Spatial and Temporal CO Concentration Over Malaysia and Indonesia Using 4 Decade Remote Sensing Dataset

Abd Rahman Mat Amin [1], Wan Farahiyah Wan Kamarudin [1], Adida Muhammud [1], Fathinul Najib Ahmad Sa'ad [1], Raja Ibrahim Petra Raja Mustapha [2]

[1] *Faculty of Applied Sciences, Universiti Teknologi MARA, 23200 Bukit Besi, Terengganu, Malaysia*
[2] *Faculty of Applied Sciences, Universiti Teknologi MARA, Perak Branch, Tapah Campus, Tapah Road, 35400 Perak, Malaysia*

***Abstract* – Malaysia and Indonesia, located in the Southeast Asia region, have experienced severe pollution due to haze especially during drought seasons ever since 1980. Among the causes of this series of hazes affecting the region is mostly the industrial scale illegal of slash and burn practices, principally practised in Sumatera and Kalimantan. The main objective of this study is to investigate the carbon monoxide (CO) distribution over Malaysia and Indonesia, within the period from January 1980 to December 2018. This study utilizes MERRA-2 dataset provided by GIOVANNI interface. The monthly CO concentrations fluctuates highly, with the highest measurement observed during the drought season (June to October), meanwhile, the lowest observed are within the rainy season (November to March). The result of this study also shows that Kuala Lumpur, Riau, Palembang and West Kalimantan are the worst affected by CO pollution, especially during forest fires. During normal conditions, the CO value is below 200 parts per billion volume (ppbv). However, the CO concentration peaked as high as 15,208 ppbv during forest fire over Palembang in October 1997. The increment of CO concentration over this area is mostly due to the fire forests that commonly occurs during the drought season.**

DOI: 10.18421/TEM83-20
https://dx.doi.org/10.18421/TEM83-20

Corresponding author: Wan Farahiyah Wan Kamarudin, *Faculty of Applied Sciences, Universiti Teknologi MARA, Terengganu, Malaysia*
Email: wfarahiyah@uitm.edu.my

Received: 15 July 2019.
Revised: 05 August 2019.
Accepted: 10 August 2019.
Published: 28 August 2019.

***Keywords* – Forest fire, carbon monoxide, MERRA-2, GIOVANNI 4.**

1. Introduction

Haze over the Southeast Asia region, especially Malaysia and Indonesia, has become a recurring phenomenon since early 1980s, especially during the drought season, which occurs from June to October every year. This is due to industrial-scale slash-and-burn practices in Indonesian provinces for agricultural purposes [1]. Since 1980, there are numbers of forest fires recorded over this area. An estimated 3.5 million hectare (ha), 50,000-ha, 120,000-ha, 160,000-ha of forest areas was burned in 1982, 1987, 1991 and 1994 respectively [2]. The worst forest fire occurred in 1997 which destroyed 5 million-ha of land of which 20% was forested [3]. This event produced thick clouds of smoke and haze that affected neighboring countries such as Malaysia and Singapore.

There are numerous poisonous gasses produced during a forest fire phenomenon. Carbon monoxide (CO), which is produced from the incomplete combustion of fossil fuels and biomass burning [4], is one of the gasses produced. The CO that is injected to the atmosphere could impact human life and contributes to climate change. Long term exposure to the high CO concentration could lead to cardiovascular and respiratory diseases, induce neuropsychiatric conditions and other systemic complications, or even fatality [5],[6]. The CO that is injected to the atmosphere does not have a direct influence on greenhouse effect but it plays a major role in atmospheric chemistry involving hydroxyl (OH) radical [7]. Due to the significance of this parameter, it is important to investigate spatial and temporal CO concentration over highly populated regions.

Nowadays, remote sensing techniques to monitor environmental parameters are widely used. This technology could overcome spatial and temporal constraints. In order to study the amount of carbon released from peat and forest fires in Indonesia during 1997, Landsat (TM) dataset was used by Page et al. [8]. Girach and Nair in 2014 have used satellite-based measurement of tropospheric CO, Measurements of Pollution in the Troposphere (MOPITT) that were located onboard the Terra satellite to study CO variation over Indian region for the period 2000-2014 [7].

One of their findings is the columnar CO that showed positive correlation with biomass burning over west, east and north-east India. Another study conducted by Ribeiro et al., over Amazon used the Atmospheric Infrared Sounder (AIRS) on-board the Aqua satellite to investigate the impact of biomass burning on the methane variability during the drought season [9]. They found that the peak CO concentration was observed during the drought season. From the above findings, it follows that remote sensing technology is widely used to study CO concentration over high spatial and temporal domain. This study is conducted to investigate four decades of spatial and temporal CO concentration over Malaysia and Indonesia. This study will use surface concentration of the CO provided by NASA Modern-Era Retrospective-analysis for Research and Applications, Version 2 (MERRA-2) and analyzed using online Geospatial Interactive Online Visualization and Analysis Infrastructure (GIOVANNI) that was created by NASA Goddard Earth Sciences Data and Information Services Centre (GES DISC).

2. Study Area and Dataset

This study area is located in the Southeast Asia region. The region is bordered by the South China Sea to the east and the Indian Ocean to the west. The coordinates of this study area are 94.0869E, 9.4189S, 119.3994E and 7.4561N. Malaysia and Indonesia are included in this study area. Malaysia consists of two major parts, Malaysian Peninsular to the west and East Malaysia to the east. East Malaysia is located on the island of Borneo. Meanwhile, the Indonesian region consists of three main regions, Sumatera to the west, Kalimantan to the east and Java to the south.

Figure 1. Study Area

Carbon Monoxide Concentration (CO)

In this study, the number of CO molecules in the atmospheric column from the Earth's surface to the top of the stratosphere above a square centimeter of the surface is the total column measurement. As a profile, or layer measurement, it is the volume mixing ratio in parts per billion (ppbv). The CO is not a direct greenhouse gas; however, CO and other pollutants can affect tropospheric ozone, carbon dioxide, and methane content. Thus, CO can have an indirect effect on the climate.

CO is a relatively short-lived species, with a lifetime of two months in the troposphere. Because of its relatively short lifetime, CO is not well-mixed, and thus it is often used as a tracer to track polluted air masses in the troposphere.

3. Methodology

Atmospheric dataset used in this study was obtained from GIOVANNI 4 interface. In this study, was chosen the CO concentration analysis assimilated by MERRA-2. As a profile, or layer measurement, is the volume mixing ratio in parts per billion. The product short name is designated as M2IMNXCHM. Its long name is MERRA-2 tavgM_2d_chm_Nx: 2d, Monthly mean, Time-Averaged, Single-Level, Assimilation, Carbon Monoxide and Ozone Diagnostics V5.12.4.

The monthly temporal resolution with $0.5^{O} \times 0.625^{O}$ spatial resolution was processed. After that the study area was selected. Then, time averaged map for the period from January 1980 to October 2018 was plotted. The time-averaged map shows the data values for each grid cell within the user-specified area, averaged (linearly) over the user-specified time range as a map layer. The seasonal averaged is then constructed by using the same geographical coordinates. The Seasonal Average maps compute averages for either a specific month or a 3-month period corresponding to the meteorological seasons (DJF=December, January, February; MAM=March, April, May; JJA=June, July, August; and SON=September, October, November). Then, time series was plotted.

The first time series is the area averaged time series. The plotted time-series is produced by computing spatial averages over the user-selected area of a given variable for each time step within the user's range. The second time series is seasonal time series. The Seasonal Time Series computes an area-averaged time series for each year in the user's selection for a given month or 3-month meteorological season. Finally, the table was constructed for the years when haze event struck. The table was plotted by using monthly area averaged time series that can be downloaded in Microsoft Excel format.

4. Result and Discussion

With the intention to investigate spatial CO over the study area, the time averaged map for the period January 1980 to December 2018 was constructed. This map was constructed to find the general view of the CO distribution. Generally, high CO concentration was observed over Kalimantan, the south of Sumatera, the west of the Malaysian Peninsular, Sarawak and the west of the Java Island. The south of Kalimantan measured most with the highest CO concentration at 65.63 ppbv. The Riau and Palembang province located in the Sumatera Island also had severe concentrations of CO, ranging between 12.37 to 45.65 ppbv. Meanwhile over to the west coast of the Malaysian Peninsular region, especially Kuala Lumpur, was measured to be the most affected area. Sarawak, located on the Borneo Island was also influenced but with moderate CO concentration.

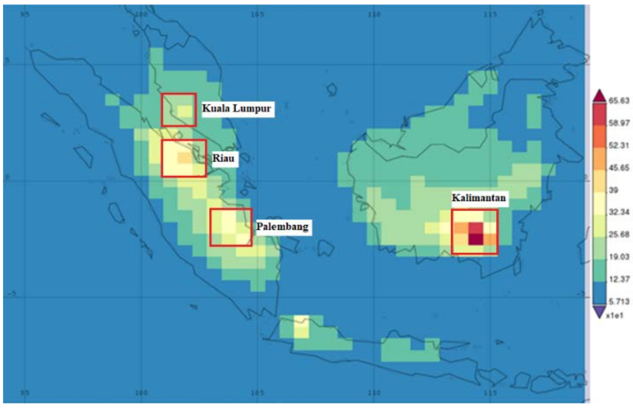
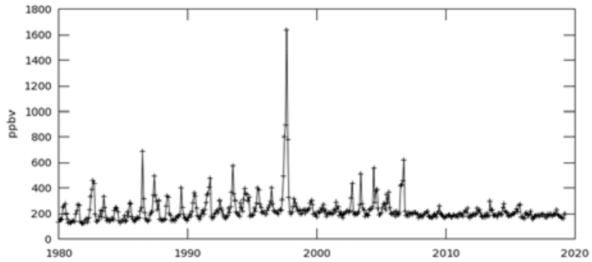
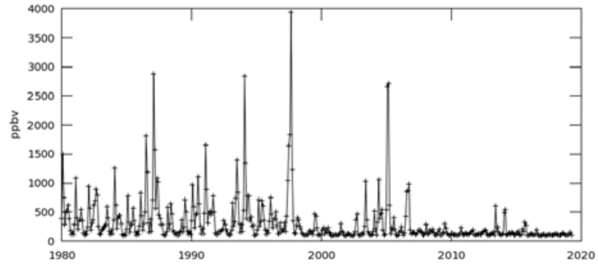


Figure 2. Time averaged map of CO surface concentration in ppbv (ESEMBLE) monthly 0.5° × 0.625° over the period of January 1980 to December 2018.

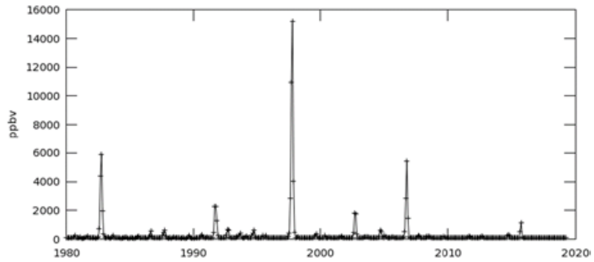
Detailed observation of Figure 2. shows that the most affected region could be located into 4 main areas which are Kuala Lumpur, Riau, Palembang and South Kalimantan respectively. Figure 3. shows the area-averaged time series of CO concentration over the four above-mentioned areas. Both time series shows the peak of CO concentration in September 1997. This is due to the forest burning activity over Indonesia that lead to more than 150, 000 acres of forest to be destroyed. Palembang, located at the south of the Sumatera island recorded the highest CO with the value of 13,000 ppbv followed by South Kalimantan, Riau and Kuala Lumpur with 6500, 4100 and 1500 ppbv CO concentration respectively. The forest fires occurring all over the world in 1997 was mostly due to the dry weather caused by the El-Niño phenomenon. Around 26,000 hectares of forest were affected at Riau.



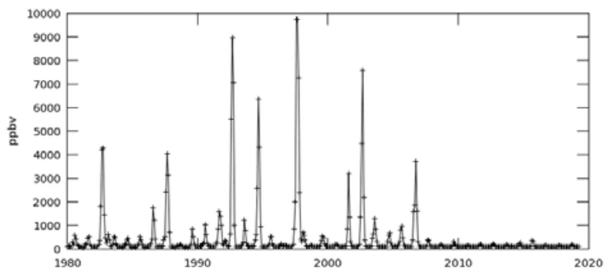
(a)



(b)



(c)



(d)

Figure 3. Area-averaged of CO surface concentration in ppbv (ESEMBLE) time series for a) Kuala Lumpur, (b) Riau, (c) Palembang, (d) Kalimantan from January 1980 to December 2018.

Figure 3. shows the averaged time series of CO concentration over 4 study regions that were severely affected by this pollution. Clearly seen in this figure,

the highest CO concentration was observed from August to October 1997. The worst region is Palembang where the CO concentration reached as high as 15,208 ppbv in October 1997, followed by Kalimantan where the CO concentration is 9757 ppbv. Meanwhile, the area averaged of CO concentration over Kuala Lumpur and Riau experienced the lowest CO concentration in October 1997 with the value 1636 ppbv and 3937 ppbv respectively.

The area averaged of CO concentration time series over Kuala Lumpur during January 1980 to December 2018 is shown in Figure 3. (a). The satellite data shows that July 1986, July to October 1997 and July 2003 have the highest CO concentration over Kuala Lumpur that also exceeded 500 ppbv. The scale for CO concentration value for Riau region is bigger with ranges between 0 ppbv to 4000 ppbv as shown in Figure 3. (b). There are 4 values of CO concentration observed exceeding 2000 ppbv, on February 1987, February 1994, September 1997 and February to March 2005. The graph for the Palembang region shown in Figure 3. (c), observed that from September to November 1997, it has the highest decadal increasing trend of 15208.47 ppbv, followed by October 2006 with 5429.173 ppbv, whereas for September 1982 it has been measured at 4399.287 ppbv. Figure 3. (d) shows the CO concentration over Kalimantan region that exhibit 4 peaks exceeding 5000 ppbv. These peaks were indicated from August to October 1992, September to October 1994, August to October 1997 and August to September 2002.

Monthly time averaged

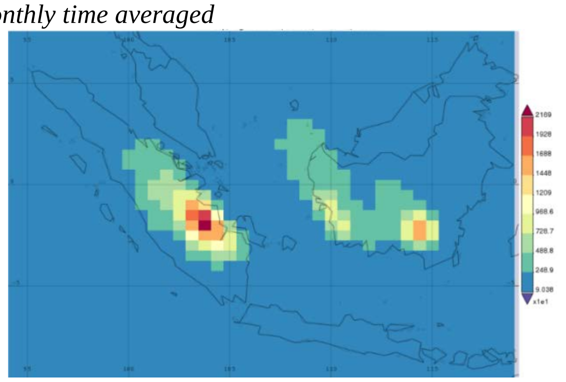


Figure 4. Monthly Area Averaged for September 1997.

In order to trigger the exact location with the highest CO concentration, a monthly time averaged map for September 1997 was constructed and shown in Figure 4. The affected area is shown in Figure 4. and clearly shows the highest CO concentration observed over a few locations which includes Palembang, located at the south Sumatera Island and a few parts of the West Sumatera Island. For the Kalimantan region, it can be seen that moderate value of CO concentration was observed at West Kalimantan and South Kalimantan. The high CO concentration over these regions was influenced by CO transport due to severe haze events occurring in 1997 [10].

Seasonal CO Time series

The analysis of Figure 3. suggests that the CO concentration over this region has a highly seasonal dependence. A new figure was constructed to verify this finding. Figure 5. shows the seasonal CO concentration time series for the period from 1980-2018. The CO concentration over the 4 study regions exhibits similar seasonal patterns. The CO concentration starts to increase in the dry season which is from July to August and decrease from November to December. Over the study region, the CO reaches its seasonal maximum from September to November, represented by orange colour. Meanwhile, in December-January-February (DJF), the rainy season recorded the lowest CO concentration trend that is represented by the blue colour.

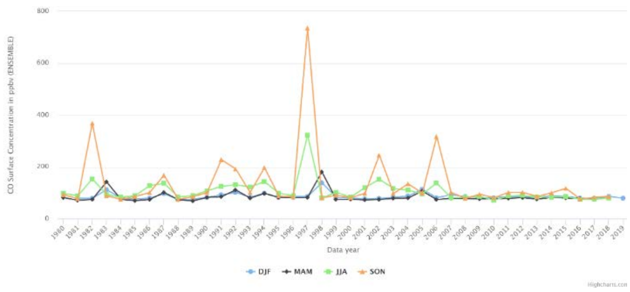
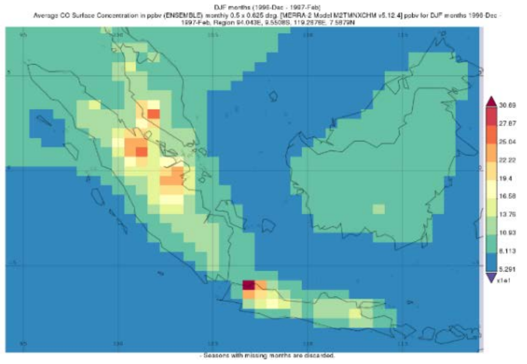


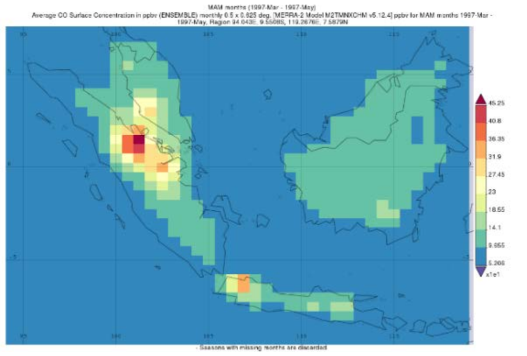
Figure 5. Seasonal CO concentration time series for the period from 1980-2018.

Seasonal CO Concentration Area Averaged

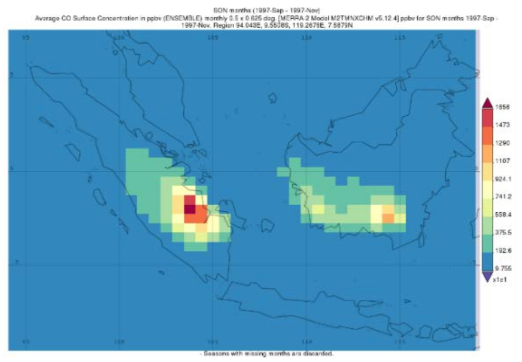
The above finding shows that the highest CO concentration was observed during the drought season (September to November) almost every year. In order to find the most affected area, seasonal averaged area map for the period from December 1996 to November 1997 was constructed as shown in Figure. 6. below. Figure 6. (a) shows the CO concentration variation during DJF season (December to February). The highest CO concentration during DJF is observed especially at the western part of Java Island. Most parts of the Sumatera Island and the western part of the Malaysia Penisular also experienced low CO concentration which is significantly influenced by CO transport from the western part of the Java Island. These figures also found that the regional CO shifts significantly from the southern part of Kalimantan and spreads over the whole of Kalimantan and East Malaysia (Sabah and Sarawak). Most parts of Malaysia and Indonesia are observed to exhibit low CO concentration during the rainy season (December to February) primarily attributed to decreasing temperatures, weakening of the wind speeds, increasing domestic biomass burned for heating, and reduced photochemical CO removal [11],[12].



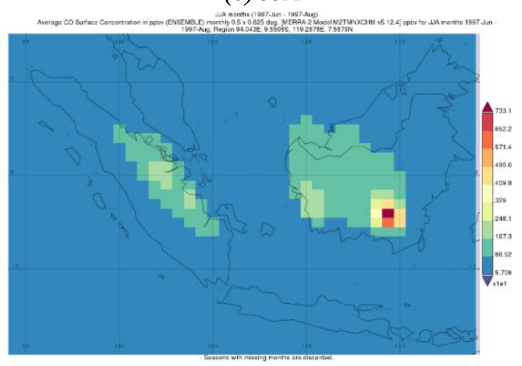
(a) DJF



(b) MAM



(c) JJA



(d) SON

Figure 6. Seasonal CO concentration area averaged for the period from December 1996 to November 1997 a) DJF, (b) MAM, (c) JJA, (d) SON

The CO concentration increased slightly during MAM season with the highest CO concentration located over the Riau Region at the western Sumatera Island. The CO concentration over the Malaysian Peninsular also increases with the most affected area located at the southern part, which is near to the Sumatera Island. The haze can be seen to originate from forest fires in the Sumatera Island especially over the Riau province. Other parts of the Malaysian Peninsular experienced moderate CO concentration. This is because of mild temperatures, large scale crop residue burning, atmospheric oxidation of methane that is an important source of the CO and the photolysis processes of carbon dioxide in the presence of solar radiation to form carbon monoxide [13],[14],[15].

The CO concentration during Jun to August period (JJA) over South Kalimantan worsened and is slightly higher as can be seen in Figure 6. (c). The increased CO even dominated the local emission sources to Sarawak, the territory adjacent to its borders with Kalimantan, Indonesia. It is linked to the uplifting of the CO during strong convective activities taking place in Kalimantan. The Riau and Palembang region experienced moderate CO concentration during this time.

In October 1997, the data satellite measurements show the highest concentration from September to November (SON) season as shown in Figure 6. (d). The highest CO concentration that was observed during this SON season, is located at the Palembang region. Meanwhile, the western part of the Sumatera Island experienced moderate CO concentration which is significantly influenced by the CO transport from the Palembang region. Kalimantan also experienced high CO concentration especially at the western and southern part of Kalimantan. The increment of the CO concentration over this area is mostly due to the fire forests that commonly occur during the drought season.

5. Conclusion

In this study, the CO distribution over Malaysia and Indonesia is analyzed for a period of 18 years from 1980 to 2018 by using MERRA-2 dataset provided by GIOVANNI interface. Four areas were found to have been affected the most during the study period, which are Kuala Lumpur, Riau, Palembang and Kalimantan. Palembang has been identified as a point source of CO emissions where the CO concentration reached as high as 15,208 ppbv in October 1997. The forest fires commonly occur during the drought season found to be the major source of the increase of the CO concentration. The CO concentration over the studied region exhibit a strong seasonal dependence showing maximum value in dry season (September to November) and minimum in rainy season (December to February). The CO concentration starts to increase in July/August and decrease in November/December.

Acknowledgement

This project was funded by the Ministry of Higher Education (MOHE) Malaysia through the Fundamental Research Grant Scheme (FRGS) Project No. FRGS/1/2017/STG09/UITM/02/1. We would like to thank the management of UiTM for their support and encouragement. Analyses and visualizations used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.

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