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International Journal of Current Research
Vol.3, Issue, 6, pp.069-073, June, 2011

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

INCREASING TREND OF CARBON MONOXIDE ALONG THE WEST COAST REGION IN INDIA

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ARTICLE INFO

Article History:
Received 29th February, 2011
Received in revised form
15th March, 2011
Accepted 15th May, 2011
Published online 2nd June 2011

Key words:
Air Pollution,
Air Quality,
Satellite data,
Seasonal Variation.

ABSTRACT

Carbon Monoxide is one of the prominent pollutant species mainly produced out of fossil fuel burning, motor vehicles and other industrial activities. Being a toxic trace gas, its impact to human health is a serious concern all over the globe. The rapid increase in Carbon Monoxide enhances the production of surface ozone which adds a pace to the global warming. This work is an attempt to retrieve the seasonal variation of the vertical profile of Carbon Monoxide column at the prominent hotspots along the coastal belt of the Arabian Sea using MOPITT version 3 of level 2 data. A strong seasonal dependence of Carbon Monoxide abundance is observed and it is validated with global 3Dimensional chemical transport model for atmospheric composition. The increasing trend in the Carbon Monoxide column abundance is estimated at these sites and it is found that a sharp rise in the concentration of Carbon Monoxide has been observed at this region lying along the coastal region of the Arabian Sea where industrial activities are fairly weak compared to other regions in India.

INTRODUCTION

Atmospheric Carbon Monoxide (CO) is an important trace gas as it plays a decisive role in determining the oxidizing capacity of the atmosphere through its reaction with the OH radical (Logan, 1981; Kanakidou *et al.,*1999; Crutzen, 1998). It is a primary component of the biomass burning products and is also emitted as a result of various anthropological activities (Novelli *et al.,* 1998, Nedelec *et al.,* 2003). With its lifetime that varies from a few weeks to 2 months, CO is a good tracer of vertical transport. Three dimensional chemistry transport models indicate that a deep convection during the summer monsoon in the Indian subcontinent that can lift boundary layer pollutions to the Upper Troposphere leading to a plume of enhanced CO levels in the 400–150 hPa range (Lawrence *et al.,*2003). An increase in atmospheric CO concentrations could reduce the self cleansing ability of the atmosphere and thus modify its chemical, physical and climatological properties (Nishanth *et al.,* 2010. In the presence of nitrogen oxides, it is a precursor to the formation of tropospheric ozone (Ridley *et al.,*1992), which in turn leads to crop damage and human health problems through its effect on the respiratory system (Tager, 1993). Quite recently, CO poisoning during winter months was one of the serious public health problems in South East Asian region. Its dominance is considered to be the highest in the world, mainly due to the unique cooking systems being adopted in most of the houses and large scale biomass burning.

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Satellite remote sensing offers the best opportunity of exploring global measurements of tropospheric trace gases over extended periods of time. CO is one of the few tropospheric gases that can be successfully monitored from space at present time. In the past few years, global measurements of CO have been carried out by the Measurement of Pollution in the Tropical Troposphere (MOPITT) instrument (Drummond et 1992 and 1996). In the context of growing abundance of CO concentrations, an attempt has been initiated to explore the seasonal variation of CO along the coastal belt of the Arabian Sea in the Indian subcontinent This paper describes the primary results of this study which mainly focuses on the seasonal variation of CO column at the prominent hotspots sites in this region and to explore the seasonal changes of its vertical profiles by using MOPITT data. The results are further validated by using global 3Dimensional chemical transport model for atmospheric composition (GEOS-Chem NRT). This study has been carried out at the Department of Atmospheric Science, Kannur University, India by continuously retrieving MOPITT sensor data supplied by NASA since November 2009.

LOCATIONS OF THE STUDY

Trivandrum

Trivandrum (76.95^{0}E, 8.51^{0}N) is the capital and most populous city of Kerala. It is located on the west coast of India near the extreme south of the mainland. The city has a tropical monsoon climate. As a result it does not experience much distinct seasonal changes. The mean maximum temperature is 34^0C and the mean minimum temperature is 21^0C. The humidity is high and will rise to about 90% during the monsoon season. Trivandrum is the first site along the path of the south west monsoon and gets rain from the receding north east monsoons which hit this city in October. December, January and February are the coldest months while March, April and May are the hottest.

Calicut

Calicut (75.78^0E, 11.26^0N) is the third largest city in Kerala and it features a tropical monsoon. The city has a highly humid tropical climate with high temperature from March to May. The primary source of rain is the south west monsoon that sets in the first week of June and continues till September. The city also receives significant precipitation from the north east monsoon that sets in from the second half of October through November. The average annual rainfall is 3,266mm. The weather is quite ideal towards the ends of the year from December and January until March when the sky is clear and the air is crisp.

Mangalore

Mangalore (74.84^0E, 12.88^0N) is situated along the west coast of India and it is the chief port city of Karnataka. Mangalore is bounded by Arabian Sea to its west and the Western Ghats to its east. Summer and winter months in Mangalore experience similar temperate conditions with the average temperature ranging from 27^0C to 34^0C. The maximum average humidity is 93% in July and the average minimum humidity is 56% in January. Mangalore has a tropical monsoon climate and it is under the direct influence of the Arabian Sea branch of the south west monsoon. It receives about 90% of its total annual rainfall within a period of six months from May to October. The annual precipitation in Mangalore is about 4,242mm. The city experiences more precipitation than most urban centers in India, due to effect of the Western Ghats.

Goa

Goa (73.94^0 E, 15.28^0N) is India's smallest state by area and is located in the south west region of India known as Konkan. Goa is bounded by the state of Maharashtra to the north and by Karnataka to the east and south, while the Arabian Sea forms its western coast. Being in the tropical zone and near the Arabian Sea, Goa has a hot humid climate for most of the year. The month of May is the hottest coupled with high humidity. The monsoon rains arrive by early June and provide a much needed respite from the heat. Most of Goa's annual rain fall is received through the monsoon which last till late September. Goa has a short winter season between mid December and February. The locations mentioned above are indicated in figure.1

METHOD OF CO RETRIEVAL FROM MOPITT

MOPITT is on board the Terra spacecraft and it is flying in a sun synchronous polar orbit with an altitude of 705 km. Measurements of upwelling infrared radiation are performed in nadir view with a near global coverage within three days.

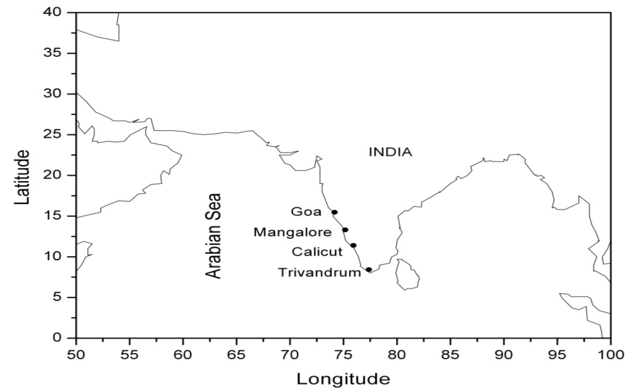


Fig.. 1. Location of the study area

CO vertical profiles (on 7 altitude levels) and the total columns are retrieved from the radiance data with a horizontal resolution of 22 x 22 km^2. MOPITT is equipped with gas correlation radiometers incorporating both length modulation and pressure modulation cells operating in two distinct spectral bands: the near-infrared (NIR) CO overtone band near 2.3µm and the thermal-infrared (TIR) fundamental band near 4.7µm. Conceptually, the NIR observations sense the attenuation (by CO molecules) of solar radiation reflected from the Earth's surface to the MOPITT instrument, whereas the TIR observations detect CO signatures in thermally emitted radiation from the Earth's surface and atmosphere. In principle, the NIR radiances provide information with respect to the CO total column with very weak sensitivity to the vertical distribution of CO, whereas the TIR radiances are sensitive to differences in CO concentrations over broad layers in the troposphere. Over land, where the surface reflectance and Near Infrared Radiances (NIR) are relatively high, the NIR radiances should provide more consistent sensitivity to CO concentration in the lower troposphere. The column (1000mb-100mb) abundance of CO at Trivandrum, Calicut, Mangalore and Goa has been retrieved from MOPITT data for a period of 9 years from 2001 and its monthly variations have been retrieved from the NASA website (http://eosweb.larc.nasa.gov/PRODOCS /mopitt/table_mopitt). From the seasonal variation profiles of CO are explored to analyse the trend of the abundance of CO over these locations in the Indian sub-continent.

RESULTS AND DISCUSSION

(a) Seasonal Variation Of Total Co Column

For the overall changes in CO concentrations over the 10 year period, a linear fit was applied to the monthly averaged data as shown in Figure 2. In addition, the mean values during the years 2001– 2010 were computed.

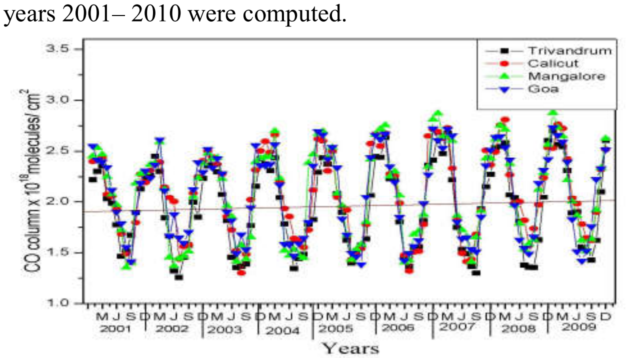


Fig. 2 Yearly variations of CO column at four locations

From the figure, a periodic variation of CO at all sites is observed and it shows an increasing trend over 2001-2010 which is observed from the linear fit marked by the straight line in the plot. One of the interesting features of this observation is that CO concentrations become higher during summer and winter months and reaches a minimum during the south-west monsoon period from June to September at all sites. To substantiate this further, whisker plots have been made to indicate statistical analysis at each location and they are depicted in figure 3 (a), (b), (c), (d). It is found that maximum variations of the CO column concentrations are noticed during summer and winter due to the hectic production and transport of this trace gas. During the monsoon period, the variation is quite small due to the loss in concentration by wet deposition. Being a tracer in the atmosphere that has an active role in the chemistry of ozone, the increase in CO over these spots lying along the coastal belt is a deep concern. The elevation of the abundance CO is mainly attributed to the increase in vehicles, burning of residues after the harvest and subsequent oxidation of methane from the abundant wetlands that surrounds these locations. The transport of CO over Arabian Sea plays a significant role in the variation of this trace gas in these locations. Subsequently, the dominance of marine air masses, coupled with rainy and unstable weather, leads to low levels of CO (and other trace gases) in summer. Pollution-laden continental flow from the north, in conjunction with the stable and warm weather in fall contributes to the CO maximum concentration in winter.

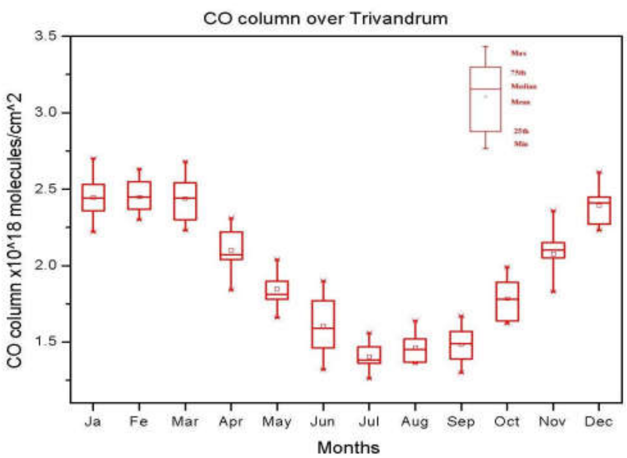


Fig. 3 (a) Whisker plots of the seasonal variation of CO over Trivandrum

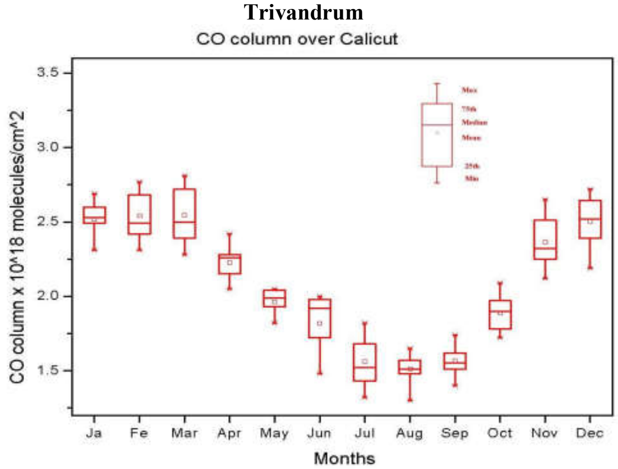


Fig. 3 (b) Whisker plots of the seasonal variation of CO over Calicut

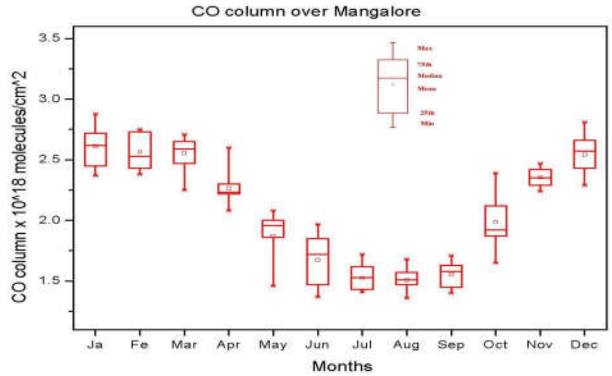


Fig. 3 (c) Whisker plots of the seasonal variation of CO over Mangalore

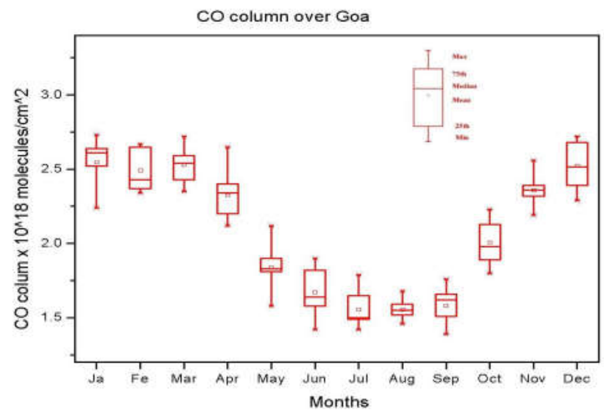


Fig. 3 (d) Whisker plots of the seasonal variation of CO over Goa

Yearly average scatter plots of CO over these locations are shown in the figure 4 to illustrate the year wise increase of total CO column. From the figure, it is clear that the CO increase is higher at Mangalore than all other locations. This may be due to the increased industrial and anthropogenic activities.

(b) Frequency Distribution of Total CO Column

To substantiate frequency distribution of total observed data of CO column at these locations, pie diagrams indicating the percentages of data falling at different ranges are shown in figure 5 (a), (b), (c) and (d).

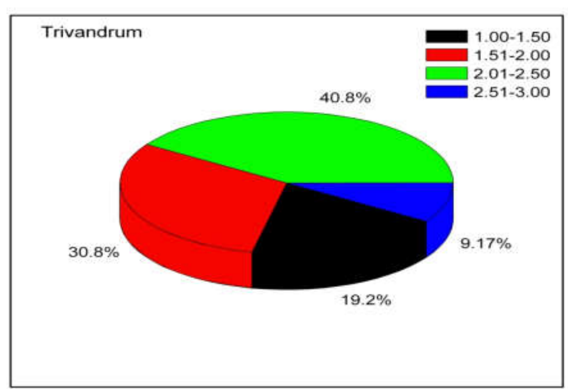


Fig. 5. (a) Percentage of frequency distribution of CO over Trivandrum

About 40.8% of total observed CO data are falling in the range between 2.01 and 2.5 x 10^{18} mol/cm^2 at Trivandrum and 9.17% are confined within the range from 2.51 to 3 x 10^{18} mol/cm^2.

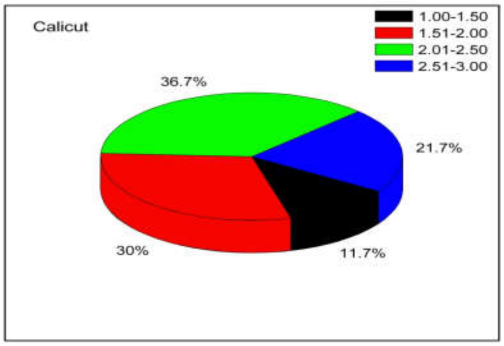


Fig. 5 (b) Percentage of frequency distribution of CO over Calicut

At Calicut, 36.7% of the total observed data of CO column are found in the range between 2.01 and 2.5 x 10^{18} mol/cm^2 and 11.7 % are within the range from 1 to 1.5 x 10^{18} mol/cm^2.

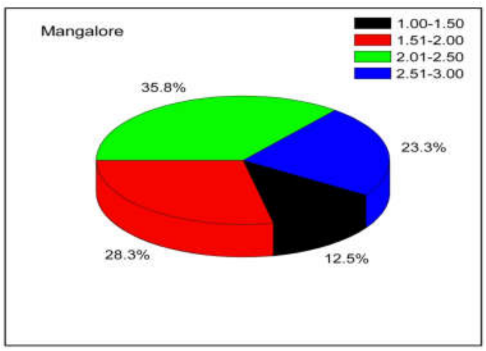


Fig. 5 (c) Percentage of frequency distribution of CO over Mangalore

But at Mangalore 35.8% of the total observed data of CO column are in the range between 2.01 and 2.5 x 10^{18} mol/cm^2 and 12.5 % are within the range from 1 to 1.5 x 10^{18} mol/cm^2.

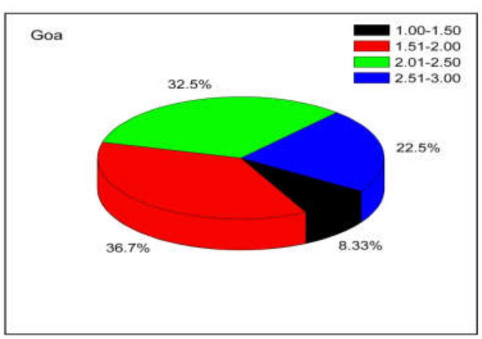


Fig. 5. (d) Percentage of frequency distribution of CO over Goa

At Goa, 32.5 % of the total observed data of CO column are in the range between 2.01 and 2.5 x 10^{18} mol/cm^2 and 8.33 % are within the range from 1 to 1.5 x 10^{18} mol/cm^2. From these pie diagrams, it is obvious that maximum percentage of frequency in the range between 2.01 and 2.5 x 10^{18} mol/cm^2 is observed at Trivandrum and minimum percentages of frequency in the range 1 to 1.5 x 10^{18} mol/cm^2 are observed at all locations except at Trivandrum.

(C) Vertical Profile of CO Column

The seasonal variation of the vertical mixing profile of CO during 2001-2010 is shown in figure 6. It is found that mixing ratio is high on the surface and it gradually reduces with height from the surface with a lowest value at a height of 15 km. The mixing ratio is high intense during winter season and weak during monsoon period. The maximum mixing ratio of CO in winter months is attributed to the lower planetary boundary layer and relatively low humidity occurring in this period. This increase in the CO concentration during winter is the main reason for the enhanced production surface ozone to a level of 50 ppbv over these locations than in the summer time at which the maximum ozone mixing ratio is 45 ppbv (Nair *et al.,*2002, Londhe *et al.,*2008). Subsequently, this enhancement of surface ozone can result in the photochemical fog formation.

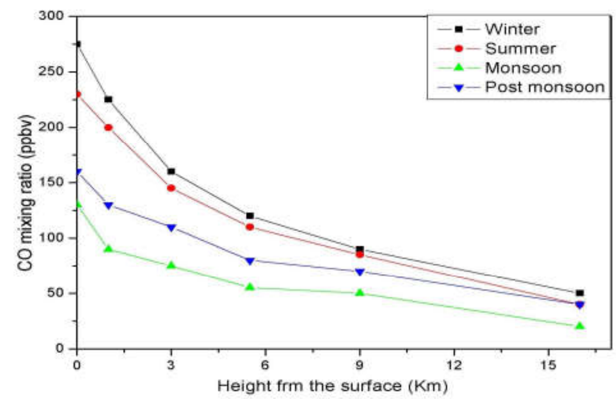
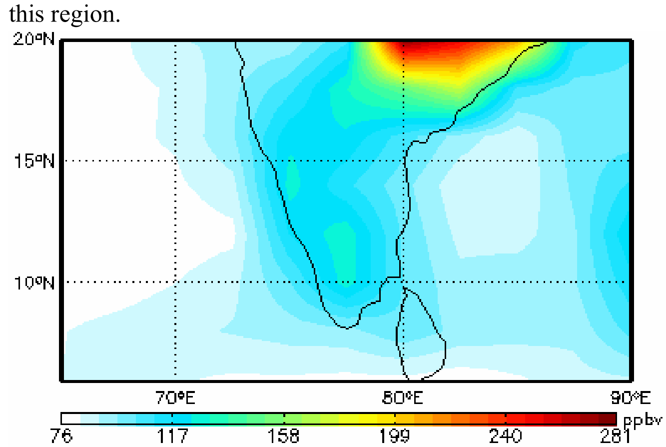
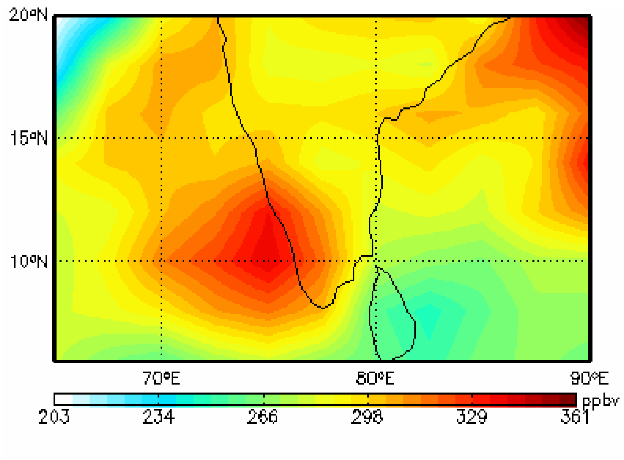


Fig. 6. Seasonal variation of the vertical profile of CO mixing ratio during 2001-2010

This is substantially furthered by the GEOS-Chem NRT simulations (http://coco.atmos.washington.edu) and the real time model is created during the winter and summer months in south India where these locations are situated. Fig. 7 shows the results of the model and it is found that the winter time mixing ratio of CO is higher than that is in the summer time during all years of observation. This finding further supplements our observation of the seasonal anomaly of the mixing of CO over this region.



(a)



(b)

Fig. 7. GEOS-Chem NRT model showing the seasonal variations of CO over this region (a) In summer months and (b) In winter months

Conclusion

The seasonal variation of CO in the prominent hot spots in south India has been analyzed with the aid of MOPITT data from 2001 to 2010. It is found that the CO mixing ratio has a strong dependence on the seasonal changes in the atmospheric and geographical parameters at these locations. The annual increase in CO column is high at Mangalore and low at Trivandrum. CO concentration has shown an increasing trend during 2001-2010 which is mainly attributed to the enhanced industrial activities, biomass burning and the increasing number of vehicles in these locations. The vertical profiles reveal that the mixing ratio is higher during winter than it is in summer at all locations. It is further observed that south-west monsoon has a significant impact on the wet deposition of CO over this region. Attempts are in progress to estimate the influence of marine pollution on the variability of CO concentration over this region and to understand the transport and dispersion in the context of enhanced ship traffic through the Arabian Sea.

Acknowledgement

This programme is carried out under the consistent financial support of ISRO-GBP through their AT-CTM programme. Authors wish to register their thanks to NCAR, USA for their valuable advice in providing the retrieval algorithm for MOPITT data.

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