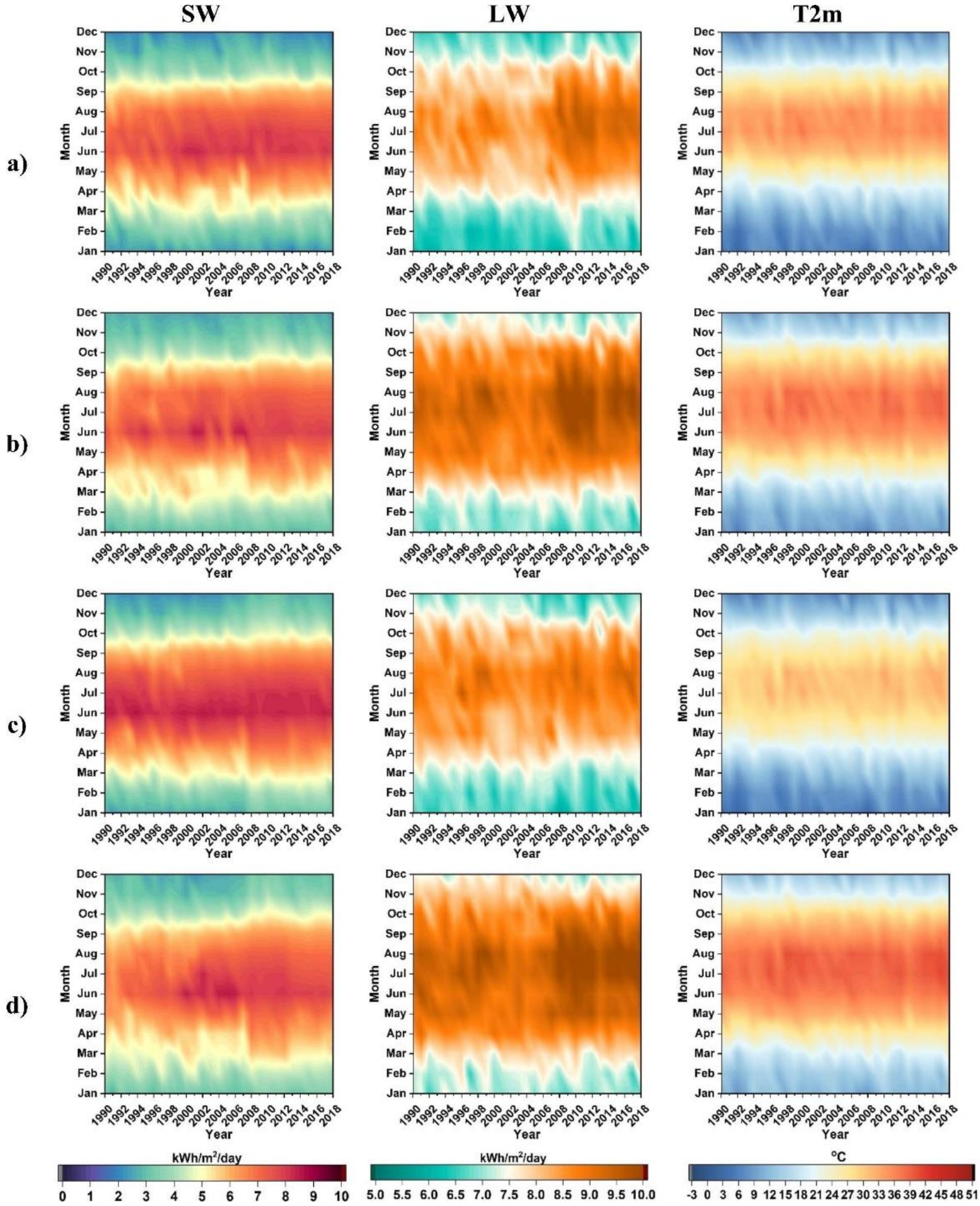


Figure 3. Monthly variations of SW, LW, and T2m for Mosul, Baghdad, Rutba, and Basra for the period 1990-2019.

The long term means of monthly of SW, LW, and T2M that presented in figure (4). It is clear that values of SW are comparable in all four cities while the LW is higher in Basra and Baghdad and notably lower in Mosul and Rutba. The T2m curves reflect the climate of Iraq; the southern city of Basra is warmest followed by Baghdad, Mosul, and Rutba. Rutba is colder than Mosul because it is a small town located on western highland of Iraq. Figure (5) exhibits the long term lag of T2m behind SW for The four cities. It is seen that SW is maximum in June, as expected, and T2m approaches its peak sometimes between mid-July and mid-Aug which suggests that roughly T2m lags SW by a month or so in Iraq. The exact lag will be determined by using the daily data of SW and T2m.

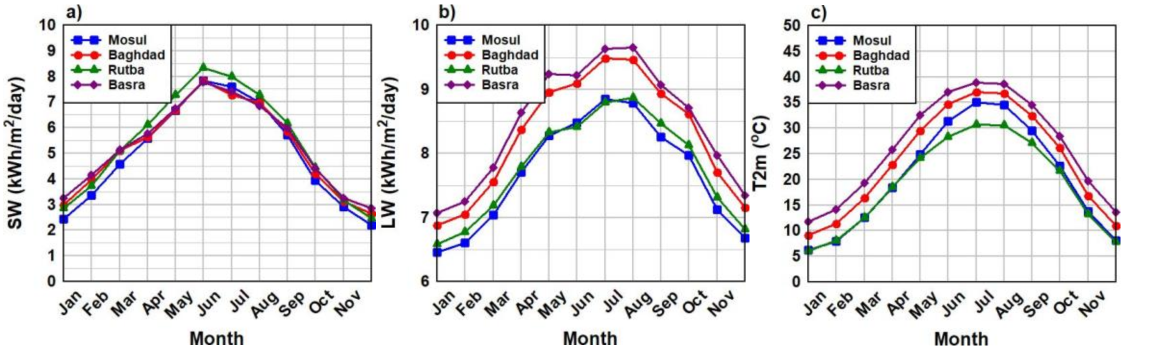


Figure 4. Long term means of a) SW, b) LW, and c) T2m for the four cities.

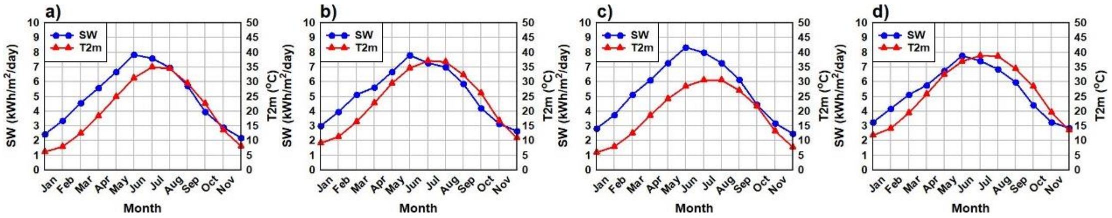
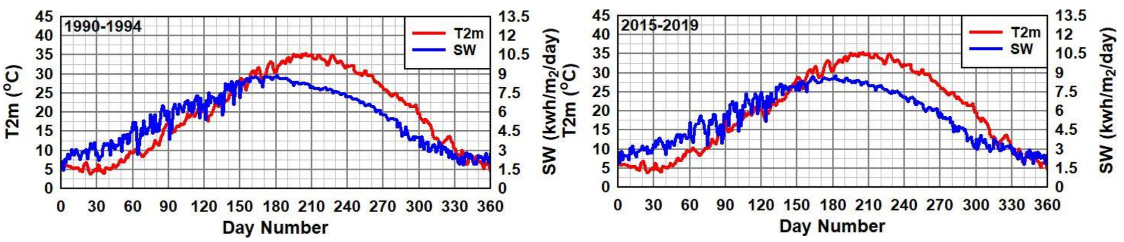


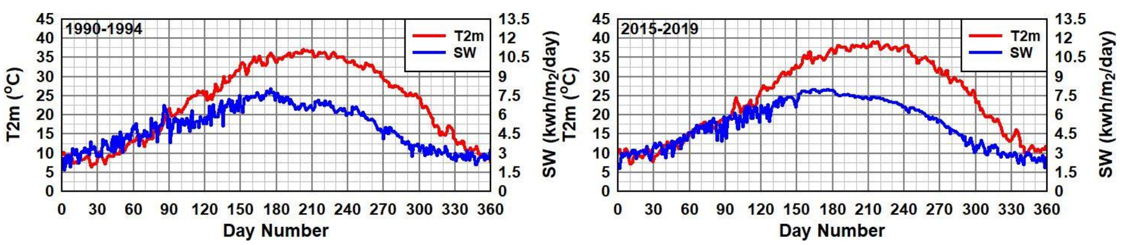
Figure 5. Long term phase lag of T2m behind SW for a) Mosul, b) Baghdad, c) Rutba, and d) Basra.

Figures (6) gives examples of the five years averaged daily time series of SW and T2m for the four cities. Shown are the 1990-1994 and 2015-2019 periods. All years were assumed to have 365 days, i.e. Leap years were excluded, and the day numbers for Jun 1st, Jul 1st, and Aug 1st are 151, 182, and 213. It seen that in all SW curves the peaks occurred in the last week of June and the peak happened between mid-July and mid-Aug depending on the location of the city. The exact date of the occurrences of the SW and T2m peaks were determined from the Excel sheets of the data and are summarized in Table 1. It is seen that almost all peaks od SW occurred in the last 10 days of June while the peaks occurred mid-July to mid-August. It is obvious that the phase lag is quite variable from one period to another. The range of the phase lag was 42-36 days in the northern city of Mosul, 27-44 days in the central city of Baghdad, 30-52 days in the western town of Rutba, and 24-47 days in the southern city of Basra. The average phase lag for the entire period was ~29 days in Mosul, 44 days in Rutba and ~36 days in both Baghdad and Basra. Figures (7) and (8) show the diurnal SW (in Wh/m^2) and T2m during equinoxes (spring and autumn) and solstices

1990-1994 **2015-2019**



a)



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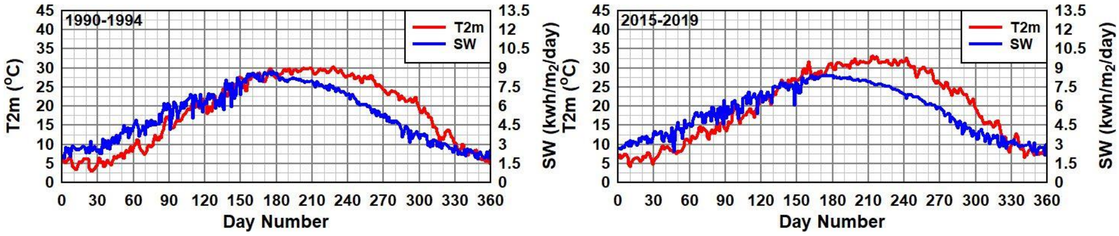

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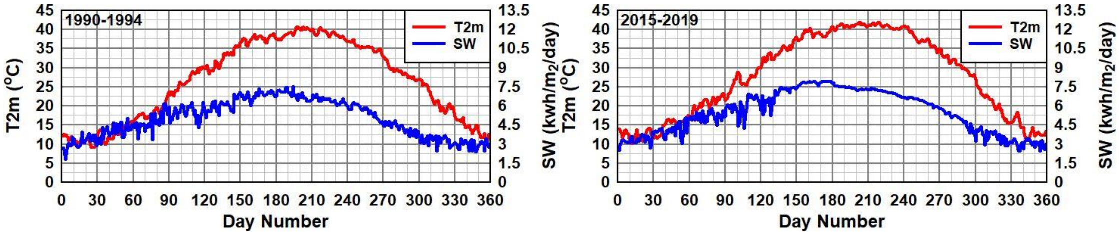

d)

Figure 6. Five years aveage of daily SW and T2m for 1990-1994 and 2015-2019 in a) Mosul, b) Baghdad, c)Rutba, and d) Basra.

(winter and summer) of 2019 in the four locations. No clouds or dust storms were observed over the four locations during the selected days (see Figure 12). Figure (10) indicates that SW peaks at 1 PM during all seasons with amount of ~ 1000 Wh/m^2 and the SW during equinoxes are comparable during most times of the daylight and differences appears only at times around noon. In general SW during spring equinox is slightly higher than its value during autumnal equinox and the opposite to that which appeared in Basra may attributed to the presence of small patches of clouds over Basra during the day of spring equinox. The presence of clouds in the sky reduces the amount solar radiation reaching the Earth's surface through absorption and scattering processes. Figure (8) shows that T2m peaks at some time after 12 noon and this time depends on location and season. The phase lags (in hours) are summarized in Table (2). It is obvious that the diurnal phase lag ranges between 2 to 3 hours and depends on location and season.

Table 1. Time lag of T2m behind peak SW for Mosul, Baghdad, Rutba, and Basra for the period 1990-2019. Values represent averages of 5-years intervals.

Period	Peak SW kWh/m^2	Date	Peak T2m (°C)	Date	Lag (Days)
Mosul					
1990-1994	8.93	30 Jun	35.4	24 Jul	24
1995-1999	8.96	24 Jun	36.7	21 Jul	27
2000-2004	8.90	23 Jun	36.9	29 Jul	36
2005-2009	8.73	24 Jun	36.7	22 Jul	28
2010-2014	8.88	1 Jul	36.7	30 Jul	29
2015-2019	8.81	1 Jul	36.6	2 Aug	32
Average	8.85		36.5		29.33
Baghdad					
1990-1994	8.07	24 Jun	37.1	21 Jul	27
1995-1999	8.11	19 Jun	38.8	27 Jul	38
2000-2004	8.43	26 Jun	38.8	9 Aug	44
2005-2009	8.25	24 Jun	38.5	26 Jul	32
2010-2014	8.06	21 Jun	38.8	30 Jul	39

2015-2019	8.02	25 Jun	39.2	2 Aug	38
Average	8.16		38.6		36.33
Rutba					
1990-1994	8.75	24 Jun	30.3	15 Aug	52
1995-1999	8.57	23 Jun	32.4	23 Jul	30
2000-2004	8.71	25 Jun	32.9	8 Aug	44
2005-2009	8.75	23 Jun	32.4	18 Aug	56
2010-2014	8.49	22 Jun	33.5	3 Aug	42
2015-2019	8.47	11 Jun	33.1	1 Aug	51
Average	8.62		32.4		45.83
Basra					
1990-1994	7.53	23 Jun	40.7	17 Jul	24
1995-1999	8.04	28 Jun	41.6	28 Jul	30
2000-2004	8.65	26 Jun	41.8	12 Aug	47
2005-2009	8.39	29 Jun	41.7	22 Jul	23
2010-2014	8.10	15 Jun	41.2	31 Jul	46
2015-2019	7.95	21 Jun	42.0	7 Aug	47
Average	8.11		41.5		36.17

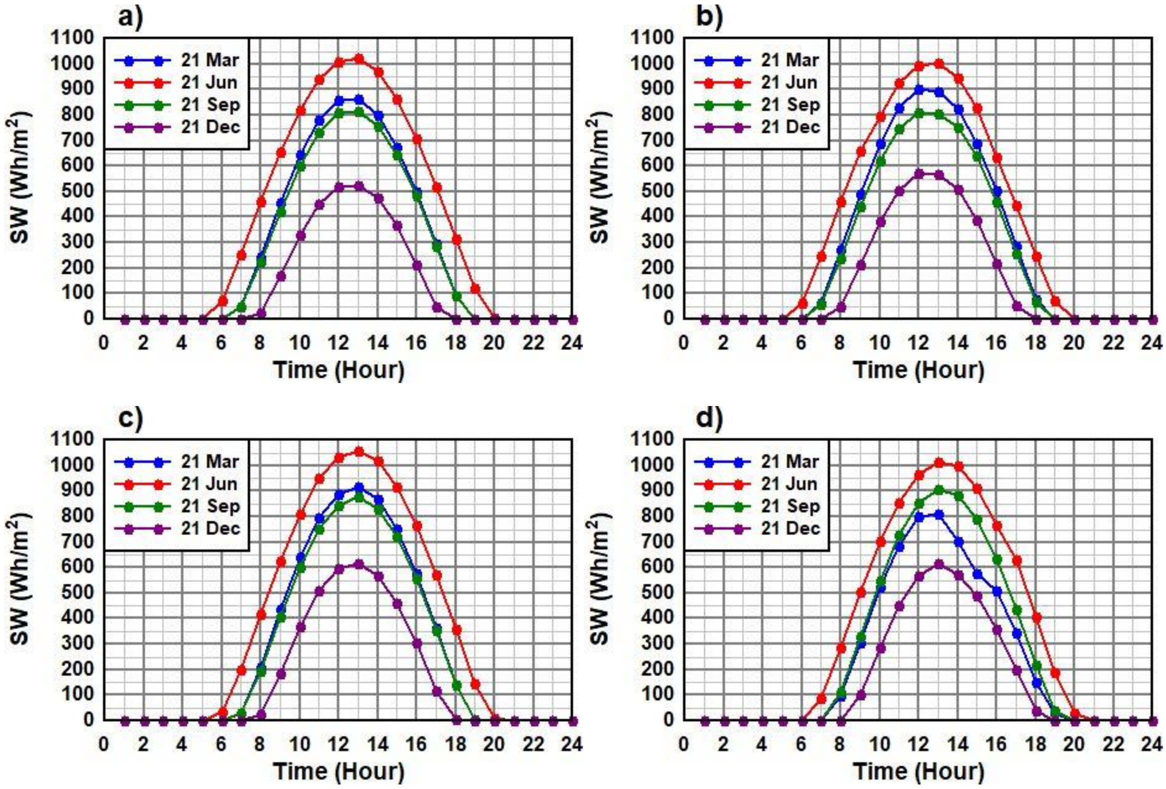

Figure 7. Diurnal variation of SW on equinoxes and solstices for a) Mosul, b) Baghdad, c) Rutba, and d) Basra.

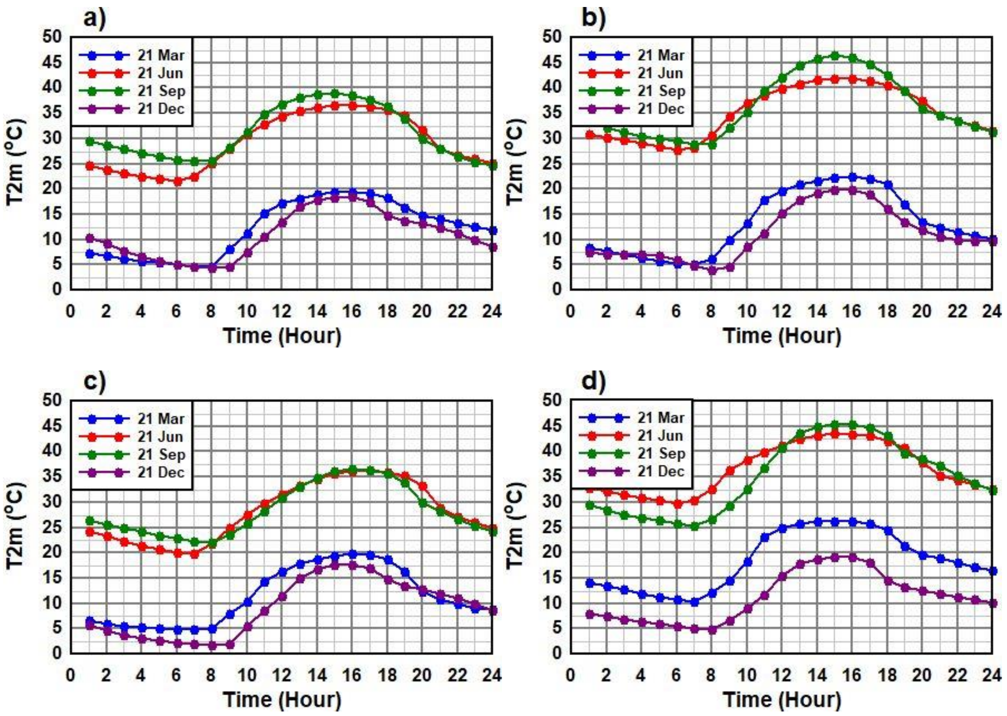

Figure 8. Diurnal variation of mean temperature on solstices and equinoxes for a) Mosul, b) Baghdad, c) Rutba, and d) Basra.

Table 2. Diurnal phase lag of T2m behind SW for Mosul, Baghdad, Rutba, and Basra during equinoxes and solstices of the year 2019.

City	Lag (hours)			
	Spring Equinox	Summer Solstice	Autumn Equinox	Winter Solstice
Mosul	3	2	2	3
Baghdad	3	2	2	3
Rutba	3	3	3	3
Basra	2	2	2	2

CONCLUSIONS

The variation of three variables that directly effect on general circulation model. The air temperature play significant role in atmospheric circulation, for this aspect this study was done. This paper used data for long time (30 years), originally came from daily and monthly time series of all sky solar radiation incident on a horizontal surface (SW) and air temperature at 2m (T2m) for four cities in Iraq, representing different north, center, west, and south parts were analyzed. The results revels that the SW normally approaches its peak in the last week of June while the peak of T2m occurs sometime between mid-July and mid-August. As a result, the seasonal lag of T2m behind SW in Iraq was significantly varies from 24 to 36 days in north city of Mosul, 27 to 44 days in the central city of Baghdad, 30 to 56 days in the western town of Rutba, and 24 to 47 days in the southern city of Basra. The relation of average air temperature of the phase lag was found that 29.33, 36.33, 45.38, 36.17 for Mosul, Baghdad, Rutba, and Basra respectively. This shortest lag in Mosul is attributed to the proximity of this city to the mountains in northern Iraq while the longest lag in Rutba is due to the fact that this rural town is located on the western highland desert. The lags in Baghdad and Basra are very comparable and this because these two cities have similar features in terms of urbanization and soil types. Analysis of diurnal SW and T2m during equinoxes and solstices days of the year 2019 indicated that SW peaks at 1 PM and peak T2m lags by 2 to 3 hours depending on the location and season.

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REFERENCES

[1] K.K.O, "Estimation of Clear-Sky Global Solar Radiation Using Hottel's Model and Liu and Jordan's Model for Qena /Egypt," Resources and Environment, vol. 11, Pp. 9-17, 2021.

[2] M. Iqbal, "An introduction to solar radiation: Elsevier", 2012.

[3] K.N. Liou, "An introduction to atmospheric radiation: Elsevier", 2002.

[4] I.N. Melnikova and A.V. Vasilyev, "Short-Wave Solar Radiation in the Earth's Atmosphere: Springer", 2005.

[5] F. El-Hussainy and K. Essa, "The phase lag of temperature behind global solar radiation over Egypt," Theoretical and applied climatology, Vol. 58, Pp. 79-86, 1997.

[6] A. Donohoe, E. Dawson, L. McMurdie, D. S. Battisti, and A. Rhines, "Seasonal Asymmetries in the Lag between Insolation and Surface Temperature," Journal of Climate, Vol. 33, Pp. 3921-3945, 2020.

[7] D.K. Kpeglo, "The relationship between incoming solar radiation and daily air temperature," University of Ghana, 2013.

[8] S. Bezari, A. Belaid, and L. Kadir, "Effet de la variation de l'énergie solaire sur la température dans le sol."

[9] H. Lettau, "Theory of surface-temperature and heat-transfer oscillations near a level ground surface," Eos, Transactions American Geophysical Union, Vol. 32, Pp. 189-200, 1951.

[10] O. Lönnqvist, "Further aspects on the diurnal temperature variation at the surface of the earth," Tellus, vol. 15, Pp. 75-81, 1963.

[11] J. Seco, P. Carlos, and A. Calvo, "The phase lag of temperature behind solar radiation. iRS'84: current problem in atmospheric radiation," Perugia, Italy, Pp. 21-29, 1984.

[12] J. Seco, A. Calvo, M. Egido, and A. Egido, "Solar radiation and air temperature: a study of Santiago de Chile and Salamanca," Atmospheric Environment. Part A. General Topics, Vol. 27, Pp. 457-462, 1993.

[13] D.H. Douglass, E.G. Blackman, and R.S. Knox, "Temperature response of Earth to the annual solar irradiance cycle," Physics Letters A, Vol. 323, Pp. 315-322, 2004.

[14] A.R. Stine and P. Huybers, "Changes in the seasonal cycle of temperature and atmospheric circulation," Journal of Climate, Vol. 25, Pp. 7362-7380, 2012.

[15] J.G. Dwyer, M. Biasutti, and A.H. Sobel, "Projected changes in the seasonal cycle of surface temperature," Journal of Climate, Vol. 25, Pp. 6359-6374, 2012.

[16] A. Donohoe and D.S. Battisti, "The seasonal cycle of atmospheric heating and temperature," Journal of Climate, Vol. 26, Pp. 4962-4980, 2013.

[17] B.D. Santer, S. Po-Chedley, M.D. Zelinka, I. Cvijanovic, C. Bonfils, P.J. Durack, "Human influence on the seasonal cycle of tropospheric temperature," Science, Vol. 361, 2018.

[18] N. Al-Ansari and S. Knutsson, "Toward prudent management of water resources in Iraq," Journal of Advanced Science and Engineering Research, Vol. 2011, Pp. 53-67, 2011.

[19] N. Al-Ansari, "Topography and climate of Iraq," Journal of Earth Sciences and Geotechnical Engineering, Vol. 11, Pp. 1-13, 2021.

[20] A.H. Sparks, "nasapower: a NASA POWER global meteorology, surface solar energy and climatology data client for R," 2018.