Comparison of remotely sensed carbon monoxide with ground-based measurements in El Paso, Texas region

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Abstract

This paper compares carbon monoxide levels obtained from Measurements of Pollutants in the Troposphere (MOPITT) sensor aboard Terra satellite to carbon monoxide values obtained from ground-based continuous ambient monitoring systems (CAMS) in the El Paso, Texas region. Findings show that a direct comparison is not possible when comparing MOPITT retrieval to ground-based measurements. Averaging kernels and *a priori* profiles must be applied to any other non-MOPITT carbon monoxide measurement in order to make a valid comparison.

Introduction

CO is a colorless, odorless, poisonous gas. It reduces the ability of the blood to carry oxygen to vital tissues, affecting the cardiovascular and nervous systems. Low concentrations can adversely affect individuals with heart disease and can decrease exercise performance in young, healthy persons. CO results from the incomplete combustion of carbon-containing compounds such as wood, coal, and liquid and gaseous fuels. Its formation is enhanced when the supply of oxygen is inadequate for the complete oxidation of fuels to carbon dioxide (CO2). Most CO emissions result from the incomplete combustion of gasoline by motor vehicles. Optimal combustion of gasoline occurs in warmer ambient temperatures because fuel combustion and pollution control equipment are more efficient at warmer temperatures. During the winter months, vehicles emit larger amounts of CO due to cold starts and longer warm-up periods.
This project will compare the remotely sensed carbon monoxide concentrations obtained from the MOPITT sensor aboard Terra with results obtained from ground-based TCEQ continuous ambient monitoring systems in the El Paso, Texas region.

Terra is a multi-national, multi-disciplinary mission involving partnerships with the aerospace agencies of Canada and Japan. MOPITT was successfully launched into sun-synchronous polar orbit aboard TERRA, NASA's first Earth Observing System spacecraft on December 18, 1999. The MOPITT instrument was constructed by a consortium of Canadian companies and funded by the Space Science Division of the Canadian Space Agency. MOPITT is the first satellite sensor to use gas correlation spectroscopy. The sensor measures emitted and reflected radiance from the Earth in three spectral bands. As this light enters the sensor, it passes along two different paths through onboard containers of carbon monoxide and methane. The different paths absorb different amounts of energy, leading to small differences in the resulting signals that correlate with the presence of these gases in the atmosphere. MOPITT's spatial resolution is 22 km at nadir and it 'sees' the Earth in swaths that are 640 km wide. Moreover, it can measure the concentrations of carbon monoxide in 5-km layers down a vertical column of atmosphere, to help scientists track the gas back to its sources.

TCEQ operates air CAMS all over Texas and in Cuidad Juarez, Mexico. An air CAMS is a small building or shelter that houses instruments that measure the amount of pollutants in the atmosphere. A small pump draws in outside air, which is then distributed to the instruments housed in the shelter. Different instruments measure different pollutants. The TCEQ operates instruments that measure the following air pollutants: ozone, carbon monoxide, nitric oxide, nitrogen dioxide, oxides of nitrogen, sulfur dioxide, hydrogen sulfide, fine particulate matter. Carbon monoxide is measured in parts per million.

Study area and data used

When it comes to overcoming air pollution, El Paso has always faced a number of obstacles. In 1990, EPA found El Paso County to be in nonattainment for the 1-hour ozone standard, carbon monoxide, and PM10. The area is semi-arid, with an average of 300 days of sunshine a year and a mere 9 inches of rain. Combine those conditions with automobile exhaust and other types of emissions, and the atmosphere is ripe for ozone formation. Topography has played a role, too. The Franklin Mountains form a natural barrier that hems in air pollutants. In the winter, thermal inversions can trap emissions close to the ground and contribute to a buildup of carbon monoxide. Add to all this a large, fast-growing neighbor just across the Rio Grande. With 1.2 million people, Juarez, Mexico, has twice the population of El Paso, and every day the booming city produces an abundance of industrial and vehicle emissions, with minimal environmental controls. Southerly winds blow emissions across the border, affecting El Paso's air quality.

To track day-to-day air quality, a total of 13 monitoring sites (CAMS) operate in El Paso and Juárez. Ten sites in El Paso and three in Juarez monitor for elements that contribute to the formation of ozone and for the presence of carbon monoxide, and/or particulate matter. Officials with the El Paso City-County Health Department cross the border each week to help maintain the Juarez sites. This project obtained data from 11 active CAMS, 8 in El Paso, Texas and 3 in Juarez, Mexico. CAMS real-time data from monitors on either side of the border are posted on the TCEQ Web site. Texas is the only state on the U.S.-Mexico border to post readings from both sides. Daily May 2005 data was obtained from all 11 active sites in this region for this study.

Carbon monoxide (CO) mixing ratio profiles are retrieved on the 6 standard MOPITT pressure levels: 850, 700, 500, 350, 250, 150 hPa, and at the surface, for global clear sky measurements. CO total columns are calculated from a 35 level representation of the profiles employed by the retrieval forward model using the corresponding temperature and surface pressure fields from the NCEP archived history tapes. The horizontal footprint of each MOPITT retrieval is 22 km by 22 km. For the vertical profile mixing ratios, the values at the standard retrieval levels that are greater than the surface pressure will be reported as "no data" (-9999).

MOPITT geophysical parameters are derived from the Level-1B radiances in combination with ancillary data describing the global distribution of surface and atmospheric temperature and humidity. Radiance measurements in the 4.7μm CO band provide the primary information on the vertical carbon monoxide mixing ratio profile in the troposphere. Clouds have a large influence on the observed radiances and their effects must be modeled appropriately in the retrieval algorithms.

The MOPITT Level-2 data product consists of the geolocated, retrieved carbon monoxide profiles and total column amounts for carbon monoxide and methane. Ancillary data concerning surface properties and cloud conditions at the locations of the retrieved parameters are also included. The MOPITT Level-2 product is archived using the HDF-EOS Swath structure for the Beta Delivery implementation. The Swath structure has been defined to represent time ordered, multi-channel instrument data. Where the MOPITT scenes are interrupted randomly by clouds or large variability in surface properties, much of the regularity of the original cross-track is disturbed and there will not be one-to-one correlation of retrieved parameters and radiance pixels.

The MOPITT Level-3 product is archived using the HDF-EOS Grid structure. The global grid has a 1x1 degree resolution. A fill value is inserted into the grid box where there is no data. The grid is compressed when written. The averaging kernels for each retrieval can be calculated from the retrieval covariance matrix and the a priori profile and a priori covariance matrix. Averaging kernels indicate the sensitivity of the retrievals to different levels of the atmosphere, and must be examined in order to properly interpret the retrieved data. Due to the sensitivity of the retrievals to surface temperature, differences between day and night will appear in retrievals over land. The averaging kernels show how the sensitivity to CO in the lower troposphere is reduced over cold surfaces. At land-ocean boundaries, similar differences can be seen. These differences should not be interpreted as changes in the atmospheric concentration of CO, but are due solely to the change in sensitivity of the measurement over different surfaces.

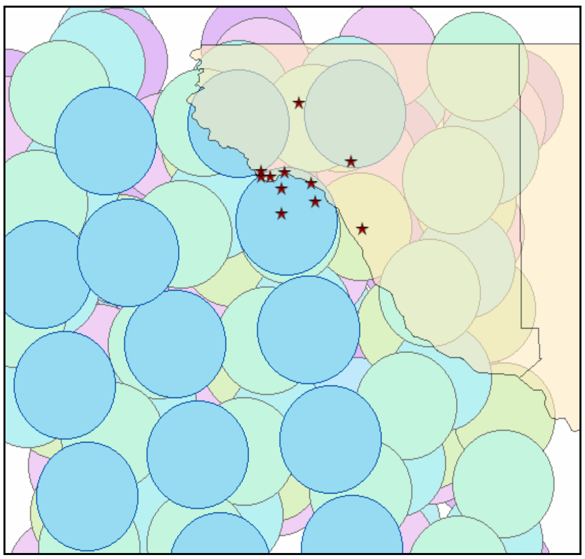
Methods

MOPITT Level-2 and Level-3 data was obtained from the Atmospheric Science Data Center's Data Pool website (http://eosweb.larc.nasa.gov/HPDOCS/datapool). All available May 2005 files were downloaded. The only unavailable days were: May 1 to 5, and May 31. Level-2 files were approximately 75MB each and contained approximately 165K records at various levels. Level-3 files were approximately 6MB each and contained 180 records at various levels.

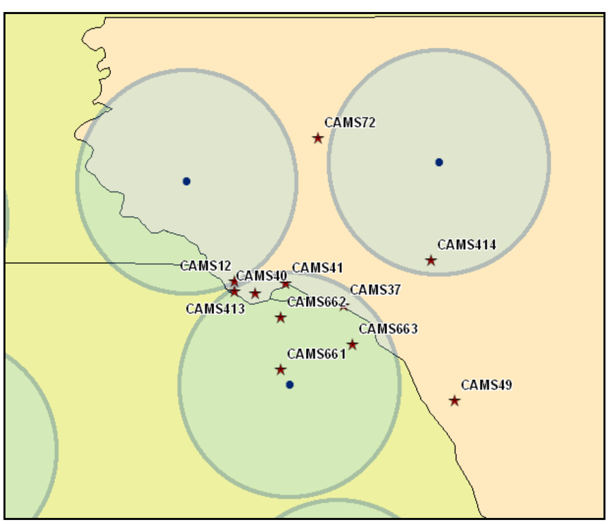
HDFView 2.2 software was downloaded from the Atmospheric Science Data Center's website at: http://eosweb.larc.nasa.gov/PRODOCS/mopitt/tools/mopitt_level2_viewer.html. Each Level-2 data contained a lot data for the entire day and planet scan. Level-2 fields copied and pasted onto excel were: latitude, longitude, seconds in day (to determine the time the data was retrieved), retrieval bottom CO mixing ratio (ppbv), and retrieval bottom CO mixing ration percent *a priori*. Since Level-2 data contained about 165K rows and excel can only hold 65,536 rows, we had to tediously copy and paste all the data into multiple worksheets within the file.

The copied data in excel was then filtered for the study area using latitude values of 31 to 32 and longitude values of -107 to -106.

Arcmap was utilized to to plot all the MOPITT data points for the study area; TCEQ CAMS sites were also plotted. Since MOPITT data represent a 22x22 km region, an 11 km radius buffer was assigned to each data point. In the picture below, same colored circles represent MOPITT data from the same day with the 11km buffer, the stars are the TCEQ CAMS sites.



To filter out MOPITT data that was not within the study area, arc map was used to determine which TCEQ CAMS sites fell within MOPITT data buffered region. For example, the image below shows data for May 6, 2005. Three MOPITT data points contained were within the TCEQ CAMS sites.



Each MOPITT date underwent the same process to determine if the data points contained TCEQ CAMS sites within them. After this process, it was determined that only 13 days actually contained MOPITT data for our study area. These days contained from only one data point up to four data points applicable to our study area. After this process, MOPITT level 2 data had been reduced from over a million data points to only 30 data points for our study area.

Since we now knew that only 13 days for the month of May 2005 contained MOPITT data pertaining to the study area, we needed only to obtain CAMS data for these 13 days for the time specified in the MOPITT data. TCEQ CAMS data was downloaded for the eleven active sites in the El Paso, Texas region:

CAMSID	Station Name	Lat	Long
12	El Paso UTEP	31.768056	-106.501111
37	Ascarate Park SE	31.746667	-106.402778
40	El Paso Sun Metro	31.758611	-106.501111
41	Chamizal	31.765833	-106.455
49	Socorro	31.662222	-106.303056
72	Skyline Park	31.893889	-106.425833
413	Tillman	31.7575	-106.482778
414	Ivanhoe	31.786389	-106.324167
661	Cd Juarez Advance	31.689722	-106.459722
662	Cd Juarez Club	31.735556	-106.459722
663	Cd Juarez Delphi	31.712222	-106.395278

CAMS May 2005 report contained hourly data, thanks to MOPITT time, we were able to retrieve the correct carbon monoxide concentration, in ppm. Whenever a MOPITT retrieval contained multiple CAMS sites, the CAMS sites reading were averaged and utilized for comparison. Since TCEQ CAMS CO readings were in ppm, we had to convert them to ppb by multiplying them by 1000.

MOPITT retrievals were now compared to TCEQ CAMS data in a scatterplot, a 1:1 line was also included in the graph.

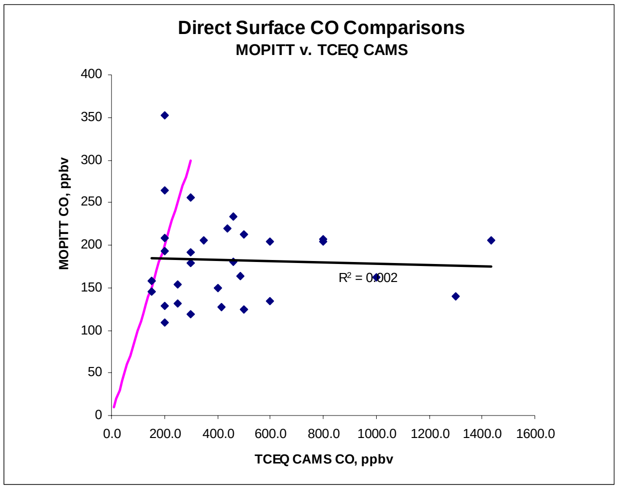
An *in situ* comparison profile (xcomp) must be transformed using the averaging kernel (A) (obtained from Level 3 MOPITT files) and *a priori* profile (xa) (obtained from Level 2 MOPITT files) before being compared to MOPITT retrieved values.

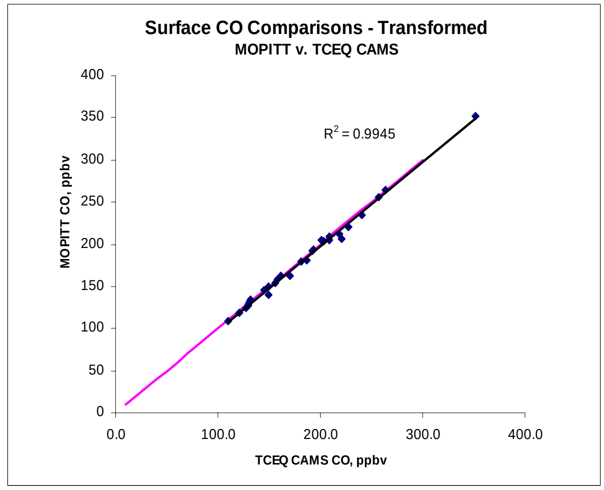
$$xcomp' = xa + A(xcomp - xa)$$

TCEQ CAMS data was transformed as described above and then compared to MOPITT data in scatterplot with a 1:1 line also included in the graph.

Results

When directly comparing MOPITT retrievals against TCEQ CAMS data, no correlation existed. However, after applying the transformation to the *in-situ* data; a good correlation was determined.





Summary

We found that:

- Cannot simply make DIRECT comparisons between retrievals and other measurements or models!!
- An in situ comparison profile (xcomp) must be transformed using the averaging kernel (A) (obtained from Level 3 MOPITT files) and *a priori* profile (xa) (obtained from Level 2 MOPITT files) before being compared to MOPITT retrieved values.

  xcomp'= xa + A(xcomp – xa)
- Averaging kernels play a big role when transforming *in situ* profiles. Averaging kernels also vary from night to day (-0.004 to 0.036).
- A very good correlation exists when comparing *in situ* ground measurements with MOPITT retrievals once the averaging kernel is applied.

Acknowledgements

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References

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