Comparisons of Carbon Monoxide Measurements using Aircraft and Model Data

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Abstract:

Carbon Monoxide (CO) is an important trace gas species in the atmosphere and is chiefly produced from biomass burning and transportation emission. CO is one of the few tropospheric gases that can be monitored and simulated successfully using aircraft, satellite and Chemical Transported Models (CTM). In this present study, comparisons of CO observations are made between aircraft and model run to evaluate the performance of the model. Measurement of Ozone and Water vapor by In-Service Airbus Aircraft (MOZAIC) aircraft CO data for the month of July 2004 has been used to compare with the Global Modeling Initiative (GMI) CTM model. As the current GMI run does not include emissions from biomass burning on-line GEOS-GOCART model has been used to include biomass burning emissions. Both the along track and vertical profiles over individual cities show GMI CO observations are in good agreement with the aircraft values. Despite the fact that aircraft measurements are point data, while model simulations represent individual grid sizes with larger resolution, model is capable of observing the variations of CO at tropopause, enhanced CO layer over India due to convective transport during monsoon season. However, the model underestimates CO when an enhanced layer of transported CO from biomass burning area are present over cities.

Introduction:

Atmospheric Carbon Monoxide (CO) is an important trace constituent as it plays a critical role in determining the oxidizing capacity of the atmosphere through its reaction with the OH radical (Kanakidou and Crutzen, 1999; Kar et al., 2004). Increase in CO concentrations can reduce the self-cleansing ability of the atmosphere and modify its chemical, physical and climatological properties (Edwards et al., 2004; Ridley et al., 1992). It is one of the six EPA criteria pollutants because of its adverse effects on public health or welfare. In the presence of nitrogen oxides, it is precursor to tropospheric ozone, which is another EPA criteria pollutant (Stavrakou and Muller, 2006). It is a primary component of biomass burning products and is also emitted by various anthropological activities (Andreae and Merlet, 2001). Secondary chemical sources are due to hydrocarbon oxidation are relatively important in the remote Southern Hemisphere (SH) (Granier et al., 1999; Edwards et al., 2004). With about a two-month lifetime, CO can serve as a useful tracer of atmospheric transport and used as important component in 3-D chemistry transport models (Ho et al., 2005). Kar et al., (2004) reported Asian summer monsoon plume in CO observed over India and China in the upper troposphere (UT) indicating the effect of deep convective transport during monsoon. By using measurements from the newly available National Aeronautics and Space Administration (NASA) Aura Microwave Limb Sounder (MLS), along with observations from the Aqua and Tropical Rainfall-Measuring Mission satellites (TRMM), Fu et al., (2006) established that the Tibetan Pleatue provides the main pathway for cross-tropopause transport of water vapor and CO to stratosphere in Asia than over the monsoon region. More recently Schoeberl et al., 2006, identified stratospheric “tape recorder” of CO, which is unlike the water vapor tape recorder, linked to seasonal changes in biomass burning.

CO has been measured at a network of ground stations as well as from aircraft (Novelli et al., 1998; Nedelec et al., 2003). The Measurement of Air Pollution from satellites (MAPS) instrument observed CO in space shuttle flights in 1984 and 1994. (Shindell et al., 2005). More recently, the Measurement of Pollution in the Troposphere (MOPITT) instrument on the Terra satellite has been observing CO since 2000. Considering the importance of CO, it has been measured by aircraft, satellite and used in

3-D Chemical Transport Model (CTM) as an important constituent. In this present study comparison between these CO observations has been done to provide useful information about the variation of CO over an area. The present study is restricted for comparison of CO using MOZAIC aircraft and Global Model Initiative (GMI) 3-D CTM observations.

Data:

Measurement of Ozone and Water vapor by In-Service Airbus Aircraft (MOZAIC) program started in 1993 by European scientists to measure atmospheric composition and also to understand influence human activity over atmosphere particularly the effects of aircraft. MOZAIC consists of automotive and regular measurements of Ozone, Carbon Monoxide, Water Vapor and Nitrogen Oxide by instruments deployed abroad long range passenger airlines of the type AIRBUS A340-300. The measurements are taken at every 4 seconds and continued from takeoff to landing, resulting both along the track and vertical profile of gases. Vertical profiles are from surface to 10 km (~250hpa), while along track measurements are of cruising altitude of 12 km (~200hpa). Figure 1 shows a particular MOZAIC flight capable of measuring both CO and O_3 of both troposphere and stratosphere in origin. In the present study MOZAIC flight data from June to August 2004 are taken from ftp://code916.gsfc.nasa.gov/pub/atmos/Duncan/MOZAIC2004.

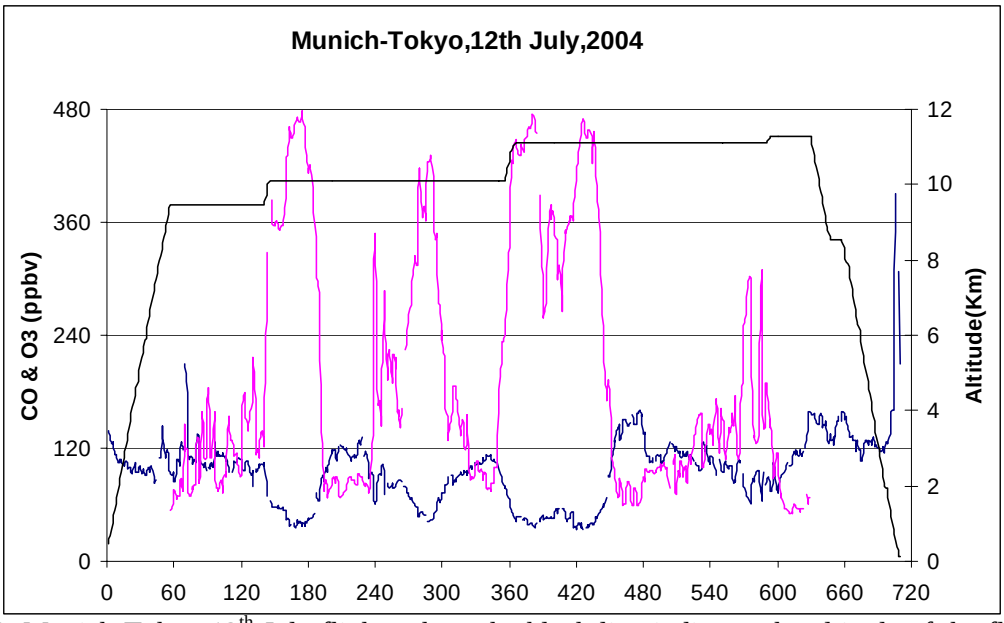


Figure 1. Munich-Tokyo 12th July flight, where the black line indicates the altitude of the flight, blue line is for the CO and pink is O_3 measured. It shows flight is able to take measurement of both troposphere and stratosphere CO and O_3, where high O_3 is measured over stratosphere

Global Modeling Initiative (GMI) was formed in 1995, is a 3-D Chemistry and Transport Model (CTM) to asses natural and anthropogenic perturbations on atmospheric composition and chemistry. GMI has developed a modular CTM with the ability to incorporate different components and inputs, such as meteorological fields, chemical and microphysical mechanisms, numerical methods, source gas emissions, and other modules representing the different approaches of current models in the scientific community, as well as carry out multiyear assessment simulations. It is an off-line transport model driven by meteorological fields (e.g. winds, temperatures) from GMAO (NASA Global Modeling and Assimilation Office) GEOS-4 data assimilation system. GMI has horizontal resolution of 2 X 2.5 degree with vertical extension from surface to 52 hpa (19 different pressure levels). In the present study, global GMI data from June to August 2004 are taken from ftp://dirac.gsfc.nasa.gov/pub/gmidata/gmic/GEOS4DAS/2004 and to focus on single species only CO data has been extracted for the time period.

The Goddard Chemistry Aerosol Radiation and Transport (GOCART) model simulates major tropospheric aerosol components, including sulfate, dust, black carbon, organic carbon, and sea-salt aerosols. The GOCART model uses the assimilated meteorological fields of the Goddard Earth Observing System (GEOS), generated by the Goddard Global Modeling and Assimilation Office (GMAO). It is on-line Global Circulation Model (GCM) run, where the transport takes place within the GCM that is initialized with assimilated fields. The GEOS-GOCART model has a horizontal resolution of 1 X 1 deg and 32 vertical layers. The major difference between GMI and GEOS-GOCART model used in this study is, in the GMI model run CO emissions from the forest fire is not included while in the second model emissions include biomass burning estimated using EOS Terra and Aqua MODIS fire counts. Dr. Joanna Joiner and Dr. Bryan Duncan of Atmospheric Chemistry and Dynamics at NASA Goddard provided MOZAIC, GMI and GOES-GOCART data.

Methodology:

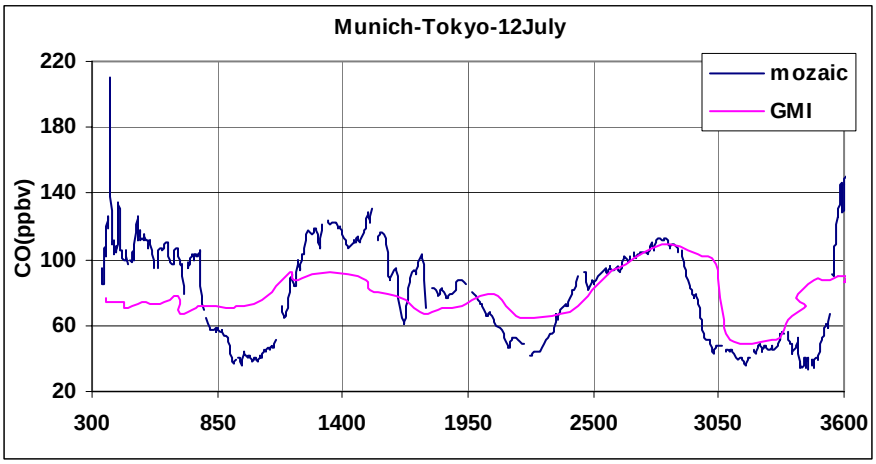
Comparison between aircraft and satellite data is limited by several major factors, of which the most important one is the difference in grid resolution. MOZAIC

measurements are point data, on the other hand GMI model is grid-box averaged with lower vertical resolution. There is also difference in flight time and model run time which makes the comparison between two data sets even more difficult. Apart from these two major limitations, the model data itself is not complete, like GMI does not consider emissions due to biomass burning. To overcome some of these caveats, co-located points from model and aircraft data are taken for comparisons. In the aircraft data all the flights of same landing/takeoff time are compared with model data to minimize the time difference problem. MOZAIC vertical profiles are smoothed in the same resolution as that of GMI for better comparisons.

In this study we divided the aircraft observations into two parts, one with the vertical profiles during take-off and landing and the other one is observation along the track to make better comparison with the model. The study has been restricted to July-2004.

Results:

At first, GMI model and aircraft observations of CO are compared for along track aircraft flight path for a single day. Figure 2a and b shows the two data sets of Munich-Tokyo and Paris-Delhi flight with cruising altitude is between 226-266 hpa in both the cases. It shows in both the cases, GMI model data is very good agreement with the aircraft data, despite several limitations described earlier. Model data is capable of observing variations of CO with nearly as same detail as the aircraft recording, while the large fluctuations in the aircraft data due to point measurements.



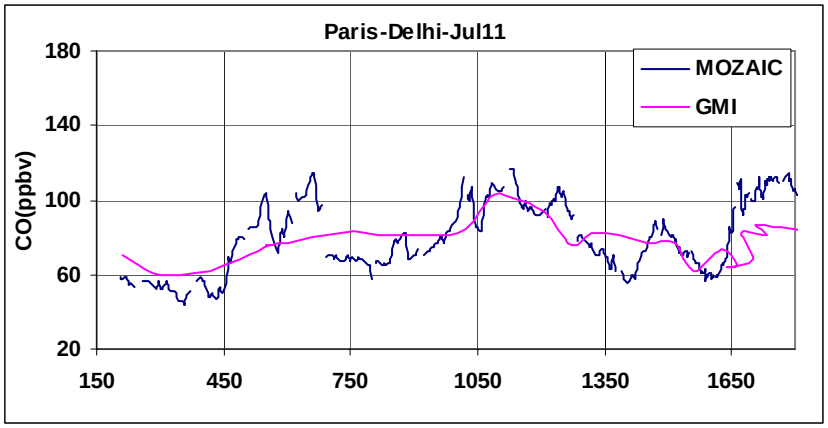
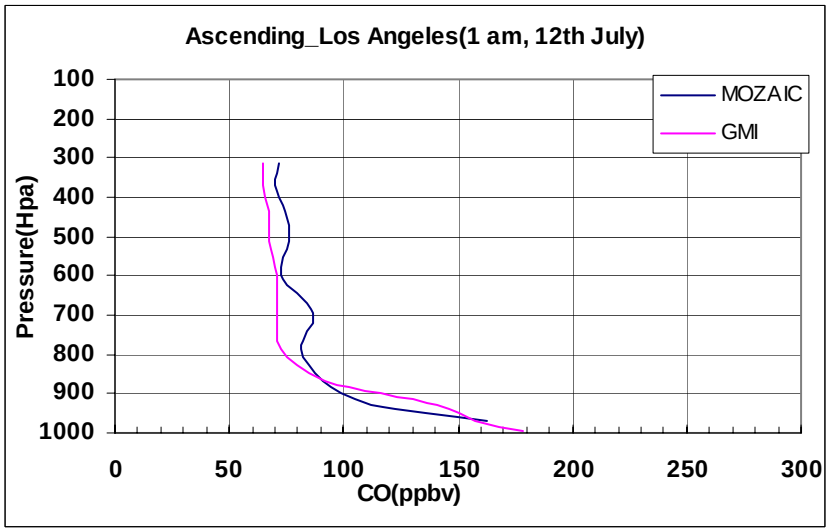
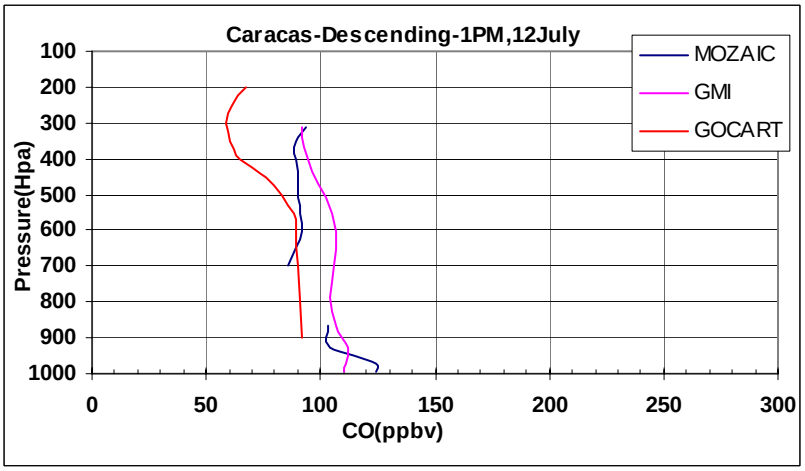


Figure 2 a & b. Comparisons of MOZAIC along track CO profile and GMI model run of the same day of two different flights

Figure 3 shows the vertical profiles of CO over Los Angeles, Boston and Caracas on 12th July. Over the Los Angeles both GMI and aircraft data shows good agreement in lower troposphere, while GMI is underestimating at the upper troposphere. In Boston, both GMI and GOCART failed to catch the enhancement of CO at 700hpa, which is seen by MOZAIC (at 700 hpa level difference between model and aircraft data is 60 ppbv). The enhancement of CO over Boston is due to biomass burning over Canada, which is then transported over the city. DeBell et al., 2004 reported similar enhanced CO layer (at some points it is >500ppbv) over eastern U.S.A which are then transported from the Quebec biomass burning on July 2002. On the other hand, over Caracas, which is relatively clean city GMI and GOCART corresponds well with the aircraft data.





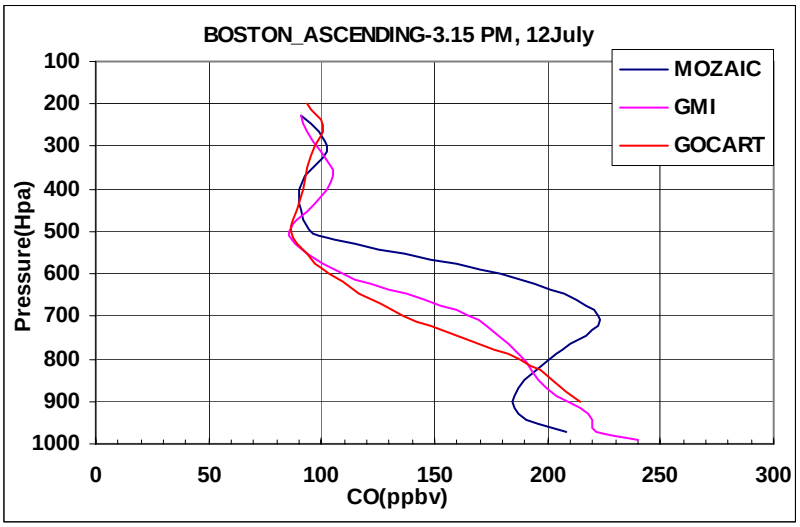


Figure 3 a, b & c: Ascending profile of CO over Los Angeles, Boston and Caracas on 12th July

Figure 4 shows profile over two European cities taken at different times to observe the variations of CO profile. Aircraft data of both the cities show an enhanced CO layer around 300hpa, which is persistent in both morning and evening time. This could be due to possible transport of CO form biomass burning areas in Canada (not simulated by GEOS-GOCART). GMI (local noon) overestimates CO in free troposphere as compared to both morning and evening flights.

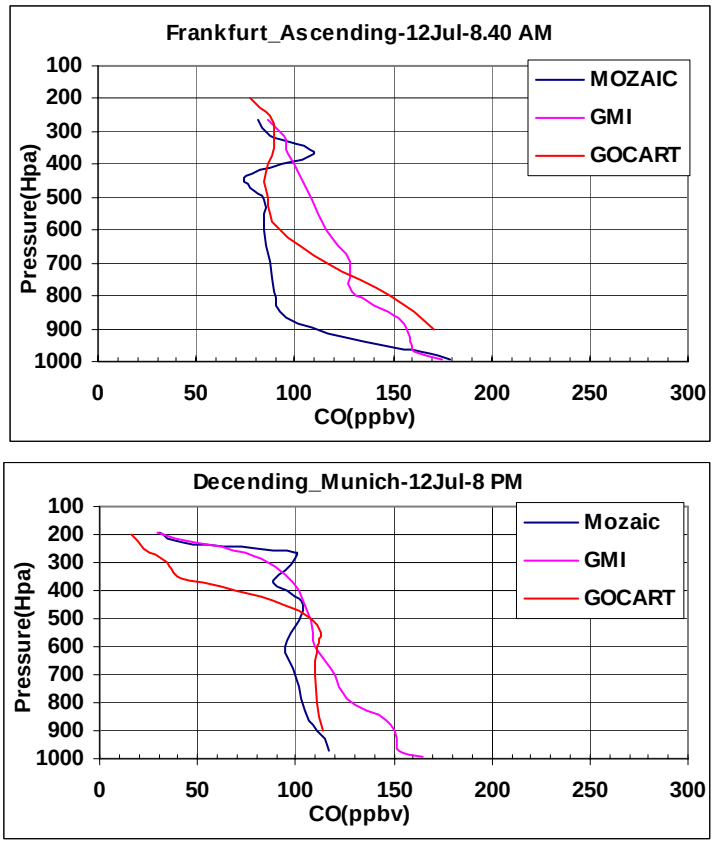
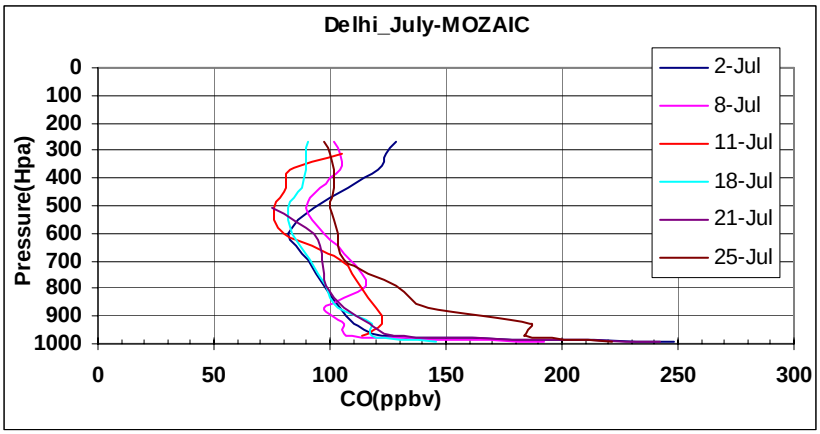
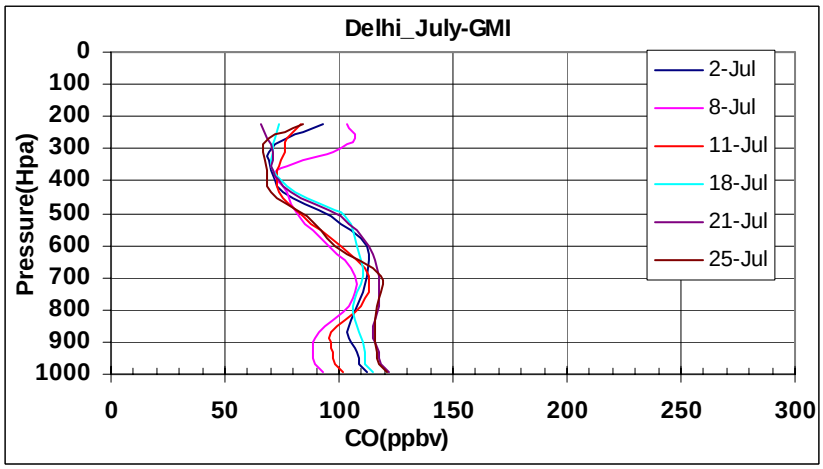
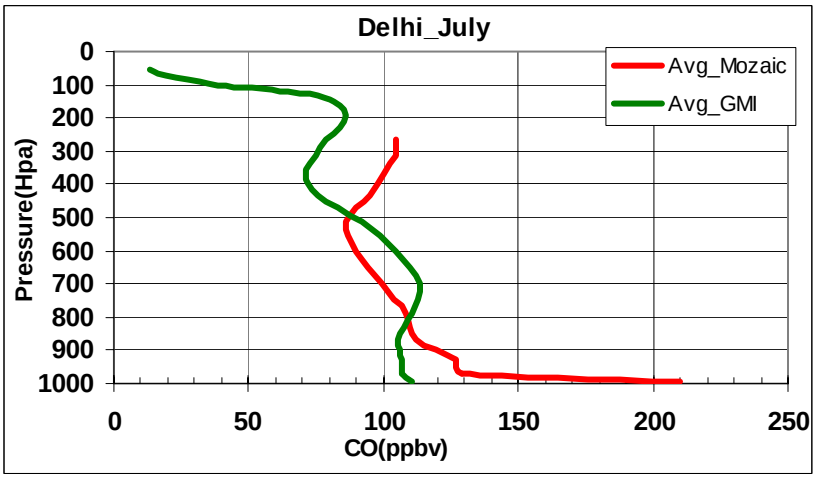


Figure 4a & b. Frankfurt and Munich profiles on 12th July, on different time

For next level comparison, we averaged the number of observations by flights and model run over an area for the entire July shown in figure 5. It shows monthly average of both data over Delhi, where GMI underestimates the CO values near surface to boundary layer compared to aircraft. GMI uniformly spreads the emission over an entire grid-box resulting less CO measurement compared to the aircraft values in boundary layers. During summer monsoon over India strong inversions takes place in the atmosphere resulting in enhancement of CO layer at the upper troposphere (Kar et al., 2004). Both MOZAIC and GMI data shows such enhancement during the month of July, with GMI showing the inversion at higher pressure level compared to the aircraft data. Figure 5c shows the enhancement layer in MOZAIC is ~350hpa, while the same is observed by GMI at ~200hpa. Figure 5d shows the similar monthly average over Boston, where an enhanced CO layer is observed around 650hpa which is due to transport of CO form Canadian forest fire.


Delhi_July-MOZAIC
Pressure(Hpa)
0
100
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
300
CO(ppbv)
2-Jul
8-Jul
11-Jul
18-Jul
21-Jul
25-Jul


Delhi_July-GMI
Pressure(Hpa)
0
100
200
300
400
500
600
700
800
900
1000
0
50
100
150
200
250
300
CO(ppbv)
2-Jul
8-Jul
11-Jul
18-Jul
21-Jul
25-Jul


Delhi_July
Pressure(Hpa)
0
100
200
300
400
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600
700
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50
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CO(ppbv)
Avg_Mozaic
Avg_GMI

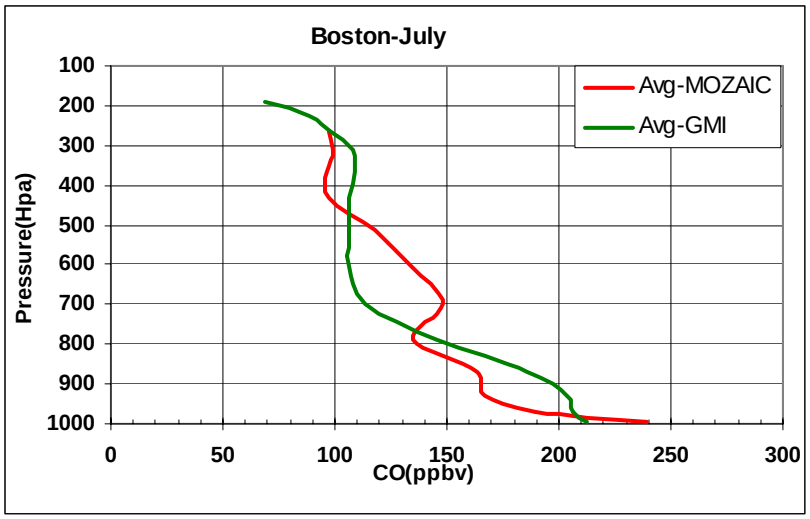

Figure 5. Monthly averages over Delhi and Boston of both flight and model data for the month of July

Conclusions:

GMI model agreement with the aircraft data is excellent, given the differences in horizontal resolution and time differences (except over biomass burning plumes not simulated by GMI model run). Along the track comparison shows that tropopause heights (mixing ratios in stratosphere and upper troposphere) are simulated well in GMI. Vertical profiles of GMI CO observations matches very well over clean areas like Caracas. GMI shows enhanced CO layers due to convective transport over India at lower pressure level, much near to stratosphere than the MOZAIC data. Overall the performance of the GMI model is encouraging but more comparisons are needed to be made between GEOS-GOCART and MOZAIC to evaluate long-range transport of CO form biomass burning. Apart form aircraft data, satellite measured CO data (Terra – MOPITT, EOS-Aqua AIRS and EOS-Aura TES) can be compared with the GMI, MOZAIC and GEOS-GOCART.

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