Satellite monitoring for Outgoing Longwave Radiation and Water Vapor during 2003 - 2016 in Iraq

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Abstract. This study explored the use of satellite data to monitor Outgoing Longwave Radiation (OLR) and Water Vapor (H2O vapor) in Iraq. The retrieved monthly data obtained from Atmospheric Infrared Sounder (AIRS), included on the EOS Aqua satellite, from January 2003 to December 2016 are employed. In order to better assess these two parameters distribution, the spatiotemporal and long term trends analysis are provided for five stations dispersed across Iraq; Mosul, Sulaimaniyah, Rutba, Baghdad and Basra. The OLR and H2O vapor monthly distribution shows important spatiotemporal variations values over study area, with a maximum in summer and minimum in winter. The higher OLR values of monthly average for study period occurred (370, 364) w/m² in July and August at Rutba, and the lowest values of monthly average occurred were (232 w/m²) in January over Mosul and Sulaimaniyah. The higher H2O vapor values (6.34 g/kg) observed in July and August over Baghdad and the lowest values of monthly average was (3.30 g/kg) in January and December over Mosul and Rutba. The satellite observation efficiently shows the spatial and temporal variations of OLR and H2O vapor. This study sheds new light on the processes and analysis of both parameters emission over Iraq.

Key words: OLR, H2O vapor, Remote sensing, Satellite, AIRS.

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1. Introduction

The anthropogenic emission of greenhouse gases (GHG’s) is major source affecting the earth’s energy balance and climate changes [1]. The Earth Radiation Budget (ERB) and global energy balance are the important topics in climatology. At the clear sky visible sunlight radiations reaches the Earth, some are reflected and scattered to space remainder is absorbed by the atmosphere and surface resulting to continuously warm the Earth [2]. The OLR has a fundamental importance for quantitatively understanding climate in terms of Earth’s radiative energy budget at the top of
atmosphere (TOA). Any variation in this essential component would cause a long-term imbalance net flux, which eventually modifies the climate as it adjusts to restore the balance. The clear-sky OLR is results from both surface emission and specific atmospheric layers contributions. Thus is a function of many important variables such as Earth surface temperature, atmospheric temperatures and absorption gases [3, 4].

The OLR is a primary and crucial parameter of Earth's energy balance. The heat of the atmosphere rises due to the contribution of OLR, which in turn causes more emission of radiation from the corresponding absorbing layers. Some of this radiation is downward and returned towards Earth increasing the Earth's surface average temperature, and plays a critical part of the global warming. Understanding the spatial and temporal variations of OLR is an important issue for managing and planning water resources by expanding the knowledge of water balance dynamics on various scales [5]. Typically, the highest OLR values correlated with the warmest regions of Earth’s atmosphere due to the significances amounts of the thermal radiation. The high convective clouds are bright and reflect solar radiation, and hence reduce OLR [6]. The OLR highly depends on temperatures but is modulated by atmospheric GHG's, clouds, and aerosols [7].

Water vapor (H\textsubscript{2}O vapor) is most Earth’s GHG's abundant provides a strong feedback mechanism that aggrandize climate change [8, 9]. It has a significant role in many atmospheric and geophysical phenomena including radiation budget, formation of clouds, exchange of energy, and weather systems. The H\textsubscript{2}O vapor atmospheric concentration ranges from less than 1% per volume over desert and Polar Regions to 4% in the Tropics. These changes due to climate warming indeed a direct result of industrialization [10]. The condenses H\textsubscript{2}O vapor form clouds which cause the rainfall, reflecting solar radiation and reducing the infrared radiation emitted by Earth [11]. The spatial and temporal distributions of tropospheric H\textsubscript{2}O vapor are determined by local hydrological processes such as evaporation, condensation and precipitation, and also by large-scale transport processes. The H\textsubscript{2}O vapor plays a major role in many of the atmospheric and geophysical phenomena that include exchange of energy, radiation budget, formation of clouds, and weather systems [12]. Iraq one of the southern west Asia countries with total area (438320) Km\textsuperscript{2} extends between (38\textdegree E and 48\textdegree E) longitude and between (29\textdegree N and 37\textdegree N) latitude. Its climate is subtropical, continental, and semi-arid; mostly have a hot arid climate with subtropical influence. The summer is hot and dry season with temperature average above 40\textdegree C daytimes, and winter is cool season temperatures 2\textdegree C night-time and infrequently exceed 21\textdegree C [13]. The variations in temperature and daylight hours during the four seasons in Iraq have made a difference in OLR and H\textsubscript{2}O vapor values. During past four decades, the abundances of the atmosphere parameters observed by sparsely distributed measurement sites, airplane and balloons. These measurements have best accuracy and more sensitive to sinks and sources. In addition to costing a lot of money and strenuous efforta, still not able to provide continuous daily global variations evaluation [14, 15]. The Remote sensing observations by satellite from space only allow such measurements, and increase the ability of scientists to analysis the abundances of atmosphere parameters. The spatiotemporal distribution patterns map of tropospheric OLR and H\textsubscript{2}O vapor for 14 years from the period 2003-2016 over Iraq using the retrieved AIRS version 6 (level 3) monthly products (AIRX3STM) data. The results used in analysis and identify the hotspots for regional H\textsubscript{2}O vapor and OLR emissions over study area. The H\textsubscript{2}O vapor and OLR satellite data were evaluated over considered stations; Mosul, Sulaimaniyah, Rutba, Baghdad, and Basra. The monthly spatiotemporal maps for mean OLR and H\textsubscript{2}O vapor were generated using kriging interpolation technique to analyse their distribution for the study area.

2. Data and Methodology

The OLR and H\textsubscript{2}O vapor data is obtained from AIRS NASA website data system for the study area of Iraq. Both monthly gridded data is obtained on spatial resolution of 1\textdegree x 1\textdegree. Using AIRS datasets of
168 months from January 2003 to December 2016 this research has been carried out. To evaluate and analysis the distribution and variation of H$_2$O vapor and OLR over the study area, five stations was selected across Iraq; Mosul, Sulaimaniyah, Rutba, Baghdad and Basra as shown in Table 1. The retrieved H$_2$O vapor and OLR level 3 (L3) monthly products (AIRX3STM) version 6 (V6) data from the AIRS sensors onboard Aqua Satellite were utilized. The AIRS, launched on 4 May 2002, is one of several instruments aboard NASA's EOS Aqua platform at a 705 Km -altitude, polar orbit. Its large global coverage,1650 km cross track scanning swath, and spatial resolution field-of-view (FOV) is 13.5 km at nadir [16, 17].

The AIRS products OLR are now reported in 16 spectral bands in the L2 Support Product (OLR Band), averaged to the AMSU resolution. The bands are from 10 Cm$^{-1}$ to 3250 Cm$^{-1}$ [18]. The AIRS retrieval algorithm utilizes a large number of channels throughout its operating range to first retrieve surface temperature (25 channels), temperature profiles (103 channels), and water vapor profiles (41 channels) [19]. In general, from the AIRS website 168 monthly L3 ascending granules downloaded to get the desired output. The AIRX3STM V6 product's was in HDF-EOS4 files and arrange in table using MS Excel. The Spatiotemporal Map of the data over study area was conducted by using golden surfer 13 Software to analyze the H$_2$O vapor and OLR data distribution along the study period.9

### 3. Results and Discussion

#### 3.1 Seasonal variation

Time-averaged maps and time series plots are analyzed to observe the spatiotemporal changes in H$_2$O vapor and OLR measurements. Figure 1 illustrated the mean average monthly OLR and H$_2$O vapor for 14 years from 2003-2016 for all considered stations; Mosul, Sulaimaniyah, Rutba, Baghdad, and Basra. The mean and standard deviation of the monthly OLR was $(296.54 \pm 45.215)$ W/m$^2$ and H$_2$O vapor $(4.82 \pm 0.88)$ g/kg for an entire period. Annual means of tropospheric OLR and H$_2$O vapor for the study period are given in Table 1.

| Stations  | Latitude (N°) | Longitude (E°) | Altitude (m) | OLR (w/m$^2$) | H$_2$O vapor (g/kg) |
|-----------|---------------|----------------|--------------|---------------|-------------------|
| Mosul     | 36.21         | 43.06          | 223          | Mean 287      | 4.933             |
|           |               |                |              | SD 49         | 1.01              |
| Sulaimaniyah | 35.33       | 45.26          | 843          | Mean 285      | 4.865             |
|           |               |                |              | SD 49         | 0.82              |
| Rutba     | 33.26         | 40.17          | 630          | Mean 300      | 4.654             |
|           |               |                |              | SD 41         | 1.01              |
| Baghdad   | 33.20         | 44.20          | 32           | Mean 302      | 4.979             |
|           |               |                |              | SD 44         | 0.98              |
| Basra     | 30.30         | 47.78          | 2            | Mean 306      | 4.683             |
|           |               |                |              | SD 39         | 0.58              |

The OLR values are different with a maximum in summer and minimum in winter over all considered stations. The OLR values keep increasing start from January and the highest values occurs on July and August then begins to decline till December. This behaviour in the OLR curve is consistent with the five cities and can be well explained because of the cyclic variation of meteorological condition particularly the associated with the verities in the surface temperature and cloud cover. The higher values of OLR that occurred was $(370, 364$ w/m$^2$) in July and August at Rutba which is a desert area with sparsely cloud cover and higher temperature during summer season. While the lowest value $(232$ w/m$^2$) in January over Mosul and Sulaimaniyah due to the considerable domination of cloud cover. Also, there are slightly reduced in OLR values over Basra stations during Summer season (June, July,
August) represented through the remains at a relatively constant value (358, 359, 357) W/m$^2$ respectively and lowest than other four stations. At Basra, the low summer OLR are related to the impacts of dust and sand storms which play a significant role in reducing incoming sunlight by reflecting it and the OLR values would reduce as a result.

H$_2$O vapor also varied over seasonal scales, with the highest values observed during the summer season (July–August) and the lowest values in winter season from December–February at all stations. The higher value (6.34 g/kg) was observed in July and August over Baghdad, and the lowest value (3.30 g/kg) was in January and December over Mosul and Rutba. On the other hand, the minima H$_2$O vapor observed in Basra between May and October, while the lowest decrease in winter and spring in desert station Rutba compared to other cities. One of the reasons for such a low value attributed to the effect of shammal wind (that is likely to be dry and have the potential to create dust and sand storms) which is strongly affected the southern and western area weather, than other areas over Iraq. In addition, fluctuations in H$_2$O vapor are induced at mid latitude sites from synoptic weather changes that are associated with the passage of high and low pressure systems and fronts.

![Figure 1: Tropospheric (a) OLR and (b) H$_2$O vapor at selected Iraq stations.](image-url)
3.2 Spatiotemporal Maps

3.2.1 Outgoing long wave radiations (OLR)

Figures 2 and 3 show the extent of the monthly coverage OLR for winter (December-February) and spring (March-May) seasons. Winter season have the minimum values of OLR through the years over the whole study area and the surrounding regions. It is still about $(250\pm12.8)$ W/m$^2$, with relatively high OLR values reach to $(295$ W/m$^2$) during February in the southern region near the Kuwait-Saudi borders. The decrease in the value of OLR also enhanced spatially in the northern parts of Iraq due to the mountainous areas, and the clouds cover existence as monsoon air mass prevails. The enhancement of OLR levels becomes increasingly intense during spring season, as shown in Figure 2. Where the highest OLR value $(306$ W/m$^2$) appeared in the southern part of Iraq. The significant increase of OLR in spring mainly was at May, and reached up to $(310$ W/m$^2$) in the south and southwest region. The highest OLR mean values observed in Summer season as shown in Figure 3 these values reach to $(370$ W/m$^2$) in July and August over almost Iraq regions because of a strong positive correlation with surface temperature. The OLR mean values start to decrease during fall season, the minimum mean values reached to $(255$ W/m$^2$) in November in the north regions and about $(270$ W/m$^2$) in the other Iraqi regions.

3.2.2 Water vapor ($H_2O$ vapor)

Figure 4 show that the winter season have the minimum values of $H_2O$ vapor through the year over the whole study area and the surrounding regions. It is still about $(3.70\pm0.16)$ g/kg, due to low winter temperature, the most $H_2O$ vapor undergoes condensation, and as such it depleted to lowest value. Also minimum values observed in spring season over western and southern regions, as a result of weather conditions which decreased $H_2O$ vapor formation, though it slightly increased over north and north east regions in April and in May over northern and central part of Iraq. The highest $H_2O$ vapor mean values $(5.58$ g/kg) observed in summer seasons (Jun - August) as shown in Figure 5, higher value observed over all Iraq regions except in the south and southwest regions, especially in August with value ranged between $(5.52$ to $6.62)$ g/kg, and the lower value $(4.45$ g/kg) observed in Jun over south, southwest and southeast regions.

The enhancement in $H_2O$ vapor also observed in fall season, and reached to $(6.33$ g/kg) in September and $(5.5$ g/kg) in October over same area while tend to decreased in November to minimum value at about $(4.5$ g/kg) over all Iraq area except the southern regions with Kuwait border as seen in Figure 5. One of reasons for the higher $H_2O$ vapor can be attributed to the strong evapotranspiration source at the surface that coincided with an increase in the temperature during this period.
Figure 2: AIRS average monthly coverage from the retrieved OLR, over Iraq for winter (December-February) and spring (March-May) seasons during 2003-2016.
Figure 3: AIRS average monthly coverage from the retrieved OLR, over Iraq for summer (Jun- August) and fall (September -November) seasons during 2003-2016.
Figure 4: AIRS average monthly coverage from the retrieved H$_2$O vapor, over Iraq for winter (December-February) and spring (March-May) seasons during 2003-2016
Figure 5: AIRS average monthly coverage from the retrieved H₂O vapor, over Iraq for summer (Jun- August) and fall (September -November) seasons during 2003-2016.
4. Conclusions

The main concluding remarks obtained from this study are summarized as follows:

1) The mean and standard deviation of the monthly OLR (296.54 ± 45.215) W/m², H₂O vapor (4.82 ± 0.88) g/kg for an entire period.

2) The OLR and H₂O vapor, monthly distribution shows important spatiotemporal variations of their values over study area. With a maximum in summer and minimum in winter. The higher values of OLR that occurred was (370, 364) W/m² in July and August at Rutba. While the lowest value (232 W/m²) in January over Mosul and Sulaimaniyah. The H₂O vapor higher values (6.34 g/kg) were observed in July and August over Baghdad and the lowest value (3.30 g/kg) was in January and December over Mosul and Rutba.

3) Maps of monthly mean values for all parameters over the study area illustrated; the high OLR values observed over almost regions especially at central and southern part of Iraq, while the low values observed at the northern regions .The H₂O vapor higher value observed over all Iraq regions except in the south and southwest regions.

4) The monthly spatial average values for H₂O vapor in inverse of OLR, showed higher value at northern regions and low values over the southern Iraq regions. The Seasonal spatiotemporal distributions of OLR shows variations values with moderate in spring and fall, high in summer and low in winter.

5) This study reveals that the AIRS-Aqua observations shed new light on the processes responsible for H₂O vapor and OLR emission over Iraq. The Satellite retrieved measurements have a good consistency for the contrasted monthly, seasonal and annual analysis results, and can be utilized to observe the atmosphere parameters variations values over different regions.

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