Research Article – Atmosphere Science

Spatiotemporal observations of CH_4 and CO_2 over Iraq using Atmospheric Infrared Sounder (AIRS) data

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Abstract

Methane (CH_4) and carbon dioxide (CO_2) are the most important greenhouse gases and most important climate forcing agents due to their significant impact on climate, and their concentrations have been increased since the pre-industrial time by 150 and 40 % respectively, basically from fossil fuel combustion and land-use change emissions. In this research, the atmospheric concentration of CH_4 and CO_2 over Iraq is measured by the Atmospheric Infrared Sounder (AIRS). Time series and time-averaged maps were generated to study and analyse the distribution of CH_4 and CO_2 concentrations. The results show a significant increase of these two gases with an average increase (3.5 and 5.11 ppbv/ year) in a rate of (2.69 % and 4 %) for CH_4 at SPL 925 hPa and 400 hPa, respectively; the average increase of CO_2 is (1.85 ppm/ year) represent (3.31%) for the whole period. The considerable increase of CH_4 and CO_2 concentration can affect human healthiness and earth radiative balance. Also, the Satellite observation of AIRS can efficiently show the spatiotemporal variations of CH_4 and CO_2 for the study area.

Key words: Methane CH4-volum mixing ratio, Carbon dioxide CO_2, AIRS, time series

Introduction

Methane (CH_4) and carbon dioxide (CO_2) are most important climate forcing agent due to their significant impact on climate; CH_4 contributes approximately 17 %, about 0.509 W.m^{-2} (Watt/square meter), and CO_2 contributes approximately 66%, about 2.013 W.m^{-2}, of the total radiative forcing (RF) by Long-Lived greenhouse gases (LLGHG's), about 3.062 W.m^{-2} in 2017. CO_2 is responsible for 82 % of the increased RF over the past ten years particularly the past five years (Butler and Montzka 2018). The atmospheric concentrations of CH_4 and CO_2 have been increased since the pre-industrial time by 150 and 40 % respectively, basically from fossil fuel combustion and land-use change emissions (Sreenivas et al. 2016).

CH_4 is released into the atmosphere by natural and anthropogenic sources. The natural sources such as wetlands and termites contribute 40%, the rest 60 % of the total emission are from the anthropogenic sources mainly from fossil fuel combustion. The atmospheric CH_4 reached 257 % of the pre-industrial level approximately 722 ppb (part per billion) due to the increasing emissions from anthropogenic sources, and then it stabilized until 2006. Since 2007, CH_4 in the atmosphere has increased again. The recent increase in CH_4 emissions is likely from wetlands in the tropics and anthropogenic sources in the mid-latitudes of the northern hemisphere. Whereas in 2017, atmospheric CO_2 reached 146 % of the pre-industrial level-approximately 278 ppm (part per million) reflected the balance among three systems; the atmosphere, the ocean, and the land biosphere (Quéré *et al.,* 2018). Many reasons have contribute the recent CO_2 increase, mostly are from the fossil fuel combustion and cement production emissions, deforestation, and other land-use change as well as due to in part to increased natural emissions of CO_2 connected to the most recent El Nino

event. The mean annual absolute increase of the last 10 years for CH_4 and CO_2 are 6.9 ppb.year^{-1} and 2.24 ppm year^{-1}, respectively (Butler and Montzka, 2018).

The air mole fractions of CH_4 and CO_2 in the atmosphere have been investigated in many studies using many methods and data sets. Many reasons are submitted of the recent rapid increase; The absence of vegetation cover and the shortage of CO_2 removal process causes an increase in CO_2 concentrations in the atmosphere (Al-Bayati and Al-Salihi, 2019). The determination of the CO_2 growth rates confirmed the record large rates attributed to the 2015-2016 El Nino (Buchwitz *et al.,* 2018). The amplitude of the seasonal variation of CO_2 retrieved from AIRS is related to altitude and coverage (Cao *et al.,* 2019), whilst the seasonal evolution of CO_2 is closely related to the transport of the wind field, removal of precipitation and absorption of vegetation (ChuanBo *et al.,* 2018). Also, the large increase for CO_2 is responding to the global increasing emissions of GHGs and the El Nino effects (Rajab *et al.,* 2014). The ENSO(El Niño-Southern Oscillation) effect can influence the CO_2 concentration in the mid-troposphere and it's a major source of inter-annual variability in atmospheric CO_2 growth rates (Jiang et al. 2016; Atique, Mahmood, and Atique, 2014) as well as ENSO can affect 36 % of the variability in CH_4 also (Schaefer *et al.,* 2018). The rapid increase of CH_4 in 2014, 2015 and 2017 is consequently either a change in the relative ratios (and totals) of emissions from the biogenic, the thermo-genic and the pyrogenic sources, or a decline in the atmosphere sink of CH_4, or both (Nisbet *et al.,* 2019). The CH_4 mixing ratio considerable increase is due to the increasing emissions from natural and anthropogenic sources (Abed *et al.,* 2017). And it is largely associated with changing synoptic meteorology (Kavitha *et al.,* 2018). A pronounced variability of CH_4 is in response to

ENSO related precipitation changes (Ribeiro *et al.,* 2016).

As one of the developing countries in Asia, Iraq has fewer emission controls that release a significant amount of CH_4 and CO_2 in the atmosphere. It is one of the top five CH_4 emitters from oil and natural gas systems in the world (EPA, 2013). Besides, Iraq is one of Middle East countries; its economic growth is affected significantly by industrialization, urbanization, and the rapid traffic growth. the intense pollution emissions that produced in major industrial zones, office buildings, manufacturing facilities, a dramatic increase in the number of residences, and increases in the number of motor vehicles (Mossa *et al.,* 2012) all these factors can contribute to the increasing levels of CH_4 and CO_2 in the atmosphere.

This study was originated to study and analyse the spatiotemporal distribution of the average values of CH_4 (2003 – 2016) and CO_2 (2010 -2016) over Iraq by employing the retrieved data of AIRS monthly CH_4 product (AIRX35TM-Ver.6) and monthly CO_2 product (AIRS3CTM-Ver.5). Time series data of CH_4 and CO_2 were analysed also to identify the intensive increase of these two gases through the study period.

Study Area

Iraq is one of the south-western countries of Asia; located between (38º 45´-48º 45´E) longitude and between (29º 05´-37º 22´N) latitude, see figure 1. From the north; it is bordered by turkey. Iran is from the east. Jordan, Syria and Saudi Arabia are from the west; Kuwait and Arab gulf are from the south. The total area of Iraq is about 438320 km^2. Its topography includes four types; the alluvial plain is the first part which occupies a quarter of the total area of Iraq and extends from the north of Baghdad into the south to the Arabian Gulf, this area is flat and embraces 19425 km^2 of marshlands. The second part includes the desert plateau located in the west of alluvial plain and comprises less than half of Iraq's total area; this arid steppe area is extended to Syria, Jordan, and Saudi Arabia. The third part is the mountain region located in the north and northeast of Iraq including the highest altitude reach 3550 meters above sea level. The fourth part is the rolling upland between Tigris and Euphrates rivers; it is a transition area between the alluvial plain in the south and the mountain region in the north and northeast (Abed *et al.,* 2017).
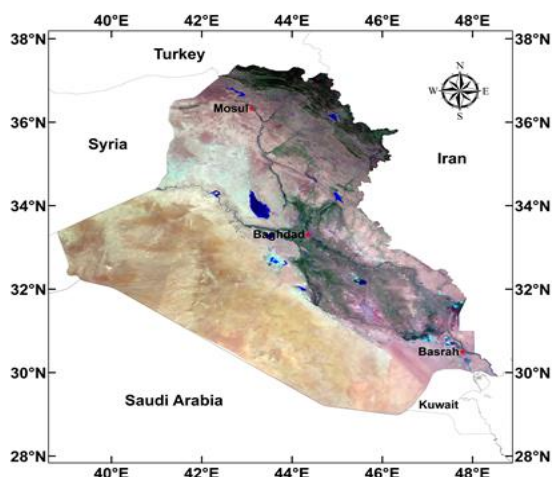

Figure 1. The geographical location of the study area (Iraq)

Data acquisition, specification, and the methodology

Methane volume mixing ratio (CH_4 VMR) and mid-tropospheric carbon dioxide (CO_2) data are obtained from AIRS - NASA Giovanni online data portal for the study area (Iraq). The infrared thermal sounder (AIRS) is one of the several instruments was launched onboard NASA's EOS AQUA platform on 4 may, 2002 used for earth's weather and climate research, the polar orbit altitude of AIRS reach 705 km with global coverage due to the 1650 km cross-track scanning swath, the equator crossing time is 01:30/13:30 local time and the spatial resolution field of view (FOV) is 13.5 km at nadir. AIRS monitors the complete globe, 95% coverage of earth surface, twice per day by employing 2378 channels at high spectral resolution $\lambda/\Delta\lambda=1200$ with low noise, the spectral coverage range of AIRS covers from 649-1136, 1217-1613 and 2169-2674 cm^{-1} (Abed *et al.,* 2017).

The most important gases retrieved from AIRS are CH_4 and CO_2. AIRS version 6-L3 provide three product; daily, 8 days and monthly for 28 pressure levels for CH_4 VMR. (VMR; is the ratio of the number density of the gas to the total number density of the atmosphere where density is the number of molecules per unit volume) (Fishbein *et al.,* 2007), each product is provided separate data of daytime (ascending) and night time (descending). The spectral resolution of the monthly CH_4 VMR is averaged and binned into a $1°x1°$ grid cell. The Grid maps coordinate is ranging from -180.0 ° to +180.0 ° for longitude and from 90.0 ° to +90.0 ° for latitude. Many parameters such as the atmospheric temperature profiles, water vapor profile, surface temperature, and surface emissivity are required as inputs to compute CH_4 retrieval data. CH_4 concentration is measured in part per billion by volume (ppbv) with peak sensitivity at 400 hPa (Olsen *et al.,* 2007).

AIRS also provides retrieval data of monthly mid-tropospheric CO_2 for day and night time under clear and cloudy conditions over ocean and land every day in high spectral resolution and stability, making it ideal for mapping the distribution and transport of CO_2 (Olsen and Licata, 2009).The CO_2 spectral radiance is located in 712-750 cm^{-1} region (mid-troposphere at a nadir with spatial resolution $90×90$ km^2) uses an analytical method based on the properties of partial derivatives for the determination of CO_2. Version 5 -L3 carbon dioxide data have averaged and binned into (2° latitude x 2.5° longitude) grid map (dimensions of those files are 91° latitude x 144° longitude). The CO_2 concentration is measured in part per million (ppm) this is the mole fraction of CO_2, It is the total tropospheric column feature. The retrievals of AIRS are based on cloud-cleared thermal infrared radiance spectra in the 15-micron band and related Level 2 geophysical profiles of temperature, water vapor, and ozone, and achieve 2 ppm accuracy in the tropics and mid-latitudes (Zhang *et al.,* 2014; Rajab *et al.,* 2014).

The monthly averaged maps of CH_4 and CO_2 were generated using the IDW (Inverse Distance Weighted) interpolation technique which can be defined as a tool that uses an interpolation method to estimate cell values by calculating the mean values of sample data points in the neighborhood for each processing cell. The closer the point to the center of the cell being assessed, the greater the effect or weight it has in the centering process. This technique was applied on the 2D raster data of CH_4 and CO_2 that converted

in to point vector format to interpolate the concentration for assessing the spatial distribution. The CH_4 and CO_2 concentrations were specified by using the area average over the entire study area for graphical analysis. The time-series of the monthly average data of CH_4 and CO_2 were plotted using Sigma-plot software.

Results and Discussion

Time series and time-averaged maps were analyzed to observe the spatiotemporal variations in the concentration of CH_4 and CO_2. The observed variation can be attributed to anthropogenic activities based on the spatial extent of each gas. CH_4 VMR data for SPL- 925 and 400 hPa was utilized from January 2003 to September 2016 for Iraq. The standard pressure level SPL at 925 hPa is the second closest level to earth surface while the pressure level at 400 hPa is the most sensitive level by AIRS CH_4 retrieval. A significant increase in CH_4 concentration was observed from 2003 to 2016, the CH_4 average concentration of 925 hPa in 2003 was (1823.96 ppbv) which is increased up to (1873.09 ppbv) in 2016 lead to an average increase of (3.5 ppbv/year) and the CH_4 average concentration of 400 hPa in 2003 was (1791.47 ppbv) which is increased up to (1863.13 ppbv) in 2016 lead to an average increase of (5.11 ppbv/year), this indicates an average CH_4 value of (1844.56 ± 17.83 ppbv) and (1824.09 ± 33.99 ppbv) for the whole study period with significant increase of (2.69 %) and (4 %) for both SPL- 925 and 400 hPa respectively (Figure 2 a-b)

For CO_2, a significant increase is observed from January 2010 to December 2016, the CO_2 average concentration was (390.37 ppm) in 2010 which increased up to (403.32 ppm) in 2016 leading to an increase of (1.85ppm/year). This indicates an average CO_2 value of (396.69 ± 4.57 ppm) for the whole study period with a significant increase of (3.31%). In one hand, the steady increase in CH_4 and CO_2 concentrations can be attributed to the global increase due to increasing emissions from its natural and anthropogenic sources accompanied with a decrease in removal process in the other hand, besides the transport effect which redistribute the pollutants through convection and advection due to the large scale dynamics of earth's atmosphere (Le Quéré *et al.,* 2009), see Figure 2- c.

Time-averaged map of CH_4 VMR distribution at SPL- 925 and 400 hPa during the study period shows a large values of CH_4 in the area located in the north and north-east parts of Iraq, see figure 3- a and b, might be related to the meteorology which cap the pollutants at these heights, as well as the diverse sources of CH_4 encompass the natural and anthropogenic. the northern area has nine months of growing season in a year and the cultivated area by rain-fed crop fields of rice is emit large amount of CH_4 as a result of the anaerobic decomposition process of organic material by methanotrophic bacteria in a flooded soil and sediment (Lagzi *et al.,* 2014; Smith *et al.,* 2010) , besides northern area of Iraq has an average annual rainfall over 400 to1000 mm thus the pastureland is in a good condition leading to increase the livestock population hence more CH_4 emission. The anthropogenic emission due to the human activities and the industry also contribute the increasing levels of CH_4. Moreover, Winds can carry pollutants from their sources due to the transport effect which affected by the atmospheric conditions such as temperature, pressure, and humidity besides the local weather patterns. The less concentrations of
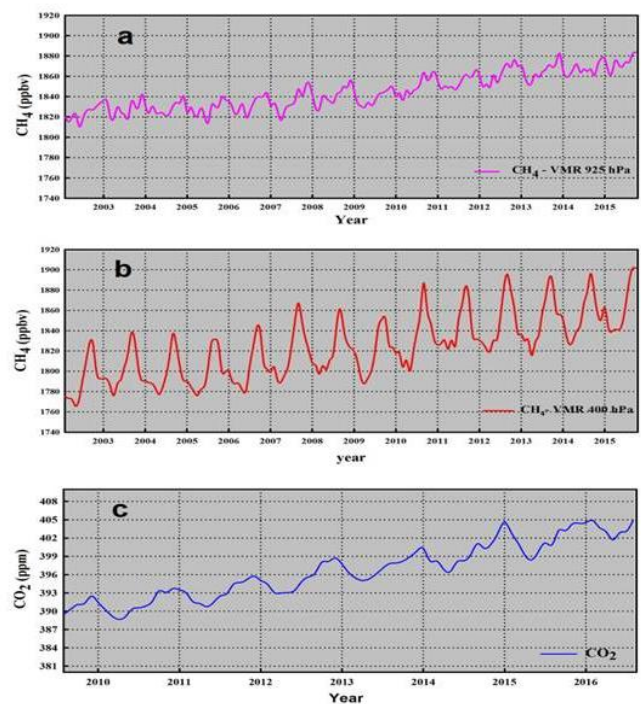

Figure 2: a and b shows the long-term time series of CH_4 at 925 hPa and 400 hPa between 2003 and 2016 and 2-**C**. for CO_2 between 2010 and 2016 of the study area (Iraq)

CH_4 VMR are appeared in the western- south part of Iraq due to several reasons; firstly it is a barren area that can acts as a sink for CH_4 due to the dry soil oxidation (Zhang *et al.,* 2014). Secondly, it is sparsely populated and cultivated with a just few crops in some irrigation spots which means a lack of CH_4 sources (Abed *et al.,* 2017). Most of the central areas of Iraq have a moderate range of CH_4 concentrations.
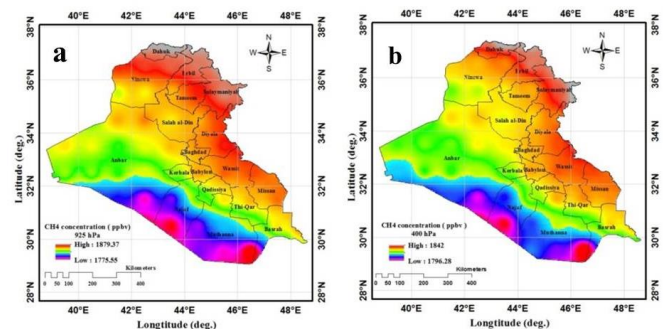

Figure 3 - a, b. Shows the spatiotemporal distribution of the averaged CH_4 VMR concentration over Iraq for SPL (925 and 400 hPa) for the period between 2003 and 2016.

The Spatial distribution of CO_2 is in contrast with CH_4 during the study period over Iraq. The highest concentration of CO_2 has appeared over the western and southern parts of Iraq. The desert covers most parts of the western area of Iraq and the arid climate has dominated these regions where no vegetation grows thus the removal process of CO_2 is weaken due to the limits of CO_2 fertilization on land and the decrease in carbonate concentrations cause the lack of CO_2 removal process. The southern part of Iraq also has a high concentration of CO_2 due to the abundance of oil and gas fields as well as it is densely populated region and human activities increase's the CO_2 emissions particularly from the fossil fuel composition beside the presence of cement production factories. The moderate and less concentration is

appeared in most parts of Iraq including the alluvial plain area due to vegetation growth which is considered as a large natural sink of CO_2 that consumes CO_2 via the photosynthesis process (Le Quéré *et al.,* 2009), see figure 4. The main processes that remove CO_2 primarily at the surface include biological (photosynthesis) and physical (solubility) (Buchwitz *et al.,* 2018).
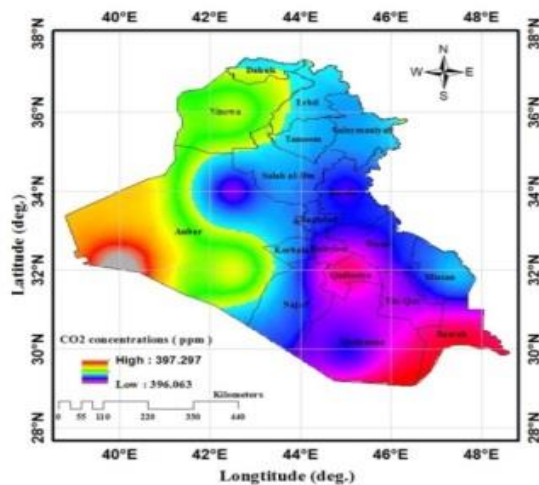

Figure4. Show the spatiotemporal distribution of the averaged CO_2 concentration over Iraq for the period between 2010 and 2016.

Conclusions

A significant increase in CH_4 and CO_2 concentrations were observed through study period with an average increase of 3.5 and 5.11 ppbv/ year for CH_4 at 925 and 400 hPa, respectively. an increase of 1.85 ppm/year for CO_2; this steady increase of CH_4 and CO_2 can be attributed to the global increase due to increasing emissions from the natural and anthropogenic sources companied with a decrease in removal process. The time average maps illustrate large values of CH_4 for both 925 and 400 hPa over the area located in the north and north-east parts of Iraq mostly due to increasing emissions from the natural sources, While the less concentrations have appeared in the western south part of Iraq, and the central area of Iraq has moderate values through the whole study period. In contrast, the CO_2 large concentrations appeared over the western area because of the arid climate is dominates these regions where no vegetation grows. The southern parts of Iraq also have large values of CO_2 due to fossil fuel composition from oil and gas fields; the moderate and less value have appeared in most parts of Iraq including the alluvial plain area. The substantial increase in this concentration can affect human health and earth radiative balance.

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