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The Vertical variations of Atmospheric Methane (CH_4) concentrations over selected cities in Iraq based on AIRS data

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Abstract:

The Atmospheric Infrared Sounder (AIRS) on EOS/Aqua satellite provides diverse measurements of Methane (CH_4) distribution at different pressure levels in the Earth's atmosphere. The focus of this research is to analyze the vertical variations of (CH_4) volume mixing ratio (VMR) time-series data at four Standard pressure levels SPL (925, 850, 600, and 300 hPa) in the troposphere above six cities in Iraq from January 2003 to September 2016. The analysis results of monthly average CH_4VMR time-series data show a significant increase between 2003 and 2016, especially from 2009 to 2016; the minimum values of CH_4 were in 2003 while the maximum values were in 2016. The vertical distribution of CH_4 was relatively high in the cities located in the north of Iraq (Sulaymaniyah and Mosul) more than other cities, especially these in western Iraq (Rutba and Najaf). The highest monthly mean of CH_4VMR and standard deviation (SD) was in Sulaymaniyah (1871.11±21.92) ppbv at 925 hPa, while the lowest was in Rutba (1812.81±37.3) ppbv at 300 hPa. Mosul has the second-highest mean and SD next to Sulaymaniyah, especially at the lower levels SPL (925 and 850 hPa) of troposphere more than the rest of selected cities. The seasonal variation of monthly CH_4VMR, averaged from 2003 to 2016, shows high values between January and August with a peak between August and September and it declines significantly between October and December with a slight increase in November. Long term trend analysis of monthly CH_4VMR at each SPL (925, 850, 600, and 300) hPa above the six cities shows positive values with average growth rates for each SPL equal to (2.9 %, 3.1%, 3.6 %, and 3.9%), respectively. These results indicate that satellite measurements were effective in determining the magnitude of increased CH_4 over Iraq that may contribute to the global increase of CH_4 in the earth's Atmosphere.

Key words: AIRS, Methane volume mixing ratio (CH_4VMR), Time- series, Trend, Iraq.

Introduction:

CH_4 is an important greenhouse gas (GHG's) next to CO_2 and since the pre-industrial times, its atmospheric concentration has increased 150% from 722 ppb to 1803 ppb - mainly driven by anthropogenic activities such as oil and gas industry, coal mining, landfills, livestock, wastewater treatment, biomass burning, and rice cultivation(1, 2). In 2016, global mean of CH_4 mixing ratio was 1953 ppb increased about 9.0 ppb compared to previous years (3). CH_4 volume mixing ratio –VMR; is the ratio of the amount (or mass) of the substance (gas) in a given volume to the total amount (or mass) of all constituents in that volume (4).

CH_4 is the second-largest contributor to global warming among other GHG's in the atmosphere with a share of (0.48 W m^{-2}-watt per square meter) of the total radiative forcing of the Earth's climate system since it traps heat in the atmosphere more effectively compared with CO_2, especially over the short term (5). Globally, the Total CH_4 emissions are currently of the order of 500–600 $Tg.year^{-1}$ (terragram/year), including the anthropogenic sources now estimated to exceed natural sources. The natural sources include wetlands, geological sources, lakes and rivers, termites, wildfires and wild animals. The global wetlands only comprise 60-80% of the CH_4 natural emissions (6, 7). Wetlands dominate the natural emissions with a range between 177 and 284 $Tg.year^{-1}$. However, agriculture and energy are dominating the anthropogenic sources by approximately 130 and 100 $Tg.year^{-1}$, respectively. The waste responsible for a further 70–90 $Tg.year^{-1}$ and biomass burning approximately 35 $Tg.year^{-1}$, Rice agriculture contribute by approximately 36 $Tg.year^{-1}$ (8).

CH_4 can be removed from the atmosphere by hydroxyl radicals (OH). It is the major sink of CH_4 and many other species including CO, NOx. The minor sinks of CH_4 include dry soil oxidation, transport to the stratosphere and reaction with chlorine (Cl) atoms in the marine boundary layer constitutes less 2% of the total sink (9). The total rate of CH_4 sinks is approximately 600 Tg (CH_4) yr^{-1}, 85-90% of the removing mechanism by the reaction with (OH) radicals in troposphere, the rest including the reaction with stratospheric (OH) and the tropospheric chlorine Cl. Soils are also a significant global CH_4 sink, estimated at approximately 30 Tg (CH_4)yr^{-1} (8).

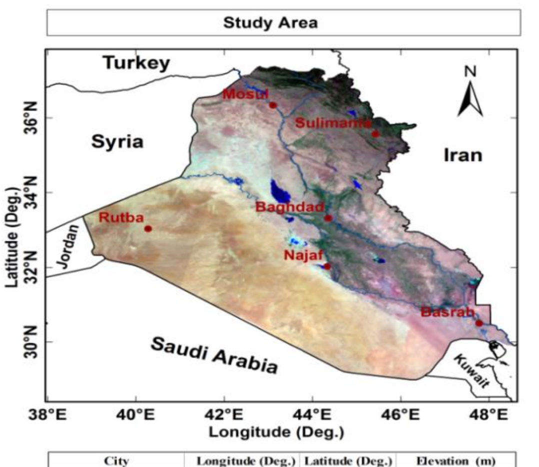
The (OH) radicals are very reactive oxidizing operators responsible of the oxidation of almost gases emitted by natural and anthropogenic activities in the atmosphere (10). 90% of tropospheric CH_4 is removed by reacting with OH radicals. Increasing temperature and humidity will increase the production process of CH_4 from natural sources (9, 11).

Prior studies have focused on studying the increasing levels of CH_4VMR in the Atmosphere using satellite data and in-situ measurements. Many studies employed AIRS measurements, one of these studies concluded that the seasonal variation of ground-level CH_4VMR is increased in an urban center interlaced by wetlands (12). The long term rang transport affects the CH_4 in Atmosphere when observing the upper CH_4VMR and CH_4-total column (13). Space and time variability of CH_4VMR and total column amount have peak sensitivity at 300-600 hPa when comparing between different satellite data (14). The spatiotemporal distributions of CH_4VMR at 925 hPa and CH_4 -TC have been studied, the results showed positive trends for the long term periods (15, 16). The seasonal patterns of the satellite - retrieved CH_4VMR in the column, upper troposphere and near surface were examined and compared with the in situ-measured near surface CH_4VMR and it is largely associated with changing synoptic meteorology (17). Besides, the spatiotemporal variations of CH_4 concentration were analyzed. The results showed significantly increasing trends, the rate of increase ranging from ~0.29 to 0.62 $ppb \cdot month^{-1}$ (18).

This research focuses on studying and analyzing the vertical variations of CH_4VMR long-term series data and its trends as well as studying the seasonal variations of monthly CH_4VMR time series averaged from 2003 to 2016 at four selected standard pressure levels SPL (925, 850, 600 and 300) hPa using AIRS data over six cities (Mosul, Sulaymaniyah, Baghdad, Rutba, Najaf and Basrah) distributed across Iraq and located in different geographic locations and topography.

The Study Area

Iraq is one of the southwest Asia countries, it is located between (38° 45` E - 48° 45` E) longitude and (29° 05` N - 37° 22` N) latitude. It is bordered by Turkey from the north, Iran from east, Kuwait and Saudi Arabia from the south, Jordan and Syria from the west (19). Iraq's topography is divided into four parts: the first part is the mountains located in the north and northeast of Iraq. The alluvial plain is the second part, located between the basin of the Tigris and the Euphrates rivers. It covers a quarter of the total area of Iraq and extended from central to the southeast part of Iraq and encompasses 19425 Km2 of marshland and lakes. The third part is the desert plateau, located to the west and southwest of the alluvial plain, and covers less than half of the total area of Iraq. The fourth part is the undulating region between the Tigris and the Euphrates rivers, a transitional region between the mountains in the north and the alluvial plain in the south (15). Six cities in different geographical locations distributed across Iraq have been selected to study the vertical variations of CH_4 concentration over it -see Fig.1.



City	Longitude (Deg.)	Latitude (Deg.)	Elevation (m)
Mosul	43.11	36.33	264
Sulaymaniyah	45.43	35.56	830
Baghdad	44.36	33.31	41
Rutba	40.28	33.03	618
Najaf	44.34	32.02	19
Basrah	47.78	30.5	3

Figure 1. shows the study area and the geographical locations of the six selected cities with its elevations.

In general, the climate of Iraq is categorized as a continental subtropical and semi-arid, and the

Mediterranean climate controls the north and northeast region of Iraq characterized by dry summers with a reasonable rainfall rate in winters. The summer is hot with low moisture and bright sunshine. In contrast, winter has perceptibly higher humidity and lower temperatures. The spring season is characterized by a significant amount of rainfall as well as mild temperatures (20).

The "Shamal" is the prevailing wind in most parts of Iraq throughout the year; it blows from the north and northwest bringing considerably hot and dry air across Iraq which prevents clouds evolution as well as precipitation. The other type is the "Sharki" is a dusty and dry wind; it blows over Iraq in early summer and early winter from the south and southeast. Summers in Iraq are dry and hot to extremely hot. The shade temperature is exceeding (43° C) during July and August dropping to (26 °C) at night; the winters are cold and the average daily temperature is (16 °C) drops to (2 °C) at night. The rainy season is confined between October and April; the average annual rainfall is 154 mm, ranges from less than 100 mm in most 60% of the country's area in the south to 1,200 mm in the northeast most of that rainfall occurs between December and March (15).

Data Collection, specification, and the methodology

Satellites are the most important remote sensing tools that provide different measurements for many GHG's such as CH_4 with large spatial and temporal coverage and at low cost, and can effectively compensate for the lack in surface data. AIRS, is one of the several instruments launched onboard NASA's – EOS/Aqua platform on May 2002 on polar orbit at 705 km altitude with 2378 channels at high spectral resolution ($\lambda/\Delta\lambda$ =1200) and low noise. It is covering from 649-1136, 1217-1613 and 2169-2674 cm^{-1}, the equator crossing time is 01:30/13:30 with global coverage due to a 1650 km cross-truck scanning swath and spatial resolution of 13.5 km at nadir. In 24 hours period AIRS observes the complete globe twice per day (19, 21).

Three standard products of CH_4 can be obtained from the AIRS Version6-Level3: standard daily product (AIRX3STD), 8-day standard product (AIRX3ST8), and monthly standard product (AIRX3STM), each standard product provides two separate portions of the orbit; ascending product (daytime) and descending product (night time), besides 24 standard pressure level for CH_4VMR products between 1000 and 5 hPa, with a spatial resolution of 1° ×1° grid (22, 23).

AIRS monthly product (AIRX3STM) for CH_4VMR data at 925, 850, 600 and 300 hPa have been used in this research to obtain the desired output. The corresponding heights of these SPL in the atmosphere are 766, 1500, 4200 and 9200 meters, respectively. This data is available on Giovanni NASA open data portal. It is to be pointed out that AIRS peak sensitivity for CH_4 retrieval lies between 600 and 200 hPa over mid-latitudes (24). Additionally to the higher levels (600 and 300 hPa), CH_4 data at 925 and 850 hPa were used to study the variation of CH_4 concentrations near the surface due to the diversity of natural and anthropogenic sources.

The relationship between two variables, the independent variable (time) and the dependent variable (monthly CH_4VMR) over the six cities with its trends were studied in this research. A linear regression analysis was performed using sigmaplot software to study the long term trend. The mean and standard deviation equation 1 and 2 were applied also on monthly CH_4 for the period from 2003 to 2016.

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \quad \text{..........}1$$

$$S=\sqrt{\frac{\sum (X_i-\bar{X})^2}{N-1}} \quad \text{...........}2$$

Where: N =sample size, Xi= sample number, $\bar{X}$=sample mean, S=sample standard deviation (25).

Results and Discussions:

Monthly Long- Term CH_4VMR Analysis

The monthly average CH_4VMR at four SPL over six cities for the period from January 2003 to September 2016 has experienced a considerable seasonal fluctuation among four seasons depending on weather conditions and the topography. See Fig 2 - a, b, c, d, e, and f.

According to the figure, the monthly average measurements of CH_4 were stable between 2003 and 2008 which indicates a balance between CH_4 emissions from the various sources and the sinks in the troposphere (17), after a period of stagnation, and after 2009, CH_4 began to increase significantly due to increasing emissions from the natural sources such as wetlands which are affected by two major climate factors, temperature and precipitation (26, 27). Additionally, to increasing anthropogenic emissions resulting from human activities due to population growth, the number of vehicles doubled, energy demand , add to the oil and gas production activities, all these reasons are accompanied with a decrease in (OH) concentrations is also believed to have enhanced CH_4 in the atmosphere (9, 28).

The highest monthly mean of CH_4VMR and standard deviation (SD) was in Sulaymaniyah (1871.11±21.92) ppbv at 925 hPa, and the lowest was (1812.81±37.3) ppbv in Rutba at 300 hPa, see Table 1. Mosul has the second- highest monthly mean and SD next to Sulaymaniyah, especially at the lower levels (925 and 850 hPa) of troposphere more than the rest of the cities, because gas density decreases when increasing altitudes above the ground surface as well as increasing height from the sources due to surface emissions (29). Also, Wind plays a major role in mixing and dispersing the gases in the upper levels of troposphere thus a lesser CH_4 concentrations. The Moderate values of monthly mean CH_4VMR appeared over Bagdad and Basrah. See Table1.

The monthly CH_4VMR values decreases in late winter. This decrease is continuing through spring until it reaches the lowest values in June and July and starts to increase gradually until early autumn in each year, this is connected to the seasonal cycle of (OH) radicals which increases in summer particularly in June and decreases in January in the northern hemisphere (30), Also, (OH) radicals decrease vertically with altitude from the surface to the upper troposphere (11).

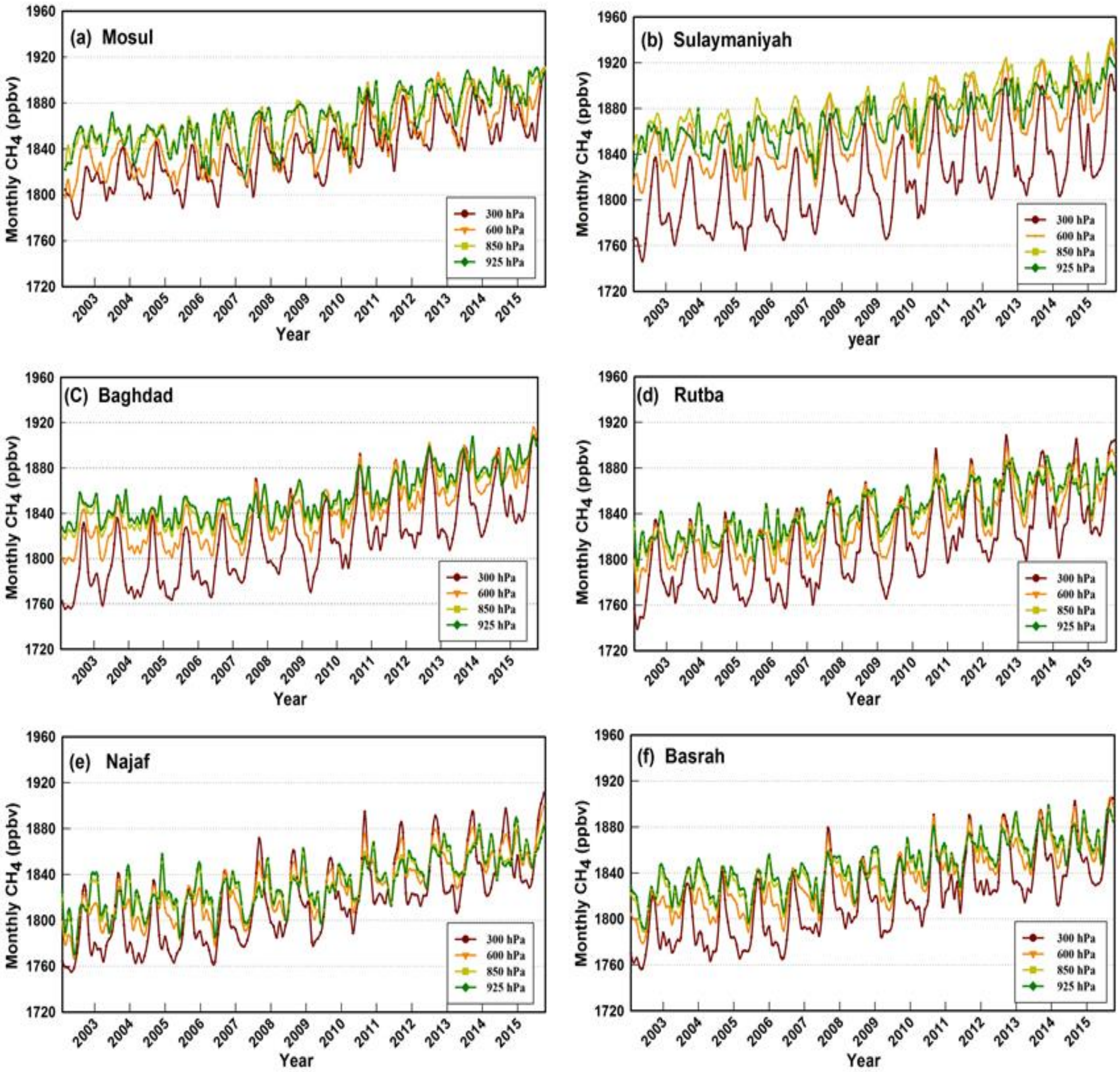


Figure 2. a, b, c, d, e and f: shows monthly average CH_4 time series of four SPL (925, 850, 600 and 300) hPa over the six cities in Iraq (Mosul, Sulaymaniyah, Baghdad, Rutba, Najaf and Basrah) from 2003 to 2016.

Table 1. Shows the statistical values of CH_4VMR; Maximum, Minimum, Mean, and SD at four SPL over the six cities in Iraq for the period 2013-2016.

CITY	Pressure Level (hPa)	CH_4-Max. (ppbv)	CH_4-Mini. (ppbv)	Mean (ppbv)	SD (ppbv)
Mosul	300	1905.2	1778.9	1837.13	26.91
	600	1913.1	1796.8	1850.58	26.81
	850	1915.7	1822.7	1868.09	21.03
	925	1915.7	1814.7	1867.48	23.73
Sulaymaniyah	300	1909.2	1746.3	1816.49	36.46
	600	1937.6	1801.06	1866.29	28.81
	850	1940.8	1827.02	1881.58	22.84
	925	1923.1	1818.9	1871.11	21.92
Baghdad	300	1906.9	1755.6	1816.27	36.08
	600	1915.9	1795.7	1842.24	27.32
	850	1908.9	1813	1852.62	22.12
	925	1908.5	1816.6	1855.75	21.18
Rutba	300	1908.2	1739.01	1812.81	37.73
	600	1897.6	1771.14	1832.89	28.43
	850	1888.7	1790.35	1841.55	23.62
	925	1896	1794.8	1843.62	22.69
Najaf	300	1910.84	1755.07	1815.88	35.67
	600	1900.13	1766.71	1828.80	26.79
	850	1884.41	1769.74	1831.58	22.74
	925	1886.16	1770.56	1832.83	22.48
Basrah	300	1904.6	1736.9	1817.62	34.68
	600	1905.2	1778.9	1837.13	26.91
	850	1895.4	1790	1843.83	22.45
	925	1898.7	1791.8	1846.32	21.90

Figure 3 a, b, c, d, e, and f illustrate the cross maps of monthly average CH_4 distributed vertically, pressure levels vs. time, for the period between 2003 and 2016 for the six cities. The vertical distribution shows the gradual increase of CH_4 concentrations over time at SPL between 925 and 300 hPa. The minimum values of CH_4 were in 2003 while the maximum values were in 2016. As shown in Fig. 3, CH_4 concentrations was relatively high in the cities located in northern Iraq (Sulaymaniyah and Mosul), followed by Baghdad more than the rest of the cities, especially between 2009 and 2016. Numerous CH_4 sources encompass natural and anthropogenic is presence in the northern area, where the conditions are much cooler with more rainfall abundant and the growing season extended into nine months in a year thus a large amount of CH_4 are emitted from flooded soil and sediment as a result of the anaerobic decomposition process of organic material by methanotrophic bacteria (9). The oil and gas production activity is believed to have enhanced CH_4 over Sulaymaniyah where venting and flaring in gas fields also are an important source of CH_4 (31, 32). The presence of various sources of CH_4 in an elevated terrain in the northern region may also have caused the highest concentration to appear; near sources the CH_4 concentrations are often high due to surface emissions (29). Added to that, wind can carry more pollutants from their sources in other places due to the large scale transport effect affected by local weather patterns and the climate (13). The less concentration of CH_4VMR appeared in western part of Iraq above Rutba and Najaf because it is a barren area dominated by the subtropical high pressure climate, and it is a sparsely populated and cultivated area with a just few crops in some irrigation area which means a shortage of CH_4 sources (15), and this area acts as a large sink for CH_4 due to the dry soil oxidation (33).

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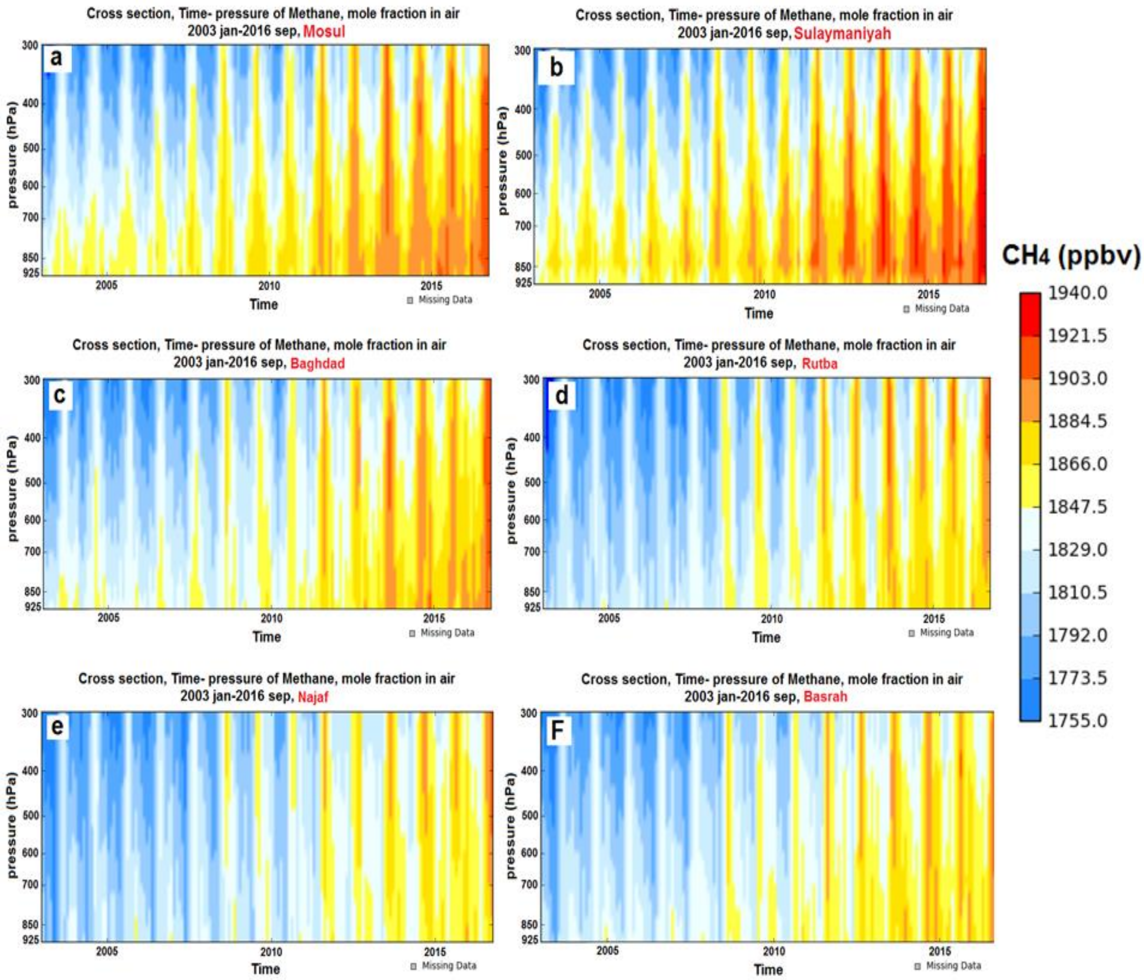

Figure 3. a, b, c, d, e and f: shows the cross maps of monthly average CH_4VMR distributed vertically, pressure levels (vertical dimension) vs. time (horizontal diminution), from 2003 to 2016 over the six cities at SPL between 925 and 300 hPa.

Seasonal variation of monthly CH_4VMR

Figure 4 a, b, c, d, e and f, shows the seasonal variation of monthly CH_4VMR time series, averaged from 2003 to 2016, at all SPL over the six cities in Iraq. The average values of CH_4VMR were high between January and August with a peak between August and September; it declines significantly between October and December with a slight increase in November. The highest average values of monthly CH_4 are ranged between 1800 and 1870 ppbv, whereas the lowest values ranged between 1670 and 1740 ppbv. The seasonal variations of CH_4 concentration in the atmosphere depend on the sources, the sinks (OH radicals), the weather conditions and topography. CH_4 sources, especially wetlands and agricultural are greatly affected by weather conditions such as rising temperature that increases CH_4 emissions due to the anaerobic decomposition process (9, 34). Also, CH_4 significant decrease is highly correlated with seasonal cycle of OH radicals which increases in summer (in June) and decreases in winter (in January) in the northern hemisphere (11, 30).Only in Mosul, the average values of monthly CH_4VMR at 925 hPa were stable, ranged between 1800 and 1870 ppbv indicating a balance between surface emissions and the sinks accompanied by an enhancement in CO values at northern area in winter which competes CH_4 in the same sink (19) OH radicals are the major sink of CH_4 beside CO and many other gases such as NO_X and CO_2in troposphere (9).

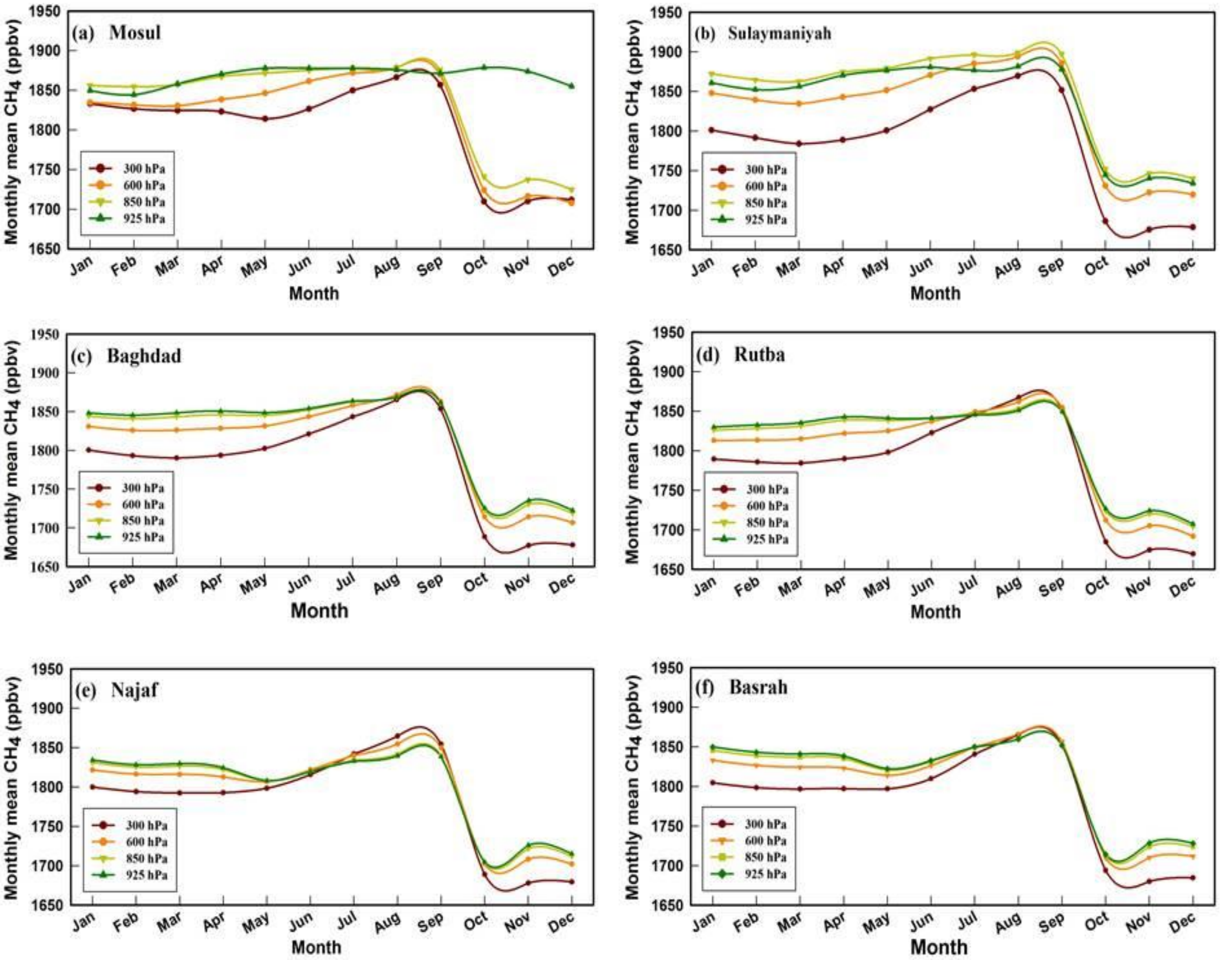

Figure 4. a, b, c, d, e, and f: Shows monthly average variation of CH_4VMR of (925, 850, 600 and 300) hPa over the six cities in Iraq for the period between 2003 and 2016.

Monthly CH_4VMR Long-Term Trend Analysis and the Growth Rates

To study long term trends, a linear regression analysis was applied on monthly CH_4VMR at four SPL for the six cities through the study period according to (35) for data shown in Fig 2- a, b, c, d, e, and f, the results show positive trends (i.e. CH_4 concentrations are increase with increasing years), trends of each city and each SPL were tabulated in Table 2. Trends per year (ppbv/ yr.) of the six cities ranged between (maximum and minimum) 4.696 and 4.027 ppbv/yr. at 925 hPa, 5.607 and 4.35 ppbv/yr. at 850 hPa, 6.789 and 5.092 ppbv/yr. at 600 hPa, and 6.352 and 5.218 ppbv/yr. at 300 hPa. See Fig.5.

The Positive trends in CH_4 concentration during the study period are associated with many reasons, most of which have been explained in the previous sections It is also believed it correlated with trends in oil and gas production activities in Iraq; it is one of the top five CH_4 emitters from oil and natural gas systems in the world (future work is needed to quantify this impact) (36). The average growth rates were calculated of monthly CH_4VMR for the same period (2003-2016) at each SPL (925, 850, 600, and 300) hPa above six cities and the results were (2.9 %, 3.1%, 3.6 % and 3.9%), respectively, it is positive and increase with SPL altitude.

Table 2. Shows the trends of each pressure level (925, 850, 600 and 300 hPa) for the six cities in Iraq between 2003 and 2016.

city	Long. (deg.)	Lat. (deg.)	Trend-925 hPa ppbv	Trend/yr. ppbv/yr.	Trend-850 hPa ppbv	Trend/yr. ppbv/yr.	Trend-600 hPa ppbv	Trend/yr. ppbv/yr.	Trend-300 hPa ppbv	Trend/yr. ppbv/yr.
Mosul	43.15	36.31	60.4	4.314	60.9	4.35	71.3	5.092	73.9	5.218
Sulaymaniyah	45.45	35.53	62	4.428	63	4.5	73	5.214	81.7	5.835
Baghdad	44.40	33.3	57.64	4.117	63.8	4.557	75.5	5.392	88.93	6.352
Rutba	40.28	33.03	65.75	4.696	68.38	4.884	77.22	5.515	85.35	6.096
Najaf	44.32	31.95	56.38	4.027	78.53	5.607	95.05	6.789	88.4	6.314
Basrah	47.78	30.52	59.14	4.224	62	4.428	73.73	5.266	86.29	6.163

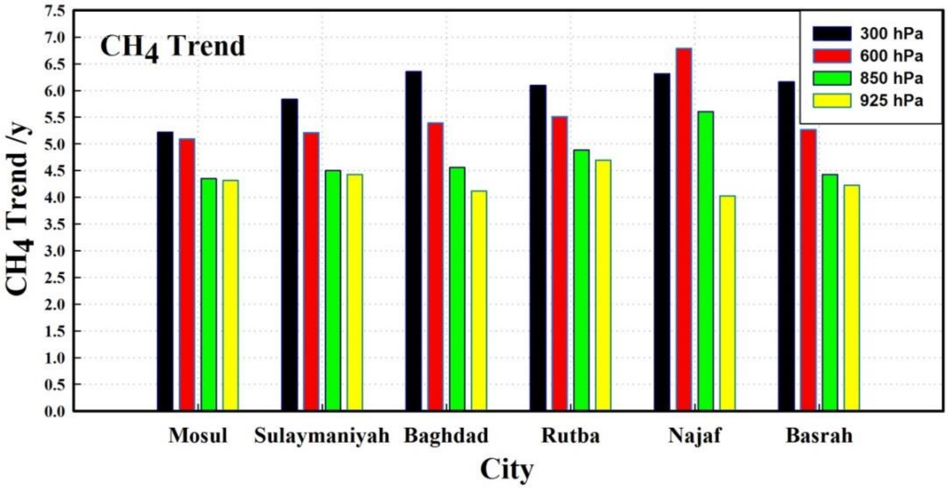

Figure 5. a graph of trends per year values of the six cities for each SPL (925, 850, 600 and 300) hPa for the period 2003-2016

Conclusions:

CH_4 concentrations in earth's atmosphere have increased significantly in recent decades resulting from the continuous increase in both natural and anthropogenic sources accompanied with a decrease in OH concentrations; an analysis is made to CH_4VMR time-series data obtained for four SPL (925, 850, 600 and 300) hPa from AIRS for the period between 2003 and 2016 above six cities in Iraq. From the results, it is clear that CH_4 concentration has increased significantly between 2003 and 2016 especially from 2009 to 2016 after a period of stagnation, and shows a considerable fluctuation between seasons due to weather conditions and topography. The highest monthly mean of CH_4VMR and standard deviation (SD) is in Sulaymaniyah (1871.11±21.92) ppbv at 925 hPa, while the lowest is in Rutba (1812.81±37.3) ppbv at 300 hPa. Mosul has the second-highest mean and SD next to Sulaymaniyah, especially at the lower levels SPL (925 and 850 hPa) of troposphere more than the rest of selected cities.

The vertical distribution analysis is useful. It shows the gradually increase of CH_4 concentrations with time at SPL between 925 and 300 hPa. It emphasizes the previous result where the highest values are in the cities located in north of Iraq (Sulaymaniyah and Mosul), followed by Baghdad and Basrah more than the rest of the cities, especially between 2009 and 2016.The seasonal variations of average CH_4VMR concentration show high values between January and August with a peak between August and September, and it decreases significantly between October and December with a slight increase in November mainly affected by weather conditions and highly correlated with the seasonal cycle of OH radicals. Long term trend analysis of monthly CH_4VMR at each SPL (925, 850, 600, and 300) hPa above the six cities shows positive values with average growth rates for each SPL equal to (2.9 %, 3.1%, 3.6 % and 3.9%), respectively.

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides,

the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.

- Ethical Clearance: The project was approved by the local ethical committee in Ministry of Science and Technology- Baghdad.

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التغيرات الرأسية في تراكيز الميثان الجوي (CH_4) في مدن مختارة في العراق بالاستناد على بيانات AIRS

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الخلاصة:

يوفر مسبار الأشعة تحت الحمراء (AIRS) المحمول على القمر الصناعي EOS / Aqua قياسات متنوعة لتوزيع الميثان (CH_4) عند مستويات ضغط مختلفة في الغلاف الجوي للارض. يركز هذا البحث على تحليل الاختلافات الرأسية لبيانات السلاسل الزمنية لـ (CH_4) نسبة الخلط الحجمي (VMR) عند أربعة مستويات ضغط قياسية SPL (925 و 850 و 600 و 300 hPa) في طبقة التروبوسفير فوق ست مدن في العراق من كانون الثاني 2003 إلى أيلول 2016 . تظهر نتائج تحليل المتوسط الشهري لبيانات السلاسل الزمنية لـ CH_4VMR زيادة كبيرة بين عامي 2003 و 2016 ,وخاصة بين 2009 و2016؛ كانت القيم الادنى في عام 2003 بينما القيم الاعلى كانت في عام 2016. التوزيع الرأسي لـ (CH_4) كان مرتفعًا نسبيًا في المدن الواقعة في شمال العراق (السليمانية والموصل) أكثر من المدن الاخرى، خاصة تلك التي في غرب العراق (الرطبة والنجف). أعلى متوسط شهري لـ CH_4VMR والانحراف المعياري كان في السليمانية (1871± 21.92) ppbv عند 925 hPa ، بينما اقل متوسط كان في الرطبة (1812.81±37.3)ppbv عند 300 hPa . الموصل لديها ثاني أعلى متوسط وانحراف معياري بعد السليمانية ، خاصة في المستويات الدنيا SPL (925 و 850 hPa) من التروبوسفير أكثر من بقية المدن المختارة. يظهر التباين الموسمي لـ CH_4VMR الشهري ، المتوسط من 2003 إلى 2016 ، قيمًا مرتفعة بين كانون الثاني و آب مع ذروة بين آب وأيلول وينخفض بشكل كبير بين تشرين الاول و كانون الاول مع زيادة طفيفة في تشرين الثاني. يُظهر تحليل الاتجاه طويل المدى لـ CH_4VMR الشهري لكل SPL (925 ، 850 ، 600 و 300) hPa فوق المدن الست قيمًا موجبة بمتوسط معدلات نمو لكل SPL تساوي (2.9٪ و 3.1٪ و 3.6٪ و 3.9٪) ، على التوالي. تشير هذه النتائج إلى أن قياسات الأقمار الصناعية كانت فعالة في تحديد مقدار زيادة CH_4 فوق العراق والتي قد تساهم في الزيادة العالمية لـ CH_4 في الغلاف الجوي للأرض.

الكلمات المفتاحية: AIRS ، نسبة الخلط الحجمي للميثان (CH_4 VMR)، السلاسل الزمنية، اتجاهات الميل، العراق.