

Spatial and Temporal Distributions of Outgoing Longwave Radiation over Iraq: 2007 – 2016

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Abstract. The Outgoing Longwave Radiation (OLR), represents the total radiation emitted to the space by earth atmosphere system, is a critical component of the Earth's radiation budget. Observations of OLR retrieved from Atmospheric Infrared Sounder (AIRS) on the EOS/Aqua platform during 2007-2016 show a strong, plume-like enhancement of OLR over central and southern-west parts of Iraq during June - September. Maximum values occurred in the southern region (365.27 watt/m²), were attributed to the hot, geographic nature and long sunny days. A greater draws down of the OLR occurred over pristine mountains environment at northern region in February (220.37 watt/m²). The monthly analysis shows the seasonal variations in the OLR values fluctuated between wet and dry seasons. The OLR value in dry season was higher than its values in wet season, and the mean standard deviation was (294.5 + 78.5 Watt/m²) over considered stations; Baghdad, Mosul, Rutba, Nasiriya and Basra for study period. The reductions of OLR values at northern area above latitude 34°, especially at mountains, through the study period due low emissivity and moist ground (low temperatures), and more cloudy sky days. Seasonal of OLR distributions shows variations in its values with high in summer, low in winter, and moderate in spring and autumn. The industrial and residential areas showed high OLR value, and low at rural and vegetated areas. The AIRS observation efficiently shows the spatial and temporal variations of OLR for the considered study area. This study sheds new light on the processes and analysis of the OLR emission over Iraq.

1. Introduction

The global energy balance and the Earth Radiation Budget (ERB) are the most fundamentals topics climatology, since any short term imbalance of the fluxes signifies a warmer/cooler overall climate. The Visible sunlight radiations reaches the Earth at clear sky, some are scattered or reflected directly back to space as shortwave radiation (albedo). The remainder is absorbed by the surface and atmosphere, acting to continuously heat the Earth [1]. The reflected solar radiation with wavelengths shorter than 4 microns called ShortWave (SW) radiation, and emitted thermal radiation with longer than 4 microns is called LongWave (LW) radiation. These fluxes generally can be divided into Incoming Shortwave Radiation (ISR); is defined as the solar SW radiation entering the Earth, and Outgoing Longwave Radiation (OLR) radiation; represents the LW radiation emitted by the climate system into space [2, 3 and 4].

The OLR is a fundamental and crucial parameter of the Earth's energy balance for studying many areas in the atmospheric science, and has continued being estimated or observed from many satellite instruments and algorithms since early era of meteorological satellites [5]. Besides the broadband instruments for observing the OLR, e.g., Scanner Radiometer for Radiation Budget



(ScaRab), Cloud and Earth's Radiant Energy System (CERES), and Earth Radiation Budget Experiment (ERBE), there are many algorithms estimate OLR by converting the observations of narrow-band radiance into broadband flux quantities [6]. The OLR datasets are used to test climate modeling [7], in climatology [8 and 9], natural (clouds, water vapor) and anthropogenic greenhouse gases (GHG) absorb longwave radiation reflected from the surface and re-radiate a proportion back to space as OLR, and in an updated energy budget [3].

The theory of Anthropogenic Global Warming (AGW) postulates that GHG emissions would cause a decrease of OLR at top of the atmosphere for a given global average surface temperature. This OLR reduction would cause an energy imbalance with the incoming solar radiation resulting in a “forcing”. Hence, the more incoming energy than out-going energy is leading an increase in global temperatures. This elevation in temperatures cause an increase the OLR values until the radiation balance is restored. The earth radiation balance has been of concern to atmospheric scientists and observed by earth-orbiting satellites since the mid-1960s [10]. The diurnal variation of the OLR is modulated by the response of the climate system to the variation of ISR on diurnal time scale and is affected by a combination of factors: surface temperature, amount of cloud and humidity of different heights in the atmosphere, etc. [11 and 12].

At last few decades, the abundances of the atmosphere parameters measured by different sources from sparsely distributed stations, airplanes, and Balloons. These ground-based observations are more sensitive to sinks and sources with best accuracy. In addition, required permanent automatic monitoring stations or expensive software, and not able to make continuous daily global variations evaluation [13]. The observations from the space by satellite remote sensing only allow for such measurements, and increase our ability to analysis the abundances of atmosphere parameters and gases [14 and 15]. The satellites ERB data improved our understanding of the global climate system [16], and recently added more information for global, regional and local heat budgets [17].

The OLR spatiotemporal variations and distributions from satellite data used in several studies for different regions, which provide information and evidence for its traces and sources in the atmosphere [1, 2, 3, 4 and 6]. The aim of this research to analyse the regional, seasonal and annual hotspots emissions, and monthly distribution of OLR, and evaluate its long term-trends over Iraq using AIRS data [AIRX3STM version 6] for the period 2007-2016. The results help in identify and analysis the hotspots for regional OLR emissions over study area. The OLR satellite data were analysed over five stations; Mosul, Baghdad Rutba, Nasiriyah and Basrah respectively, the monthly mean OLR were generated using kriging interpolation technique to analyse its distribution for the study area.

2. Materials and methods

2.1 Study Area and Meteorological characteristics

As one of the southern west Asia countries, Iraq extends between (29° 05' N and 37° 22' N) latitude and between (38° 45' E and 48° 45' E) longitude with total area is (438320) Km². It bordered by Iran to the east, Saudi Arabia, Jordan and Syria to the west, Kuwait and Arab gulf to the south, and turkey to the north 'figure 1'. Iraq has a wide variety of natural resources: alluvial plain in central and southeast sections; high mountains in the north and northeast are home of forests, which is considered the most favorable for rainfall, and is used for agriculture; rolling upland between upper Tigris and Euphrates rivers; and desert in west and southwest. In the north Mosul is a commercial and agricultural city, in the extreme south of the country, Basrah is a harbour city, and Baghdad the business and industrial capital of Iraq [18 and 19].

The climate of Middle East is mainly affected by four systems: (a) The Siberian anticyclone over central Asia in winter; (b) The Polar anticyclone over east of Europe and Mediterranean Sea in summer; (c) The monsoon cyclones over the south and southeast of Iran, southeast of Arabian peninsula, and India Subcontinent in summer; (d) The depressions travelling from north of Africa and east of Mediterranean sea and south across the Middle East and southwest of Asia in the nonsummer seasons [20]. The Iraqi climate is continental, subtropical, and semi-arid; mostly have a hot arid climate with subtropical influence. The cool season is the winter and its temperatures 2°C night-time and infrequently exceed 21°C. The rainfall happen during winter and it's extremely rare during the

summer. The Mountain regions are having a Mediterranean climate and colder with heavy snows, sometimes causing extensive flooding. The dry and hot season is summer, the temperature average above 40°C daytimes at most parts and drops to 26°C at nights, frequently exceed 48°C. During summer months the Shamal winds prevailing; it is steady wind and blows from north and northeast [21].

Data for five selected distinct cities in Iraq 'figure 1' have been investigated and the variations in OLR concentrations analyzed. The Baghdad, Nasiriyah, Basrah and Mosul cities comprise major urban centers of Iraq, with generally dense populations and varied distribution patterns for commercial, industrial, and residential land use areas.

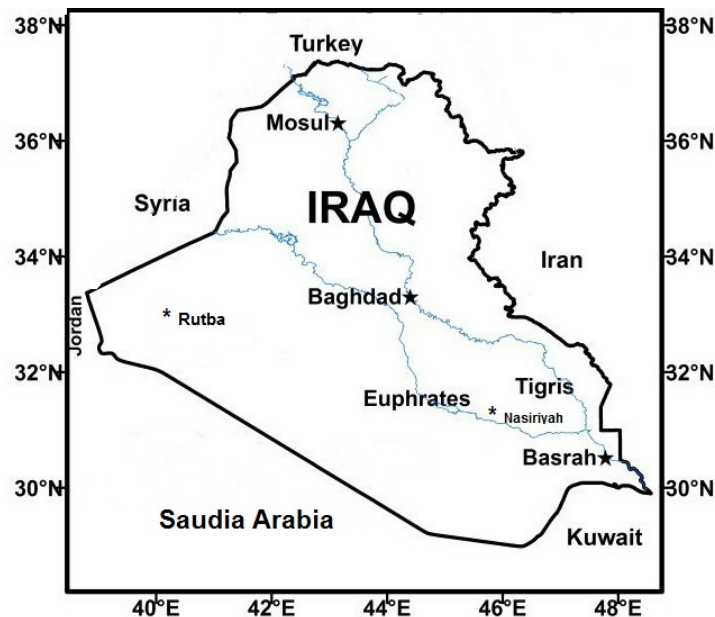


Figure 1. Map of study area

2.2 Data Acquisition and Methodology

This research has been carried out for 120 months data from January 2007 to December 2016. The AIRS datasets have been used for this research. In order to analysis and evaluate the variation and distribution of OLR over the study area, we selected five stations dispersed across Iraq; Baghdad, Mosul, Basra, Rutba, and Nasiriyah, as shown in Table 1 and Figure 1. The retrieved OLR level 3 (L3) monthly products (AIRX3STM) version 6 (V6) data from the AIRS sensors onboard Aqua Satellite were used to analyse and understand the variability of OLR over different parts of Iraq. Recently, the satellite remote sensing has utilized to measure OLR with the large spatial and temporal coverage, which can effectively compensate the lack of surface observations measurements. The AIRS is one of several instruments aboard NASA's EOS Aqua platform at a 705 Km -altitude, polar orbit, was launched on 4 May 2002. Its global coverage due to a 1650 km cross track scanning swath, and spatial resolution field-of-view (FOV) is 13.5 km at nadir [22 and 23].

AIRS V6- L3 is providing three products: daily, 8-day and monthly [24 Standard Pressure Levels for volume mixing ratio (VMR)] besides total column, each product provides separate ascending (daytime) and descending. The AIRS products OLR are now reported in 16 spectral bands in the L2 Support Product (OLRBand), averaged to the AMSU resolution. The bands are from 10 Cm^{-1} to 3250 Cm^{-1} [24].

Generally, 120 monthly L3 ascending granules were downloaded to obtain the desired output. From AIRS website, the AIRX3STM V6 product's files are extracted and saves in HDF-EOS4 files, which is a convenient file extension can take out data from it easily and arrange in table using MS Excel. The monthly data basis is in a Hierarchical Data Format (HDF) format including the corresponding time and location along the satellite track. Map of the study area was conducted by using Kriging

Interpolation technique to analyze the OLR data distribution along the study period. The OLR data were obtained from $1^\circ \times 1^\circ$ (latitude \times longitude) spatial resolution ascending orbits.

Table 1. Stations GMD.

Name	Longitude	Latitude	Country
Baghdad	44.36	33.31	Iraq
Mosul	43.16	36.35	Iraq
Basra	47.78	30.50	Iraq
Rutba	40.25	33.03	Iraq
Nasiriyah	46.26	31.04	Iraq

3. Results and Discussion

Figure 2 illustrated the average monthly OLR from 2007-2016 for all considered stations; Baghdad, Mosul, Rutba, Nasiriya and Basra. The mean monthly and standard deviation was $(294.5 + 78.5 \text{ Watt/m}^2)$ for the study period. The OLR values experience various seasonal fluctuations that depend strongly on weather conditions and topography. The seasonal variation in the OLR fluctuated considerably observed between Wet (November - April) and dry (May - October) seasons. A more particular examination shows subtle variations in the OLR spatial patterns for each season, with higher values for OLR in the dry season than in the wet season. In addition, elevation in OLR values can be observed throughout the year over the southwest regions and the highest values in July. A lower value of the OLR occurs at the pristine mountain environment in the northern regions and the lowest value in December.

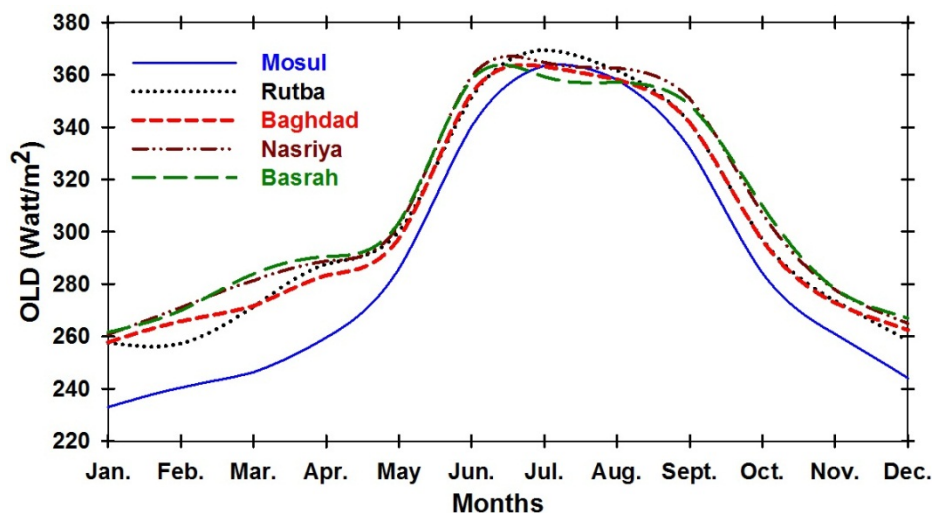


Figure 2. The average monthly OLR between January and December 2007 - 2016 for the stations; Baghdad, Mosul, Rutba, Nasiriya and Basra.

Seasonal variations are visible, but none are as pronounced or regular during the study period. The reductions of OLR values at northern regions above latitude 34° for the months of the year over all stations due to more cloudy sky days and temperatures are lower in the northern region than in the rest of Iraq. The average monthly coverage retrieved OLR for the wet seasons [December–May] 2007-2016 showed in Figure 3(a). The gradual decline of OLR values at the onset of wet season was observed, especially at the northern region (mountains), as a result of reduction in the number of sunny days and greater cloud cover which were influenced by the effects of topography. With increasing temperatures and sunny days, the increase of OLR values in March to reach the highest value in May (304.2 watt/m^2 , green pixels) above Basrah was observed. Plainly evident was the increase in OLR

values during March–May, due to the slight elevation in temperature compared to the previous months, with the declining influence of the cloud and decrease in the number of rain days. In May OLR increased to its highest value during wet seasons, and the lowest value was at the pristine coastal environment in the mountains regions at Dohuk in February (220.37 watt/m^2 , blue pixels). This fluctuation in the OLR values during wet season was caused by the climatic variations and geographic nature of the areas.

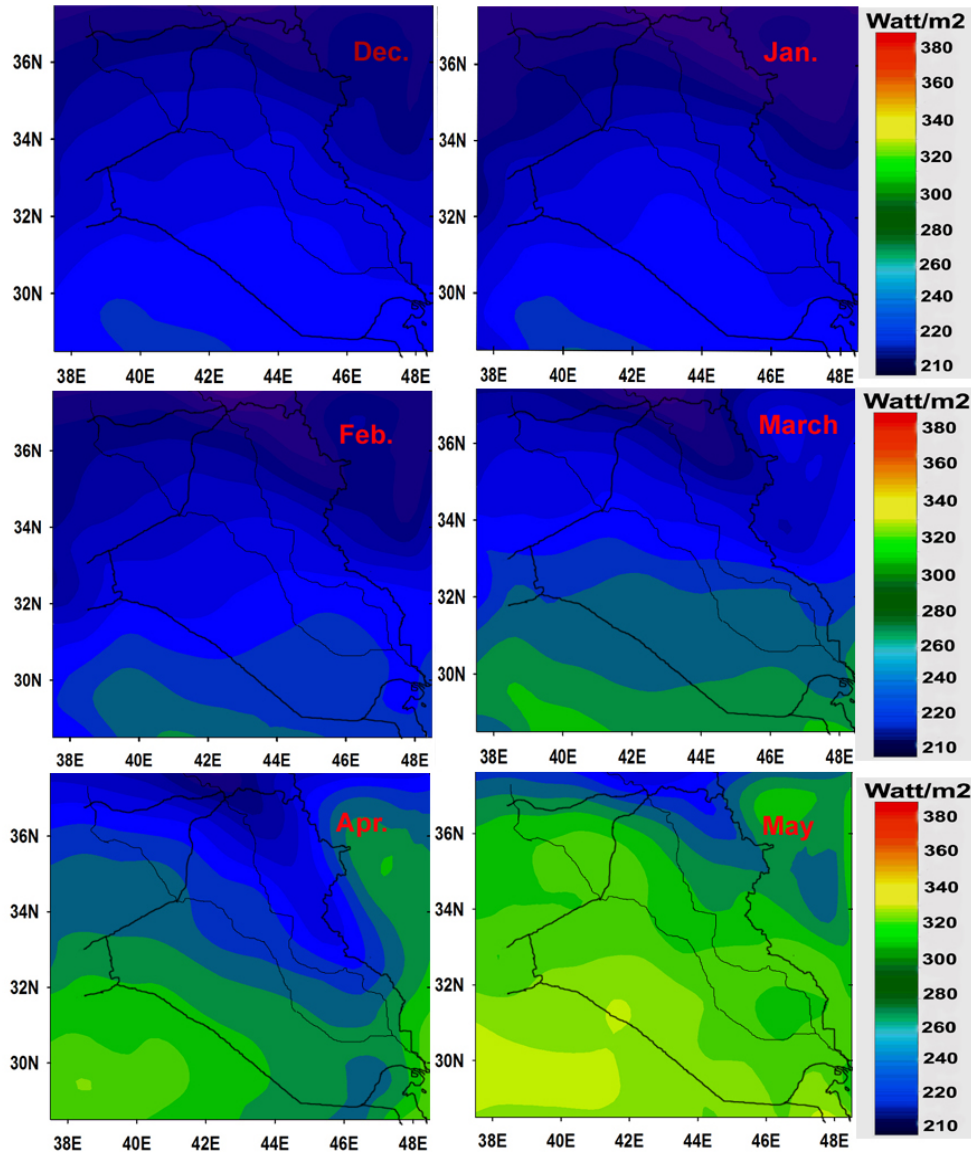


Figure 3(a). The AIRS monthly coverage from the retrieved OLR for wet season [December–May] 2007–2016 over Iraq.

As illustrated in Figure 3(b), at the early dry season (June–August) the OLR values increase when the temperature and sunshine days increase, also absence of cloudy days. It was more evident in the central southern areas, which experience high temperatures during this period. During the late dry season (September–November), the OLR value decreases to be slightly high in September, moderate in October and low in November. Slightly high values of OLR are still dominated the southern region due to the clear sky coincided with the dry summer subtropical climate. The highest value that occurred in this period was in July over Basrah (365.27 watt/m^2 ; Orange pixels), and the lowest value was in November over Dohuk (240.64 watt/m^2 ; Purple pixels).

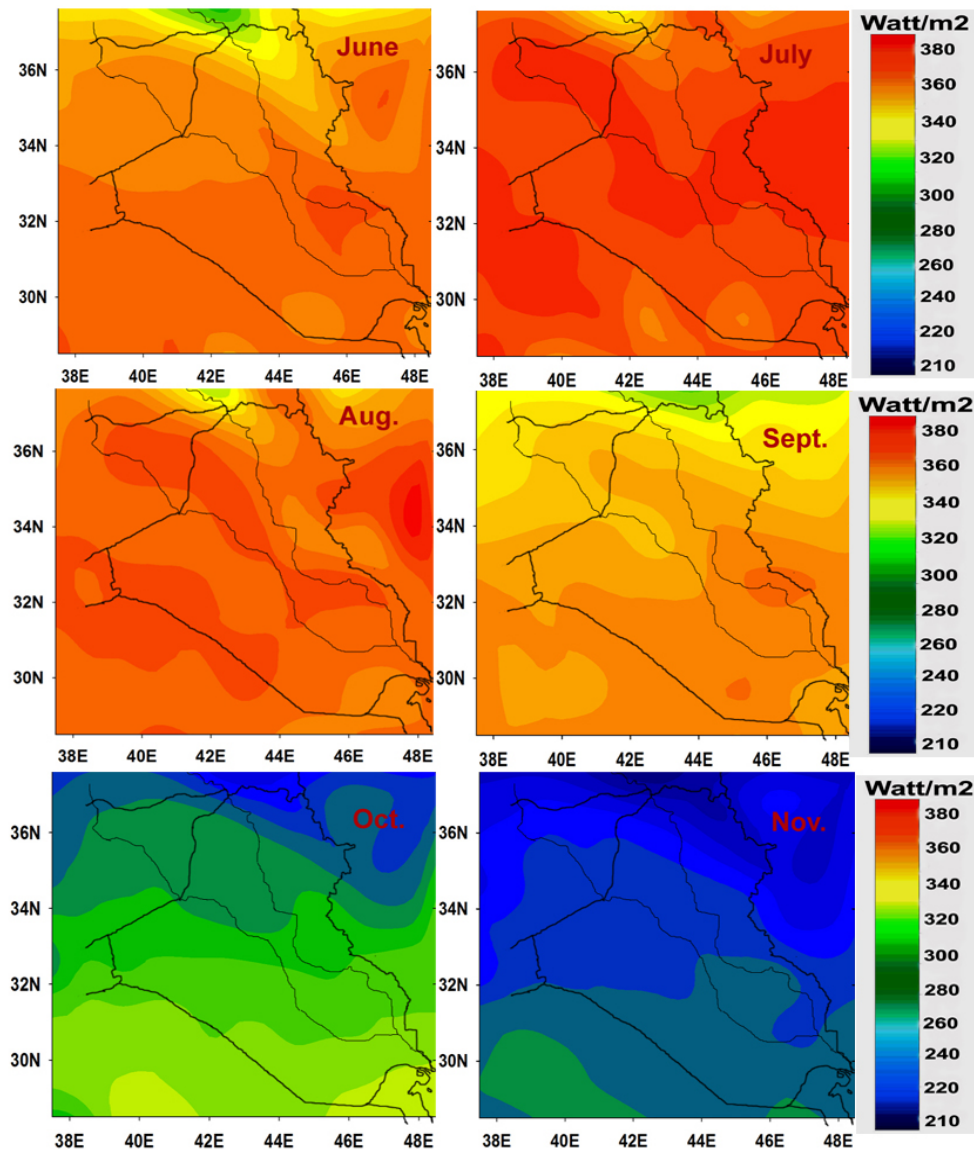


Figure 3(b). The AIRS monthly coverage from the retrieved OLR for dry season [June–November] 2007–2016 over Iraq.

The AIRS average seasonally coverage of OLR (four seasons), the nominal peak of AIRS sensitivity and the magnitude of the seasonal variations in OLR illustrated in Figure 4. Note the difference between the seasons with high values in the summer, low in winter and slightly high in spring and autumn. The OLR in winter shows lower value due to either overcast or cloudy sky for most times, cold weather moist ground (low temperature), low emissivity, and the creation of warm pockets (higher air temperature/radiation) reduce energy demands for heating. Spring and autumn showed moderate to slightly high OLR due to elevation in temperature and high emissivity. The high OLR values in summer due to the clear sky associated with excessive temperatures exceeding 50 on some dry summer days. However, the all radiation balance components magnitudes were less during wet seasons (winter and spring) compared to dry seasons (summer and autumn) as result of less intense solar radiation associated with foggy/cloudy weather conditions.

Figure 5 illustrates the annual average distribution of OLR during 2007 - 2016. The local OLR maximum over southern area occurs precisely at Basrah (314.10 watt/m^2 ; 30.5N , 47.5E), that experienced extensive hot weather. In contrast, minimum OLR occurs at the pristine mountain in the northern region at Dohuk (280.62 watt/m^2 ; 37.5N , 43.5E). In addition, from figures 4 & 5, the values

of OLR were higher in the southern and central regions than in the other regions above latitude 34° throughout the year because there were different on weather conditions and topography.

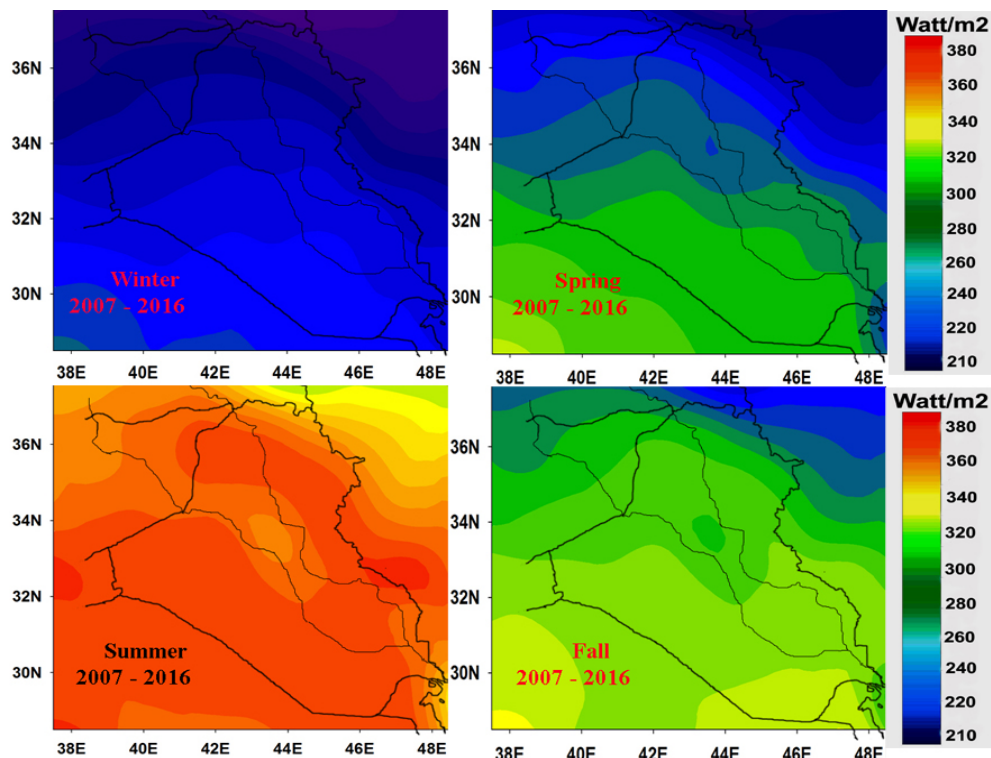


Figure 4. The AIRS Seasonal coverage from the retrieved OLR for all seasons [winter, spring, summer, and autumn] 2007-2016 over Iraq.

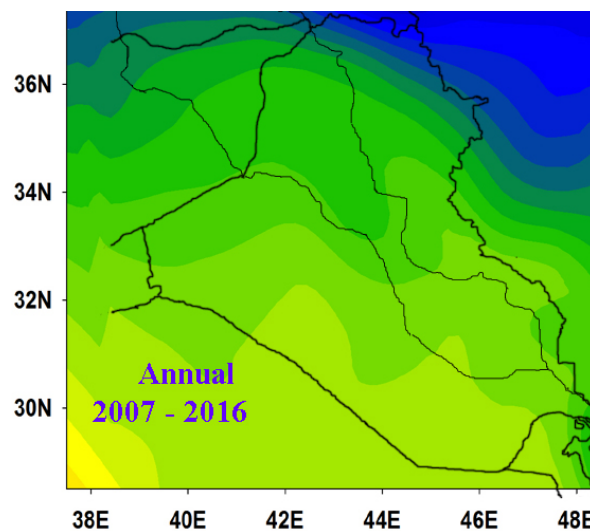


Figure 5. The AIRS Annual coverage from the retrieved OLR during 2007-2016 over Iraq.

Overall, the figures 2, 3, 4 and 5 shows the OLR values in the southern and central are higher than in the rest of areas, and elevation in OLR values can be observed over the Industrial area and congested urban cities throughout the year. Industrial areas and residential sites showed higher OLR due to anthropogenic activities; these add up to OLR, in spite of their low emissivity (due to concrete surfaces). However, moderate to high OLR values were observed in the urban parks and vegetated areas. In contrast, lower values of OLR observed at rural areas due to low emissivity and moist ground

(low surface temperature). Rural and vegetated areas are unable to show high OLR due to wetness of the emitting surfaces.

4. Conclusion

The 10 years (2007-2016) AIRS data investigated reveal that topography and weather conditions highly correlated and influenced with OLR values. The monthly distribution shows significant spatiotemporal variations of OLR over study area and seasonal variations fluctuated considerably observed between wet and dry season. The mean and standard deviation was $(294.5 + 78.5 \text{ Watt/m}^2)$ over considered stations; Baghdad, Mosul, Rutba, Nasiriya and Basra for the entire period. The highest value of OLR occurred in July (dry season) over Basrah (365.27 watt/m^2), and the lowest value in February (wet season) over Dohuk (220.37 watt/m^2). The reductions of OLR values at northern area above latitude 34° , especially at mountains, due to low emissivity and moist ground (low temperatures), and more cloudy sky days. And high OLR values dominated the southern region due to increases of temperatures and sunny days, and absence of cloudy days.

Seasonal spatiotemporal of OLR distributions shows variations in values with high in summer, low in winter, and moderate in spring and autumn. In addition, the annual OLR distribution showed the maximum values at southern area and minimum at northern area. The industrial and residential areas have high OLR value due to anthropogenic activities, moderate to high at urban parks and vegetated areas, and low at rural areas. Rural and vegetated areas are unable to have high OLR due to wetness of the emitting surfaces. This study shows that the AIRS-Aqua measurements shed new light on the processes responsible for OLR emission over Iraq. The Satellite retrieved observations have a good consistency for the contrasted monthly, seasonal and annual analysis results, and can be used to observe the variations of the atmosphere parameters values over different areas.

5. Acknowledgment

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