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Observed local enhancements in Atmospheric Carbon Monoxide during Biomass Burning Events

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ABSTRACT

An attempt is made to present the observed enhancements in atmospheric carbon monoxide (CO) associated with local biomass burning events at a tropical coastal environment Thiruvananthapuram (8° 29′ N, 76° 57′ E) and with approximations to compare these epochs with empirical estimates. An IR analyzer (Monitor Europe 9830B) was used for the continuous CO monitoring. CO emitted from two massive biomass burning events, including fresh biomass and dry biomass burning near the measurement site, ~200 m were measured and estimated empirically. CO measured using the analyzer showed about 30- fold and 27- fold enhancements compared to normal days. Emperical estimates of CO showed 0.287 kg/m^2 CO emission on fresh biomass burning and 0.198 kg/m^2 on dry biomass burning. Enhancement in CO during two grassland burning events occurred at a high altitude location about 20 km from the measurement site were studied and about 1.5 fold and 1.4 fold enhancements in CO respectively were observed. Local enhancements in CO during massive biomass burning in open associated with religious festivals were also investigated in the present study.

INTRODUCTION

Biomass burning is a major source of trace gases such as carbon monoxide (CO), methane (CH_4), nitrous oxides (NO_x) and hydrocarbons in the troposphere (Crutzen & Andreae 1990, Crutzen et al., 1985). The gaseous pollutants and particulate matter released from biomass burning into the atmosphere can alter the atmospheric radiation budget and contribute significantly to the uncertainty in climate change. Biomass burning includes human initiated fires of vegetations for land clearing and land-use change as well as natural fires such as those in forests, lightning induced etc. About 90% of global biomass burning is human initiated. These fires have both short-term and long-term impacts on the atmosphere.

Biomass burning is one of the main sources of CO emission in the tropics. Incomplete burning of massive biomass associated with grassland burning, forest cleaning and religious festivals results in local and temporal CO enhancement. CO emission from biomass burning including forest fires is considered to be accountable for 30% of the total CO emission in the globe. Carbon monoxide is the third most abundant carbon based trace gas in the atmosphere, after carbon dioxide and methane. The largest sources of CO in the global atmosphere are combustion processes and the oxidation of hydrocarbons. More than half of all CO emissions are considered to be man-made. The main sources of man-made CO emissions include biomass burning and fossil fuel use (followed by oxidation of hydrocarbons and oxidation of methane). All forms of biotic material burning at insufficient oxygen levels produce CO in excess.

Even though CO is a weak greenhouse gas, it affects the oxidizing capacity of the Earth's atmosphere through its reaction with hydroxyl radicals (OH), a significant tropospheric sink for strong green house gases. As a precursor of tropospheric ozone, CO substantially affects the budget of ozone, which is one of the important constituents in the troposphere (Jane et al., 2005). Since CO has a relatively long lifetime in the atmosphere (between about 2 weeks and 2 months (Novelli, Masarie Lang 1998)), it can be used as an important pollution tracer. Increased levels of CO affects human health, which reduces the amount of oxygen carried by haemoglobin around the body in red blood cells, affecting the nervous tissues, heart, brain etc. (U.S. Environmental Protection Agency (EPA), 1995)

Several recent studies (Eric, Lori & Bruhwiler 2002) have reported high CO emission from massive biomass burning. Only emperical relationships exist now between high CO and the quantity of biotic material burned. Joao et al., 1998 estimated the amount of carbon released into the atmosphere from biomass burning associated with a forest clearing experiment. Naseema Beegum et al., 2008 reported an enhancement in carbon monoxide during a mountain grassland fire at Ponmudi (8.75°N, 77.1°E), near Thiruvananthapuram. They reported an enhancement in CO by a factor of ~1.5 at the measurement site ~ 20 km away from the burning site, the present work was carried out at the above-mentioned measurement site. Ambient atmospheric CO at this coastal site (Thiruvananthapuram (8° 29′ N, 76° 57′ E)) was continuously monitored since 2003. The present work describes the enhancements in CO during massive biomass burning associated with cleaning processes, grassland burning and religious festivals.

INSTRUMENT AND DATA ANALYSIS

Instrument

CO in ambient air was monitored continuously using a non-dispersive infrared analyzer (Monitor Europe Model 9830B). The analyzer measures CO concentration in ambient air by the non-dispersive spectroscopic absorption at 4.6μm. A gas filter correlation wheel rejects the interferers in the air sample and the narrow band-pass filter measures the CO sensitive IR wavelengths. It measures CO from 0-200 (parts per million by volume) in 4 ranges, with 0–50 as the default range and has an auto-ranging facility. The lowest CO level detectability is ~10 ppb full range and the accuracy of measurement is 1% of measured value in the lowest range. This instrument is internally calibrated against a known source of CO gas that is traceable to the National Institute of Standards and Technology, USA. A data interval of 5 min. was selected considering the response of ambient air to changes in wind speed and direction, location of the instrument, storable duration in the analyser memory module and the data length. More details are available elsewhere (Mohan Kumar, Sampath & Jeena 2004).

Data Analysis

The amount of a specific trace gas released during biomass burning fires (E_t) can be estimated as

$$E_t = C_t * E_{fs} \qquad .... (1)$$

Where C_t is the total carbon emitted and E_{fs} is the emission factor (in weight of gas released per weight of carbon burned) for the gas species.

Total carbon release through biomass burning (Ct) can be estimated (Seiler and Crutzen 1980) as

$$C_t = ABf_cb \qquad .... (2)$$

Where A is the total area burned (ha), B is the biomass density (t ha^{-1}), f_c is the fraction of the biomass that is carbon, and b is the fraction of biomass consumed (or combustion efficiency) during biomass burning.

The nature and amount of the combustion products depend on the characteristics of both the fire and the biomass material burned. Two types of combustion were considered when estimating emission factors: flaming and smoldering. Flaming phase of the fire approximates the complete combustion, while smoldering phase approximates the incomplete combustion. Smoldering combustion is less efficient than flaming combustion, resulting in greater production of CO, methane (CH_4), and a variety of non-methane hydrocarbons (NMHCs) and lower emissions of carbon dioxide (CO_2). But flaming produces mostly carbon dioxide with little CO, CH_4, and NMHCs. In this study we have assumed combined flaming and smoldering combustion.

DESCRIPTION OF THE EVENTS

Biomass burning as a part of campus cleaning

Massive biomass burning was carried out as a part of the campus cleaning at a coastal site, Thiruvananthapuram (8° 29′ N, 76° 57′ E) during winter (January 2006). The main burning practice was carried out on January 23rd 2006. Fresh leaves and twigs were burned in 11 units of circular patches each with a diameter of 1m & height of 0.2m. The burning started at about 07:00 h on January 23 2006 and continued till ~17:00 h. Dry leaves and twigs were burned one week after the main burning on January 29, 2006 at the same location, where the fresh biomass burning practices were carried out. During these burning practices, the CO analyzer was located at 200m away from the burning sites.

Mountain grassland fire

Wide grassland fire occurred at Ponmudi (8.75°N, 77.1°E, and 915m msl) that is a high altitude location in Western Ghats in December 2006 and also in March 2008. The fire outbreak occurred at around 16:00h local time on December 15, 2006 and completely extinguished by 11:00h on the next day. About 54 hectares of grassland was burned during this event. Another grassland fire occurred at the same site on March 9, 2008 that burned about 10 hectares of grassland. The burning sites were ~20 km away from the coastal measurement site.

Pongala

Pongala is a south Indian religious festival associated with massive biomass burning in open places. This festival occurs in the months of February-March in every year. In this paper we present the enhancement in CO during the *Pongala* days in 2004 and in 2007. During the *Pongala* in 2004 the enhancement in CO at the burning site, located 2 km away from the coast was monitored. The CO analyzer was operated at 100 m away from the burning site. In 2007, CO measurements during *Pongala* were carried out at a valley region, which is about 7 km away from the coast and the CO analyzer was operated ~3 km away from the burning site.

Prevailing meteorology at the measurement site

The prevailing winds at this coastal site are the sea breeze and the land breeze. At the measurement site, till 08:00 h, the winds are esterly (90^0). From 08:00h to 20:00h, when the sea breeze is operational the winds are westerly (270^0). Sea breeze becomes stronger in the afternoon period, and weakens by sunset. The land breeze sets-in during 20:00-22:00 h and continues till next morning. A change in wind direction brings fresh air over the site and this affects the gaseous pollutant distribution. Mohan Kumarm, Sampath & Jeena 2004 revealed that the change in wind direction from esterly to westerly and from westerly to easterly coincide with the CO enhancements at the measurement site. Miller et al., 2003 revealed that the land and sea breeze have important implications for coastal meteorology, air quality, and pollutant dispersal in coastal regions.

RESULTS AND DISCUSSION

CO diurnal pattern at Thiruvananthapuram shows two peaks, morning peak at around 07:00- 09:00h and evening peak at around 20:00- 22:00h. These peaks are attributed to the onset of sea breeze and land breeze respectively along with the Atmospheric Boundary Layer (ABL) height variations (Mohan Kumar, Sampath & Jeena. 2004).

Figure 1 shows CO diurnal pattern from 22 - 24 January 2006, including the day with fresh biomass burning (23rd January 2006) near the measurement site. CO diurnal pattern on 22nd January shows a clear two peaks pattern with an average of 0.284ppm, similar to normal days in the winter. A considerable enhancement in CO was observed on 23rd January 2006, compared to the previous as well as the successive days. On 23rd January 2006, the morning peak occured at around 08:00 h and the CO levels started decreasing as a part of the normal diurnal forenoon peak. Soon after, CO from the burning sites kept the CO high from about 08:15 h, which is substantial at 14:00 h and CO continued to be high till the next morning (24th January 2006), 03:00 h. A 30-fold enhancement in CO was observed on 23rd January (6.16 ppm average), compared to a normal day in winter (0.206 ppm average). High CO during fresh biomass burning were persisted for 14 h. Burning of dry biomasses on January 29, 2006 yielded a 27-fold enhancement (5.74 ppm average) in CO compared to normal days in winter (Fig.2). High CO emitted from dry biomass burning persisted for 18 h. CO concentration from January 15 , 2006 to January 31, 2006, including the burning days is shown in Fig 3.

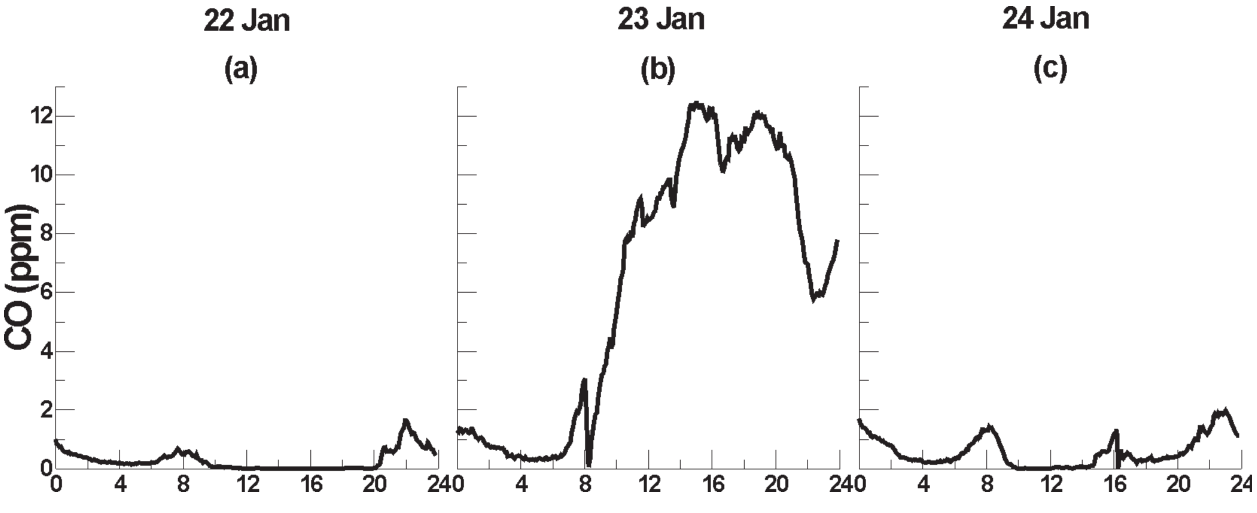

Figure 1. Diurnal variation of CO from 22nd to 24th January 2006 in panels respectively from left to the right.

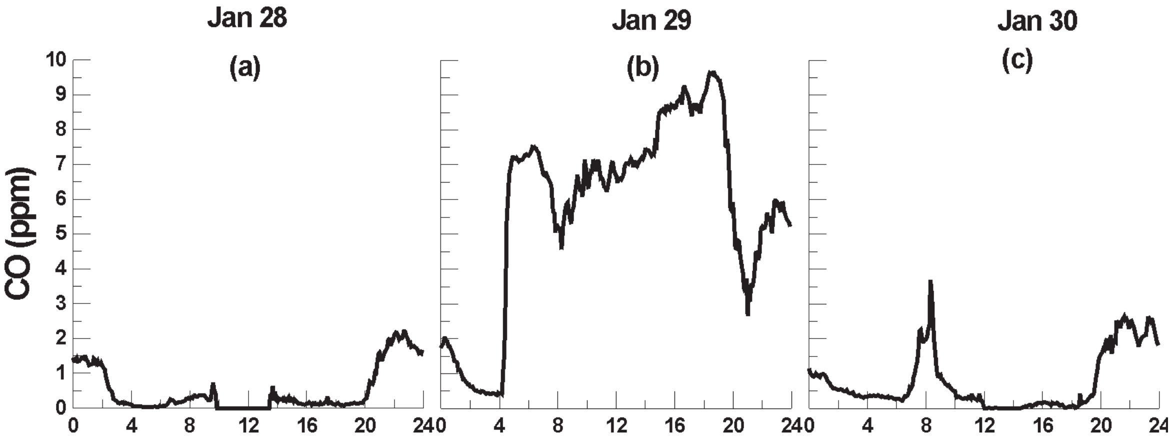

Figure 2. Diurnal variation of CO from 28th to 29th January 2006.

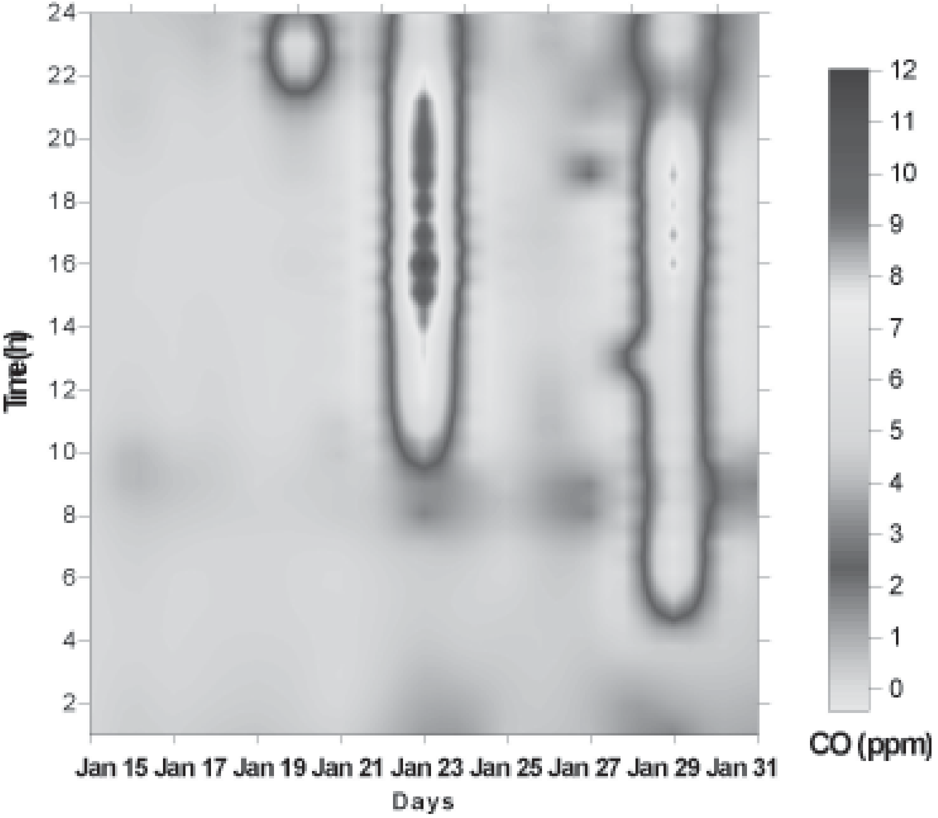

Figure 3. A 17-day CO concentration including the biomass burning days.

Table 1. Empirical estimates of CO

Biomass burning days	Area burned A (m2)	Biomass density B (kg/m2)	C fraction in biomass	CO Emission rate (kg/m2)	Persistence of CO (h)
23 Jan 06	8.635	55	0.4	0.287	14
29 Jan 06	8.635	30.19	0.5	0.198	18

Table 1 shows the empirical estimate of CO during 23rd January and 29th January 2006. As combined flaming and smoldering combustion were considered, CO emission factor is E_{fco} = 26.2 g/Kg [U.S. Environmental Protection Agency (EPA), 2002]. Combustion efficiency b was assumed to be 0.5. Carbon fraction in biomass (f_c) for dry biomass was taken as 0.5, as it contain 50% weight by carbon. According to Hewitt & Andrea 2003, fresh biomass materials contain only about 40% carbon by weight (with the remainder hydrogen (6.7%) and oxygen (53.3%). Empirical estimate of CO showed 0.287kg/m^2 and 0.198kg/m^2 CO emission from fresh biomass burning and dry biomass burning respectively.

CO measured and estimated were high during fresh biomass burning compared to dry biomass burning due to high smoldering combustion, unlike high flaming combustion on dry biomass burning (Fig.4). From Figure 1 & 2 it is seen that, the high CO on the burning day did not persist on the successive days due to the strong dispersal at this coastal site. As the burning was about 3 km from the coast, the land and sea breeze activities were strong and cause faster dispersion of gaseous pollutants like CO. High CO on 23rd January started to decrease at the time of strong sea breeze, 20:00h. A similar fall in high CO level around the same time was seen on 29th January 2006. The strong sea breeze at the burning site caused faster dispersion of CO during the two burning events.

Figure 5 depicts the diurnal CO pattern from14th-16th December 2006 as well as the massive enhancement in CO during the grassland fire at Ponmudi (15th December 2006). The fire outbreak occurred at around 16:00 h and continued till 11:00h on the next day (16th December 2006). CO at the measurement site started rising at around 17:15h and the increase was quite substantial by 18:00 h. CO evening peak (~0.8 ppm) on the 15th December 2006 occurred at around 21:00 h (Figure 5), which was more than double the peak values on the normal days (Dec 14, 2006). A 1.7 fold CO enhancement occurred during the grassland burning on 15th December 2006. High CO remained till the early morning hours of 16th December 2006 due to low wind speed and low boundary layer height during night (nocturnal boundary layer) compared to daytime (Kunhikrishnan et al., 1993). A high CO morning peak (0.767 ppm) occurred at around 08:00h on 16th December. As CO takes more time to disperse, the morning peak was quite broad (~ 3 hours) compared to corresponding peaks on other days. A 1.4 fold enhancement in CO occurred on 16th December. It was also observed that CO at the measurement site (~20 km away from the burning site) started rising within an hour of the fire outbreak in the hills. As the burning site was elevated with respect to the measurement site, the upwind of the strong sea breeze persisted during the evening hours of 15th December 2006, which transported high CO from the burning site to the coastal measurement site (Naseema et al., 2008).

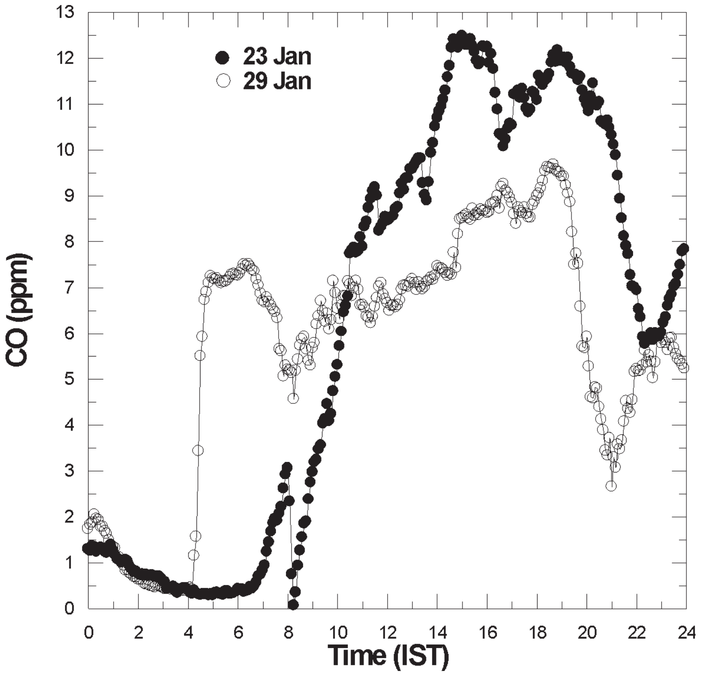

Figure 4. Diurnal variation of CO during 23rd and 29th January 2006.

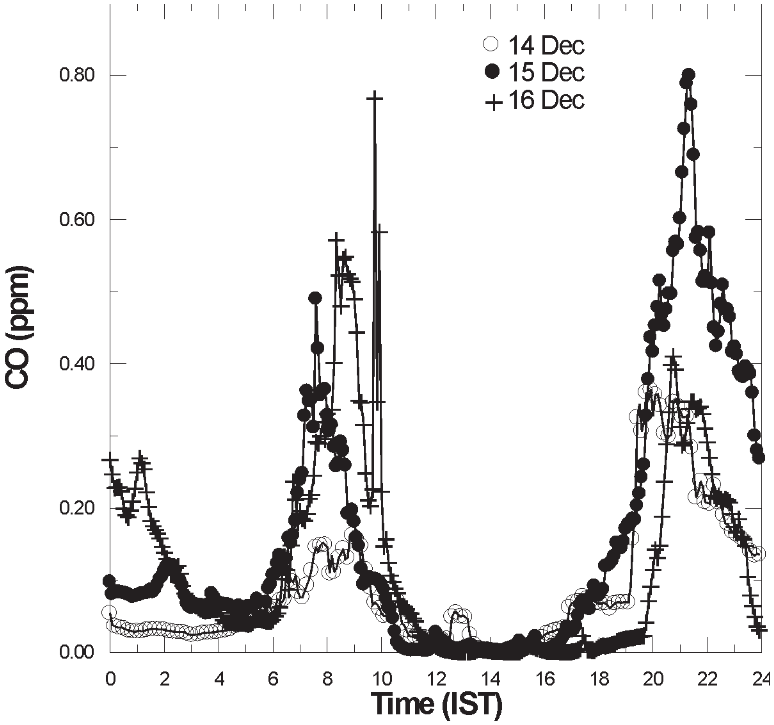

Figure 5. Diurnal variation of CO from 14th to 16th December 2006.

Another grassland burning occurred on 8th March 2008, at the same location, Ponmudi and it burned more than 15 ha of grassland. Impact of this grassland fire on CO persisted on the three successive days (9th-11th March 2008) of burning. All these days were cloudy with a heavy rain on 10th March 2008. The fire out break occurred during the evening hours on 8th March. Enhancement in CO was observed at the measurement site during the early morning hours on the next day of burning (9th March 2008) and continued till 11th March 2008. A high CO enhancement was observed on 11th March compared to previous days. Enhancements of 1.4 fold CO (avg = 0.219 ppm) on 9th March, 1.3 fold CO (avg = 0.199 ppm) on 10th March and 2.47-fold CO (avg = 0.386 ppm) on 11th March 2008 (Fig.6) were observed respectively.

Figure 6 shows that CO concentration at the measurement site start increasing near to 01:00h on 9th March, with a peak (0.421 ppm) at around 03:10h. High CO was observed during the morning hours on 09th March compared to the previous day. CO diurnal pattern on 09th March 2008 showed a high morning peak (0.914 ppm) at around 08:59h, there after it decreased to a steady low value, that continued till the evening hours and showed a broad evening peak (0.376 ppm) close to at 23:00h. Diurnal CO pattern on 10th March showed low CO during daytime with a subdued morning peak (0.266 ppm) and ~ 0.003 ppm close to at 14:30h, due to heavy rain during the morning hours. CO during the late evening hours of the same day was found to be high (1.14 ppm) at around 23:50h. This high CO persisted till the early morning of 11th March, with a peak (1.37ppm) at around 01:50h due to the cloudy atmosphere after the heavy rain on 10th March 2008. A morning peak of 0.756ppm close to 09:40 h and low CO concentrations (0.149 ppm) during the after noon hours was also seen in Figure6. It was seen that the high CO from the grassland burning on 8th March persisted only up to 11 March and a normal CO concentration was observed on the successive days.

High wind speed along with the return flow of sea breeze transported the emitted CO from the high altitude source location to the coastal measurement site during the grassland burning on 15th December 2006. Transport of CO during the grassland burning at the same site on 8th March 2008 was attributed to the sea breeze along with the meteorological conditions like rainfall, low temperature due to cloudy atmosphere etc. on the successive days of burning.

Figure 7 shows the CO diurnal pattern on *Pongala* and a normal day in 2004. A 1.6 fold increase in CO

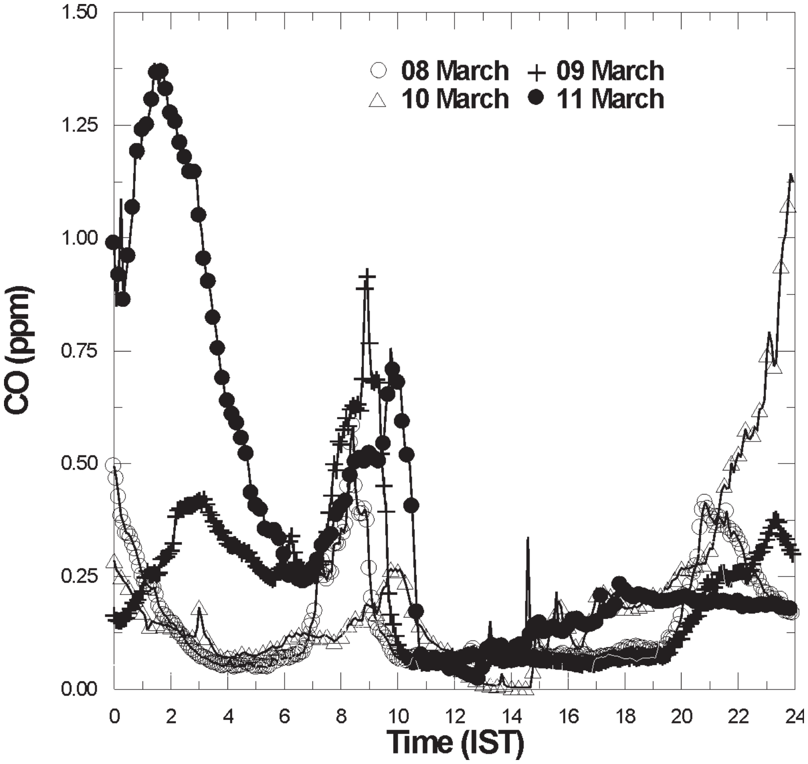

Figure 6. Diurnal variation of CO from 8th to 11th March 2008.

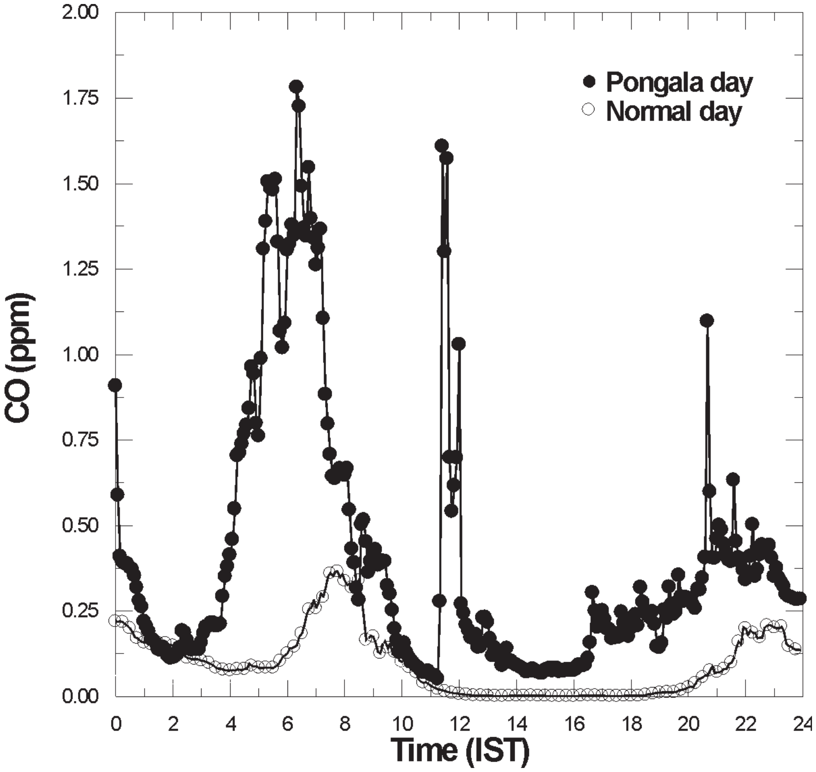

Figure 7. Diurnal variation of CO during *Pongala* and a normal day in 2004.

was found on 6th March 2006 (Pongala day). CO concentration was high on the previous day of *Pongala* (5th March 2006) due to heavy traffic and burning practices as a part of cleaning processes at the *Pongala* site. Since the nocturnal boundary layer traps the gaseous pollutants low to the ground, CO during the late evening hours of 5th March and the early morning hours on 6th March were found to be high. CO morning peak on 6th March occurred at around 08:45h was also high due to the transport of high CO, which accumulated on the previous day. Burning process started at around 11:15h and continued for one hour. CO level at the burning site was found to increase at around the same time and reached maximum of 1.6 ppm close to at 11:25h, there after it decreased to a steady low value during the noon time. As the sea breeze become stronger during afternoon hours, CO during the late afternoon hours started to increase at around 16:40h and continued to be high till the next day morning (02:00h) with an evening peak of 1.09ppm close to 20:40h.

High CO emitted during *Pongala* persisted for the successive days. From Figure 8 it is seen that CO was high on 7th March and on 8th March 2004. On normal days CO during noon hours are nearly zero (~0.001ppm), but CO during noon hours on the successive day of *Pongala* was ~0.16 ppm. A normal CO diurnal pattern was seen on 9th March 2004 with

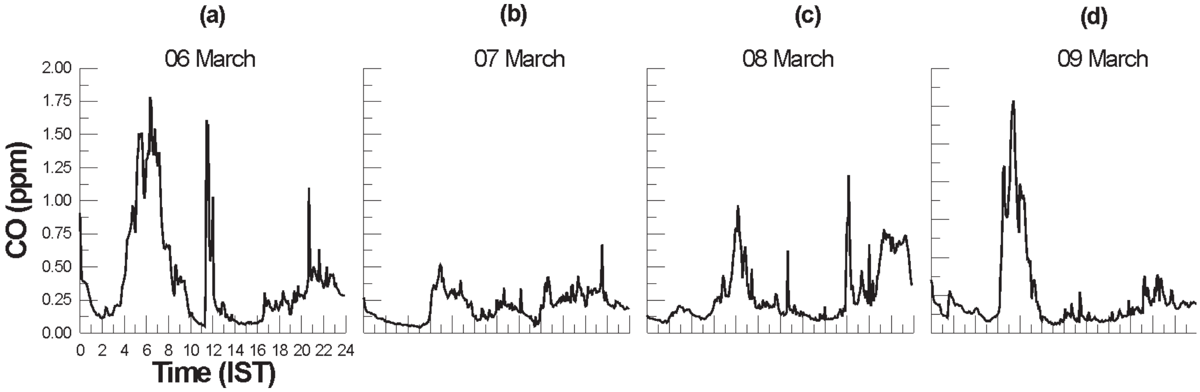

Figure 8. Diurnal variation of CO from 6th to 9th March 2004 in panels respectively from left to right.

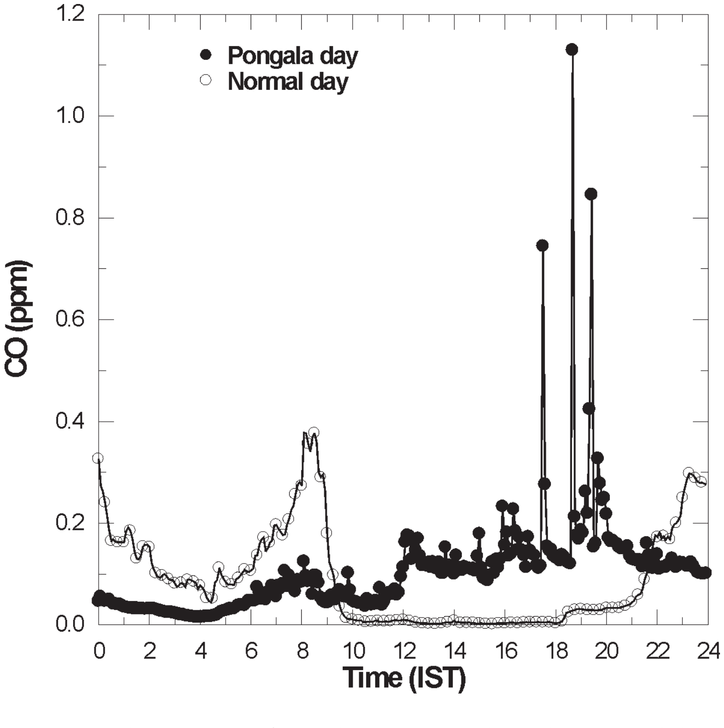

Figure 9. Diurnal variation of CO during *Pongala* and a normal day in 2007.

high morning peak (~1.8 ppm) due to high CO concentration during the previous night (Fig.8). Since the burning carried out in a dry month (March), the presence of local wind effects was less compared to other seasons. This leads to the persistence of CO at the burning site for two more days from the burning day.

CO enhancement during *Pongala* in 2007 is shown in Fig.9. A factor of 1.2 times increase in CO was observed on 3rd March 2007 (*Pongala* day) compared to the previous day. A morning peak with 0.124 ppm was seen close to at 08:05h. Burning started at around 11:00h and a small increase in CO (0.17ppm) was seen from 12:15h and sharp peaks with 0.744 ppm at 17:30h, 1.22ppm at 18:40h and 0.845ppm at 19:25h respectively. Enhancement in CO occurred one hour after the burning (11:00h-12:00h) possibly due to the absence of wind at the burning site (7 km from the coast in a sloping terrain) and due to the large distance between measurement site (3 km from the burning site) and *pongala* site. High CO produced from this burning remained till 4th March 2007, the successive day of *Pongala*. Diurnal CO pattern on 4th March 2006 (Figure 10) showed morning peak with 0.418 ppm close to at 08:15h, ~0.122 ppm during noon hours, and small peaks (~0.45ppm) during heavy traffic hours (17:30-18:00h). CO on 4th March 2006 was found to be high as compared to a normal day on the same week (Figure 8).

High CO produced during the *Pongala* in 2007 persisted only for one day (4th March 2007), the successive day of *Pongala* (3rd March 2007) but during the *Pongala* in 2004, emitted CO persisted on three successive days of *Pongala*. This may due to the topography as well as the existing winds at the burning sites.

CONCLUSIONS

Enhancements in CO during biomass burning associated with campus cleaning, grassland burning and religious festivals (*Pongala*) were studied. We estimated CO emission from the first mentioned event. A 30- fold enhancement in CO was inferred on fresh biomass burning (mean CO= 6.16 ppm) while a 27-fold increase in CO (mean CO=5.74 ppm) was seen on dry biomass burning compared to a normal day in winter (mean CO=0.206 ppm). Empirical estimates of CO showed 0.287 kg/m^2 emission from fresh biomass burning and 0.198 kg/m^2 from dry biomass burning. CO measured and estimated were both high on fresh biomass burning compared to the dry biomass burning. The highs in CO did not persist on the successive days of burning due to strong dispersal by the sea and land breeze at this coastal site. A 1.7-fold CO enhancement was seen at this site during the grassland burning at Ponmudi on December 15, 2006 and the impact of this grassland fire persisted for a day. Grassland fire burning at Ponmudi on March 8, 2008 caused ~1.4 fold CO increases and CO enhancement persisted for 3 days. This may possibly due to the presence of cloudy sky and drizzle during the day of burning and on the successive days. Sea breeze circulation along with the prevailing winds could have caused the transport of CO emitted from the grassland burning at a high altitude location to the coastal measurement site, which situated at about 20 km from the source region. A considerable enhancement in CO was also found during *Pongala* festivals. Enhancement in CO measured by the analyzer, about 100m from the burning site (2 km from coast) during *Pongala* in 2004 was 1.6 ppm around the same instant of burning and this high CO persisted for three successive days of *Pongala*. A 1.2 fold CO enhancement was observed at ~ 3 km from the *Pongala* site (~7 km from coast) during the *Pongala* in 2007 and this high CO were persisted only for one day. The persistence of CO throws light into the dynamics of air and it was observed that residence time of CO emitted from biomass burning in open depends on the topography as well as the existing wind regimes in the vicinity of the burning site.

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