Monthly Carbone Monoxide (CO) Distribution Based on the 2010 MOPITT Satellite Data in Iraq

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Abstract
Carbon monoxide (CO) plays an important indirect greenhouse gases due to its influences on the budgets of hydroxyl radicals (OH) and Ozone (O_3). The atmospheric carbon monoxide (CO) observations can only be made on global and continental scales by remote sensing instruments situated in space. One of instrument is the Measurements of Pollution in the Troposphere (MOPITT), which is designed to measure troposphere CO and CH_4 by use of a nadir-viewing geometry and was launched aboard the Earth Observing System (EOS) Terra spacecraft on 18 December 1999. Results from the analysis of the retrieved monthly (1ºx1º) spatial grid resolution, from the MOPITT data were utilized to analyze the distribution of CO surface mixing ratio in Iraq for the year 2010. The analysis shows the seasonal variations in the CO surface fluctuate considerably observed between winter and summer. The mean and the standard deviation of monthly CO was (172.076 ± 62.026 ppbv) for the entire study period. The CO value in winter was higher than its values in summer season and its values over Industrial and congested urban zones higher than its values in the rest of regions throughout the year. Maximum values occurred in the northern region (234.105 ppbv) on February at Erbil, were attributed to the increased human activity, geographic nature of the areas and climatic variations. The elevation of CO values on the south-eastern region during the June - November period was due to the emissions from the oil extraction and the burning of agricultural residues in the paddy fields. A greater draws down of the CO occurs over pristine desert environment in the western region (110.047 ppbv) on July at Al Anbar (41.5°log. × 32.5°lat.). The monthly CO surface VMR maps for 2010 were generated using kriging algorithm technique. The MOPITT data and the Satellite measurements are able to measure the increase of the atmosphere CO concentrations over different regions.

Keywords- IRAQ; MOPITT; Carbon monoxide; Satellite measurements

التوزيع السطحي لأول أوكسيد الكاربون (CO) الشهرية في العراق لعام 2010 بالأعتماد على بيانات القمر الصناعي (MOPITT)

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الخلاصة:
أول اوكسيد الكاربون (CO) يلعب دور مهم وغير مباشر كغازات البيت الزجاجي بسبب تاثيره الرئيسي على توازن الهيدروكسيدل راديكال (OH) والأزون (O_3). أن الارصادات لأول أوكسيد الكاربون العالمية

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والقارية يمكن الحصول عليها فقط عن طريق أجهزة الأستشعار عن بعد الموضوعة في الفضاء. وأحد هذه الأجهزة هي قياسات التلوث في التروبوسفير(MOPITT)، والتي صممت لقياس الأوزون والميثان في التربوسفير بأستخدام أرصادات نظير السمت الهندسي و المحمولة على نظام مراقبة الأرض (EOS) على القمر الصناعي تيرا (Terra) في 18 كانون الاول عام 1999. النتائج من تحليل البيانات للاسترجاع الشهرية وبالدقة المكانية (1°x1°) أستخدمت من بيانات جهاز MOPITT لتحليل توزيع نسبة خلط CO السطح في العراق لعام 2010. التحليل بين بأن التغييرات الموسمية في قيم CO لوحظت الى حد كبير تتقلب مابين موسمي الشتاء والصيف. أن المتوسط والأنحراف المعياري الشهري لقيم CO كان (172.076 vbpp ± 62.026) على طول فترة الدراسة. أن قيم CO في فصل الشتاء كان أعلى من قيمها في فصل الصيف، وقيمها فوق المناطق الحضرية المزدحمة والصناعية أعلى من قيمها في بقية المناطق على مدار السنة. القيم العليا ل CO كانت على المنطقة الشمالية (234.105 vbpp) في شهر شباط في أربيل، نتيجة لأزدياد النشاطات البشرية وطبيعة المنطقة الجغرافية والتغييرات المناخية. أن أرتفاع قيم CO على المنطقة الجنوبية الشرقية خلال الفترة من حزيران – تشرين الثاني كان نتيجة الأنبعاثات من أستخراج النفط وحرق بقايا المخلفات الزراعية في حقول الرز. أكبر أنخفاض لقيم CO حدثت على البيئة الصحراوية النظيفة في المنطقة الغربية (110.047 vbpp) في شهر تموز في الأنبار (41.5° طول، 32.5° عرض). أن خرائط نسب الخلط السطحية الشهرية لأول أوكسيد الكاربون أنتجت بأستخدام تقنية ، Kriging Interpretation. بيانات MOPITT ومقاييس القمر الصناعي قادرة على قياس زيادة تراكيز CO في الجو وللمناطق المختلفة.

Introduction

Both as a key player in atmospheric chemistry and as an air pollutant, carbon monoxide (CO) is an active research topic that requires accurate representation of the magnitude and location of CO surface emissions [1]. CO is emitted into the atmosphere from the incomplete combustion of industrial processes and hydrocarbons such as iron smelting, affecting air quality and climate. Also acts as an important indirect greenhouse gases (GHGs) because of it does not absorb terrestrial thermal Infrared (IR) from the Earth, and it significantly affects the OH budget, and thus indirectly impacts the Ozone (O_3) and Methane (CH_4) concentrations. These is due to the characteristic of CO by the indirect radiative forcing increases and effect the concentrations of troposphere CH_4 and O_3 through chemical reactions with other atmospheric constituents. It also regulated as an Environmental Protection Agency (EPA) criteria pollutant due to its direct adverse effects on human health. The levels of normal carboxy hemoglobin in an average person are less than 5%, whereas cigarette smokers (two packs/day) may have to levels up to 9% [2,3].

World-wide, the anthropogenic sources produce about 50% of CO emissions with the remainder coming from biomass burning and oxidation. Anthropogenic pollutants are emitted mainly from stationary sources, such as industrial or urban areas, or from specific locations are known, such as roads [4,5]. The two largest surface sources of CO are the combustion of biomass (forest and savanna fires, biofuel use, and waste burning) and the combustion of fossil fuel. Essential amounts of CO are also produced in the atmosphere through the incomplete oxidation of methane and other hydrocarbons [6]. Generally agreed that biomass burning accounts for about one quarter of CO emission to the atmosphere and in the northern Hemisphere its concentrations are much higher, where industry and human population are much more than in the southern Hemisphere [7].

The CO molecular weight is close to that of air and it have a global-average lifetime of about two months. It is widely used as a tracer to track pollution transport. Uncertainties in the CO budget are still fairly large due to the difficulty in quantifying the variability of CO sinks and sources and due to a lack of emissions statistics and measurements utilized to derive emissions inventories [5]. It is very important to record and document changes in the forcing terms such as gases, in order to assess and understand their impact of climate change, and to achieve more dependable longer range projections. During the past three decades, the abundances of the atmosphere parameters (gases) were acquired from many sources such as airplane, balloons and sparsely distributed measurement sites [8]. Whilst aircraft-mounted and ground-based instruments are able to make accurate measurements of the tropospheric concentrations of CO, they are not able to provide large-scale regional or global coverage as well as cost a lot of money and strenuous efforts [9].

Observations from space only allows for such measurements (in the absence of cloud) in order to make over a reasonably short time period. The satellite remote sensing has very good global coverage increase our ability to access the impact of human activities on the chemical composition of the atmosphere, and climate change. In addition, can provide the quantitatively data with high temporal or spatial resolution [10]. Furthermore, the free download satellite data provided by the Measurements of Pollution in the Troposphere (MOPITT). Over the past decade the TES (Tropospheric Emission Spectrometer) [11], AIRS (Atmospheric Infrared Sounder) [12], IMG (Interferometer Monitor for greenhouse Gases) [13], and MOPITT [14] instruments have all successfully increased the vertical information content of profiles and also global coverage using observations in the 4.7 μm spectral band. The University of Leicester IASI Retrieval Scheme (ULIRS) has been improved to convert IASI Top Of Atmosphere (TOA) radiances into an atmospheric CO product, and the latest instrument in the Thermal InfraRed (TIR) suite of tropospheric sounders was the IASI (Infrared Atmospheric Sounding Interferometer) [15].

The MOPITT instrument, on board NASA's Terra satellite since March 2000, is designed to measure tropospheric CO and CH_4. For CO, the objective is to obtain profiles with a resolution of 4 km vertically, 22 km horizontally and with an accuracy of 10% throughout the troposphere. This instrument is a gas correlation radiometer makes radiance measurements in two CO-sensitive spectral bands. Thermal-infrared (TIR) measurements near 4.7 μm are sensitive to both thermal emission and absorption by tropospheric CO, which is sensitive to the vertical distribution of CO. Near infrared (NIR) measurements in the adjacency of 2.3 μm are designed to provide a practical constraint on CO total column, which are fairly insensitive to the vertical distribution of tropospheric CO [10,16]. The operation of MOPITT instrument triggered similar studies based on remote sensing data at a regional scale [17], at a global scale [18], or for specific events [19].

In this study the analysis of CO surface mixing ratio was investigated for the Year 2010 in Iraq using the retrieved MOPITT Level 3 monthly product Version 5 data. The CO surface Satellite data evaluated for seasonal, annual, and over six stations; Baghdad (33.20°N, 44.20°E), Basra (30.30°N, 47.50°E), Mosul (36.2°N, 43.06°E), Flughafen 2 (32.44°N, 39.35°E), Al Salman (30.30°N, 44.32°E), and Radif Al Khafi Hwy strip (31.55°N, 42.08°E), in study period. The monthly CO surface mixing ratio maps were generated using Kriging Interpolation technique to analyse its distribution on 2010 for study area. This interpolation technique produced high correlation coefficient R and low root mean. The MOPITT data and the Satellite measurements are able to measure the increase of the atmosphere CO concentrations over different regions.

Study Area

The study area is Iraq, a country located in south-western Asia. It lies in the western part of Asia and occupies mostly the Mesopotamian Plain, located, between 29° and 38° N latitudes, and 39° and 49° E longitudes (a small area lies west of 39°). Iraq borders Turkey to the north, Syria to the northwest, Kuwait and Saudi Arabia to the south, Iran to the east, and Jordan to the southwest. An area (Fig. 1) comprises of 437,072 square kilometres (168,754 sq mi); it is the 58th-largest country in the world. Country divided into four major regions: highlands in north and northeast; alluvial plain in central and southeast sections; and desert in west and southwest; rolling upland between upper Euphrates and Tigris rivers. These two major rivers, run through the centre of Iraq, flowing from northwest to southeast are fertile alluvial plains. The north of the country is mostly composed of mountains; the highest point being at 3,611 m (11,847 ft). Iraq has a narrow section of coastline measuring 58 km (36 mi) on the northern Arab Gulf.

Most of Iraq has a hot and arid climate with subtropical influence. Typically precipitation is low; the maximum rainfall occurs during the winter months, and most places receive less than 250 mm (9.8 in) annually. Except in the far north of the country, the rainfall is extremely rare during the summer. Winter temperatures infrequently exceed 21 °C (69.8 °F) with maximums roughly 15 to 19 °C (59 to 66.2 °F) and night-time lows 2 to 5 °C (35.6 to 41 °F). Summer temperatures average above 40 °C (104 °F) for most of the country and frequently exceed 48 °C (118.4 °F). The northern mountainous regions have cold winters with occasional heavy snows, sometimes causing extensive flooding [Metz, H. C., 1990].

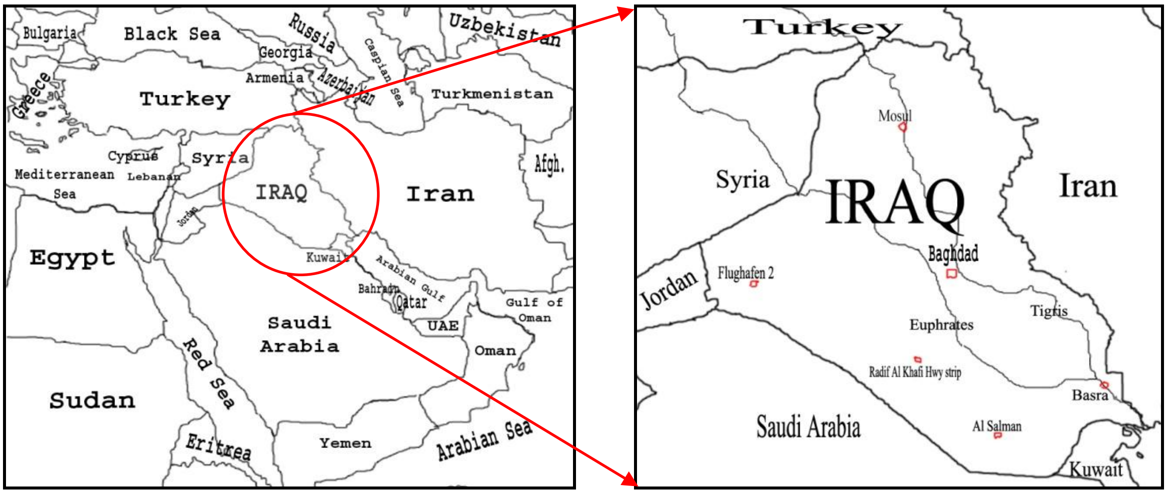


Figure 1- the geographical feature of study area

Acquisition and Specification

MOPITT is a nadir sounding instrument flying on NASA's EOS Terra spacecraft, measuring tropospheric carbon monoxide (CO) on the global scale, which measures upwelling infrared radiation in both the 2.4 µm and 4.7 µm spectral bands. From 705 km above the Earth's surface MOPITT makes observations every 0.4 seconds. These observations are compiled into daily files. Terra orbits the Earth in a sun-synchronous orbit. MOPITT swaths cover the Earth after three days. The orbit repeat cycle is approximately every 16 days, or 233 orbits. MOPITT is an eight-channel gas correlation spectroscopy using Length Modulation Cells (LMCs) and Pressure Modulation Cells (PMC) to calculate total column amounts and profiles of CO in the lower atmosphere with pixel resolution of about 22 km by 22 km at nadir and a swath width of about 640 km, so it takes about three days to obtain approximately complete global coverage [9,16].

In each modulating cycle the detector outputs two signals corresponding to the two states of the modulating cell. A difference (D) signal is obtained when the difference of the two signals is taken, and average (A) signal is obtained when these two signals are averaged. The MOPITT instrument includes two LMC's each for the CH4 and CO total column amounts, and two LMC's and two PMC's for measurement of the CO profile. The eight channels employed in MOPITT measurements, commensurate to the eight modulating cells, and in each channel there is a D signal and an A signal. MOPITT measurements enable scientists to analyze the distribution, a trace gas produced by methane oxidation, sources and sinks of CO, transport, fossil fuel consumption and biomass burning [5]. The MOPITT channel information is listed in Table 1.

Table 1- MOPITT Correlation Radiometer Channel Characteristics [19]

Channel Number	Target Gas	Cell Type	Center Wavelength (µm)	Filter Band FWHM (µm)	Nominal Cell Pressure (kPa)
1	CO	LMC	4.617	0.111	20
2	CO	LMC	2.334	0.022	20
3	CO	PMC	4.617	0.111	7.5
4	CH_4	LMC	2.258	0.071	80
5	CO	LMC	4.617	0.111	80
6	CO	LMC	2.334	0.022	80
7	CO	PMC	4.617	0.111	3.8
8	CH_4	LMC	2.258	0.071	80

Following the launch of Terra, the MOPITT Version 3 product became available in 2000. This product was followed in 2009 by the Version 4 (V4) product. It was the first satellite dataset for tropospheric CO featuring global coverage. Containing the MOPITT calibrated radiances the Level 1 data product are placed and reserved in the HDF files, is mostly unchanged for V5. Like previous products, the MOPITT V5 Level 2 product is stored in HDF-4 format data files. The V5 retrieved profiles are expressed on the same ten-level grid (surface, 900 hPa, 800 hPa ...); each retrieval level simply corresponds to a uniformly-weighted layer immediately above that level. Retrieved profiles are separated into (1) the “Retrieved CO Mixing Ratio Profile,” and (2) the “Retrieved CO Surface Mixing Ratio” formed by the retrieved CO VMR at the nine fixed-level pressures (beginning with the level closest to the surface). Depending on their requirements, Version 5 (V5) retrieval products are meaningfully different than earlier products, offer to the users a choice of three distinct products: (1) a Near InfraRed (NIR)-only product, (2) a Thermal InfraRed (TIR) only product, qualitatively similar to the V4 product and (3) a TIR/NIR “multispectral” product, which represents a unique capability of MOPITT [16].

Material and Methods

This research has been carried out for one year data from January to December 2010. In order to evaluate and analysis the CO distribution over the study area, we selected Six stations dispersed across Iraq; Baghdad, Mosul, Basra, Flughafen 2, Radif Al Khafi Hwy strip and Al Salman. Results from the analysis of the retrieved for the CO obtained from MOPITT Level-3, version 5 data. The MOPITT CO Surface mixing ratio day time products are derived from the near and Thermal Infrared Radiances retrieval. A priori CO mixing ratio profile day time is produced at ten levels between 100 hPa and 900 hPa. Data including the corresponding time and location along the satellite track in a HDF (Hierarchical Data Format) format on monthly basis. This study was used CO Surface mixing ratio day time data closed to the earth surface.

Generally, 12 monthly Level-3 versions 5 day time granules were downloading to obtain the desired output. Extract the MOP03JM.005 product’s files from the Satellite using the MOPITT website, and saves in HDF-EOS4 files; this is a convenient file extension that can be easily extracted data from it and arrange in table using MS Excel. Map of the study area was conducted by using SigmaPlot 11.0 and Photoshop CS software to analyze the surface carbon monoxide data distribution along the study period. To better assess the distribution and the effect of CO over Iraq the maps of CO was generated by using Kriging interpolation technique for the year 2010. The CO data were obtained from 1° × 1° (latitude × longitude) spatial resolution day time orbits.

Results

Figure 2 shows the monthly CO surface from January to December 2010 for Six stations; Baghdad, Mosul, Basra, Flughafen 2, Radif Al Khafi Hwy strip and Al Salman. The mean and the standard deviation of monthly CO was (172.076 ± 62.026 ppbv) for the entire period. The CO experience various seasonal fluctuations depend on weather conditions and topography. The seasonal variation in the CO surface fluctuated considerably observed between winter and summer seasons. A more particular examination shows subtle differences in the CO spatial patterns for each season, with higher values for CO in the winter (at northern region) than in the summer season (at southwest region). In addition, elevation in CO values can be observed throughout the year over the Industrial and congested urban zones, i.e., Baghdad, Mosul and Basra. A lower value of the CO occurs at the pristine desert environment in the western and southwest regions, i.e., Flughafen 2, Radif Al Khafi Hwy strip and Al Salman. Seasonal variations are visible, but none are as pronounced or regular during the study period. This seasonal dichotomy results are primarily from the seasonal photochemical cycle of the hydroxyl radical (OH) in the troposphere. In the Northern Hemisphere, the winter and early spring coincides with the minimum of OH concentrations and thus a maximum for CO concentrations [4]. At Figure 2, one very localized area stand out against its background on July: Mosul. It reveals enhanced in CO value, due to the extensive biomass burning from the forest fire that have occurred on July in the neighboring province of Dohuk.

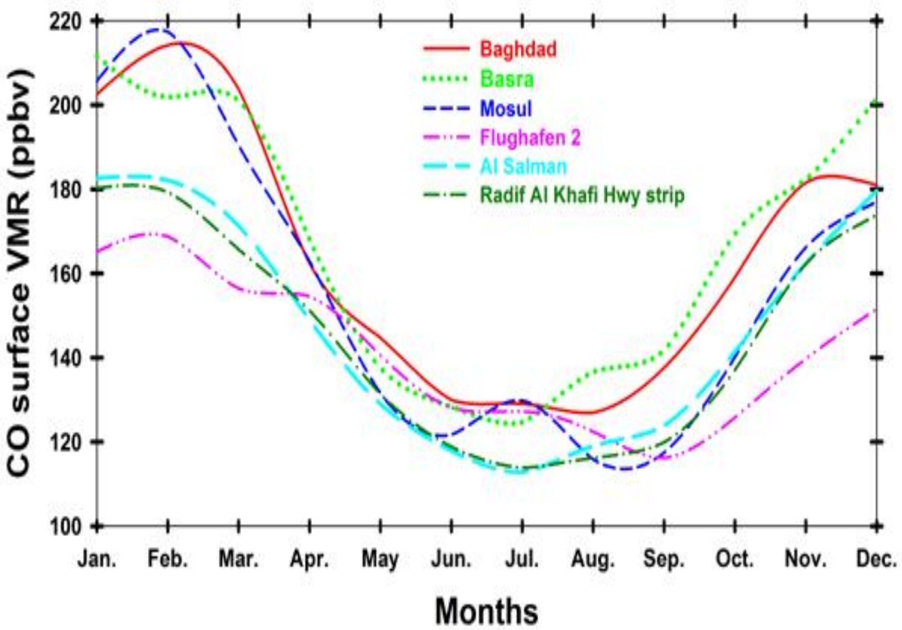
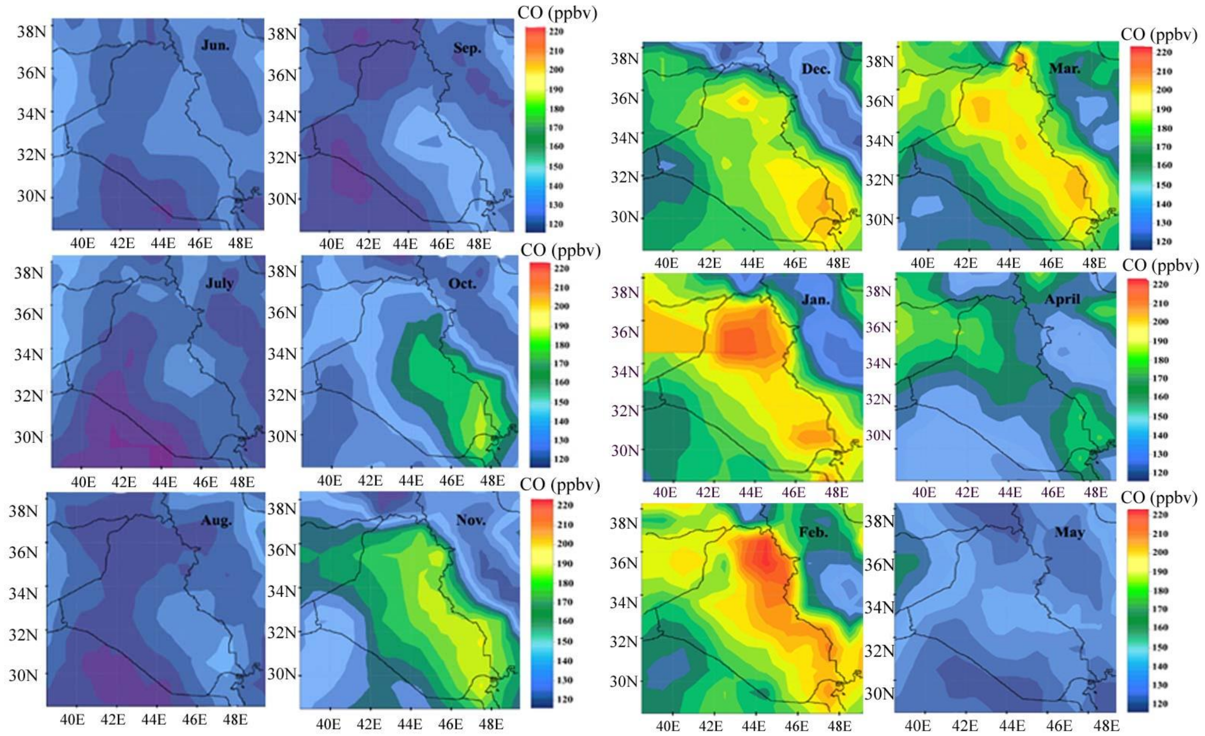


Figure 2- Monthly CO surface VMR between January to December 2010 for the stations; Baghdad, Mosul, Basra, Flughafen 2, Radif Al Khafi Hwy strip and Al Salman.

CO is released from many sources which vary in their magnitude, temporal and spatial variability. The CO transport and diffusion in the atmosphere depends, among other factors, on these properties. CO sources can be categorized in several ways; in this study can observe the effect of three types of CO sources: anthropogenic, fire, chemical production. Anthropogenic emissions are considered as surface sources whereas CO release from biomass burning depends on the fire radiant heat and the CO originated from hydrocarbon oxidation can be released at higher levels. The main contributor to the total CO is the anthropogenic. Its seasonal cycle is as expected, i.e., due to increased emissions from the excessive use of oil heaters, elevated concentration during winter and early spring, decreasing during the summer; and slightly increasing again during the autumn. CO from chemical production contributes substantially with defined seasonal cycle; high over winter and early spring and autumn and low during summer. Biomass burning has no defined seasonal signature and contributes episodically. Except for July in the northern area, daily variation is small [5].

The CO surface VMR level-3 monthly 1° × 1° spatial resolution day time were used for mapping CO in 2010. Figure 3(a) illustrated that the highest value of CO occurred during the winter and early spring seasons, especially at northern region above latitude 34°, as a results of the increased of incomplete product by combustion of thermal heaters, were used excessively for heating during the cold season. In February CO increased to its highest value throughout the year at Erbil (234.105 ppbv, red pixels), though it slightly decrease to moderate in March, compare to previous months, and low in May. The lowest value was at the pristine desert environment in the western (29.5°N, 43.5°E) on May (120.951 ppbv, blue pixels).This fluctuation in the CO values during this period (December – May) were caused by the human activity, geographic nature of the areas and climatic variations.



(a) (b)

Figure 3- MOPITT monthly coverage from the retrieved CO surface VMR, (a) for winter and spring seasons [December - May] and (b) for summer and autumn seasons [June - November] 2010 on a 1×1 degree grids.

As illustrated in Figure 3(b) for the summer and autumn seasons (June – November), a decrease in the CO values during June to September, whereas slightly increase to moderate values of CO in October and November. There was an elevation of CO values on the south-eastern region compared to their values on the rest of the regions during this period. This is due to the emissions from the oil extraction and the burning of agricultural residues in the paddy fields. The highest value that occurred in this period was on November at Mysan (188.078 ppbv; at 31.5°N, 47.5°E), and the lowest value was in July (110.047 ppbv; at 32.5°N, 41.5°E).

Figure 4 illustrate the extent of MOPITT seasonally coverage of CO surface (winter and summer), the nominal peak of MOPITT surface sensitivity and the magnitude of the seasonal variations in surface CO. Note the difference between the seasons with high values in the winter and low values in the summer. This seasonal contrariety results essentially from the seasonal photochemical cycle of OH, the primary oxidizer for CO. The winter/early spring are coincides with the minimum of OH concentrations and thus a maximum for CO concentrations. Extensive sources are evident in both North and south-east of Iraq with subsequent plumes contributed to CO concentrations are from Turkey bring by northwesterly wide (winter shamal) driven by the passage of a strong synoptically forced cold front. In contrast, the summer map is near the lack of the CO sources, anthropogenic sources have very small variability during summer. CO emissions from Turkey have very small contribution during summer. In addition, the summer shamal, or "wind of 120 days" blows almost daily during the summer months of June through September and has great vertical motion over a large horizontal area, which can reduce the CO concentrations.

Figure 5 illustrates the annual average distribution of CO surface for 2010. The local CO maximum just east of Maysan and north of Al Qurnah occurs precisely in a region (166.88 ppbv; 31.5N, 47.5E), that experienced extensive incomplete product of CO by oil fields in 2010. In contrast, minimum CO occurs at the pristine desert in the western regions (136.74 ppbv; 32.5N, 40.5E). In addition, the values of CO surface were higher in the southern and central regions than in the other regions throughout the year because there were many sources, such as crowded cities, and there was more of an effect from the Oil extraction operations from the fields widespread in these regions.

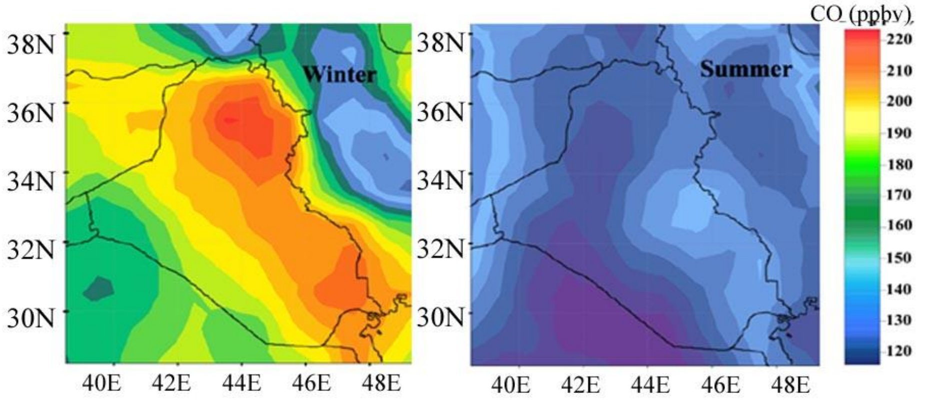


Figure 4- Seasonal coverage 2010 from the retrieved CO surface VMR for winter and summer. Both maps are on 1×1 degree grids.

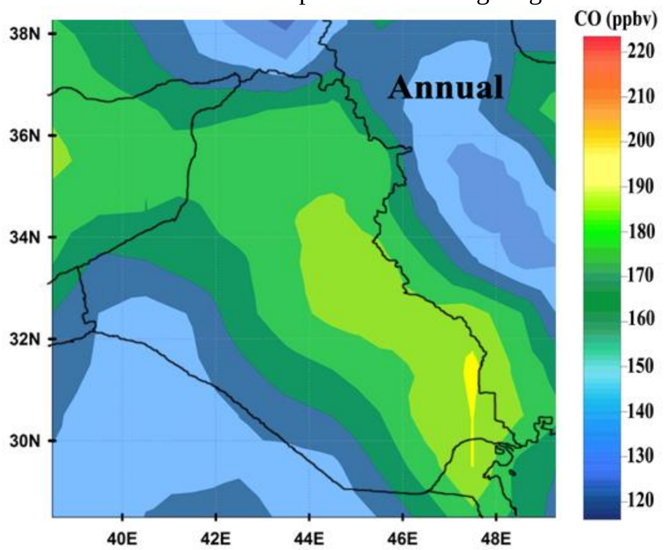


Figure 5- Yearly (2010) average distribution of CO surface on a 1×1 degree grid.

Conclusion

This paper represents the first attempt to quantify the CO surface distributions in Iraq using satellite (MOPITT) data. As demonstrated here, MOPITT monthly views of surface CO across the study area enable detailed analyses of both the spatial and temporal variations in the visualization of subsequent transport and emissions. We have just begun to investigate the wealth of information for the 2010. The CO values are strongly correlated with weather conditions and topography. The mean and the standard deviation of monthly CO was (172.076 ± 62.026 ppbv) for the entire period. The seasonal variation in the CO surface fluctuated considerably observed between winter and summer seasons. The lowest CO values were observed during the summer season on July (110.047 ppbv) at Al Anbar, and the highest CO occurred during winter season on February (234.105 ppbv) at Erbil. In addition, elevation in CO values can be observed throughout the year over the congested urban and Industrial area.

The CO concentration over the Iraq can be described by three main components: anthropogenic CO sources seasonal cycle, fires, the CO from hydrocarbon oxidation seasonal cycle and synoptic scale. The main contributor to the total CO is the anthropogenic. The excessive use of oil heaters elevated the CO concentrations during the winter and early spring, decreasing during the summer; and slightly increasing again during the autumn. The enhanced in CO value observed in July above Mosul, due to the impact of the extensive biomass burning emissions from the forest fire occurred in Dohuk.

The fluctuation in the CO values during the December - May period were caused by the human activity, geographic nature of the areas and climatic variations. While the elevation of CO values during the June - November period on the south-eastern region compared to their values on the rest of the regions, was due to the emissions from the oil extraction and the burning of agricultural residues in the paddy fields. The winter shamal bring subsequent plumes from Turkey are contributed to CO concentrations, and summer shamal have very small contribution to CO concentrations. The CO surface have high values in the southern and central regions throughout the year due to the presence of many sources, such as crowded cities, and the effect of the Oil extraction operations from the fields in these regions. The CO maps were generated using Kriging Interpolation technique. The MOPITT data and the Satellite measurements are able to measure the increase of the atmosphere CO concentrations over different regions.

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