

A Decade of Observations of Carbon Monoxide from the Measurements of Pollution in the Troposphere Instrument (MOPITT) on TERRA

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Abstract – The Measurement of Pollution in the Troposphere (MOPITT) instrument was launched on the Terra satellite in 1999. It now provides an unprecedented decadal record of carbon monoxide (CO) from space. This important tropospheric trace gas is an excellent indicator of combustion processes, both from anthropogenic urban regions and biomass burning, and serves as a proxy for the study of pollutant transport around the globe. The MOPITT mission has improved our understanding of the processes determining the seasonal variability of CO and highlighted the importance of wildfires and biomass burning in driving inter-annual variability. Through new retrieval capability, MOPITT is also the first sensor for which instantaneous multispectral measurements have been utilized to map out pollution concentrations in the lowermost atmosphere.

Keywords: MOPITT, carbon monoxide, pollution

1. INTRODUCTION

Carbon monoxide is one of the few air quality (AQ) relevant trace gases that can be measured from space and is also routinely monitored by surface networks, potentially allowing for a cross-scale analysis of distributions. CO is a reactive gas that plays an important role in tropospheric chemistry. Its sources fall into two main classes: secondary chemical production and anthropogenic incomplete combustion processes. Chemical production results from hydrocarbon oxidation while combustion sources include urban/industrial fossil fuel burning, biofuel use in developing countries, wildfires, and tropical biomass burning. In the presence of nitrogen oxides, CO oxidation processes are important in determining the tropospheric ozone budget. The principal CO sink is oxidation by the hydroxyl radical (OH) resulting in a medium lifetime with a global average of about two months. Since this is not long enough for CO to become evenly mixed in the troposphere, it serves as an excellent tracer of transport processes and large pollution sources can produce concentration enhancements of several times background levels [Edwards et al., 2004; 2006]. As a primary indicator of incomplete combustion it can also be used as a proxy for inferring emissions and distributions of other species that are not so readily measured.

There are two rotational-vibrational spectral bands of CO that can be utilized by passive remote sensing techniques to probe the troposphere. The fundamental band lies in the thermal infrared (TIR) at 4.6- μm and the first overtone band lies in the near infrared (NIR) at 2.3- μm . A discussion of atmospheric radiative transfer in these regions can be found in Edwards et al. [1999]. Of the current satellite missions measuring CO, only the Terra/MOPITT instrument [Drummond et al., 2010;

<http://www.acd.ucar.edu/mopitt/>] launched in 1999 is able to utilize both CO bands in instantaneous multispectral retrievals, and this leads to increased sensitivity to the CO concentration in the lower-most troposphere (LMT) [Deeter et al., 2009; Worden et al., 2010] which is here defined as being below about 850 hPa. This is important for the characterization of near-surface pollutant sources and pollution variability. MOPITT now provides over a decade of near-continuous CO data. The instrument uses a cross-track scan that allows for almost complete coverage of the Earth's surface in about 3 days, with individual pixels of 22 km x 22 km horizontal resolution and a 10:30 am local time overpass. The current Version 4 data release uses TIR channel signals only in conjunction with a maximum a posteriori (MAP) optimal estimation retrieval approach [Rodgers and Connor, 2003; Deeter et al., 2003]. These data have undergone extensive validation studies covering a wide variety of locations and environments, most recently described by Emmons et al. [2009]. The new multispectral TIR+NIR Version 5 data release will be available in Spring 2011.

2. CARBON MONOXIDE VARIABILITY

The production of long-term datasets facilitates atmospheric composition science in general, and in particular, studies aimed at understanding the seasonal and inter-annual variability of atmospheric pollutant loadings together with any underlying trends. Figure 1 illustrates the zonal mean CO daytime column observed during the MOPITT mission. CO shows highest concentrations in the Northern Hemisphere (NH), which reflects the greater population and the fact that the primary sources are anthropogenic. The CO seasonal cycle is driven mainly by the atmospheric concentration of the OH sink, and this is greatest during the summer months. CO loading usually peaks in April and reaches a minimum in September. Perturbations to these cycles are usually a direct result of sporadic wildfire emissions.

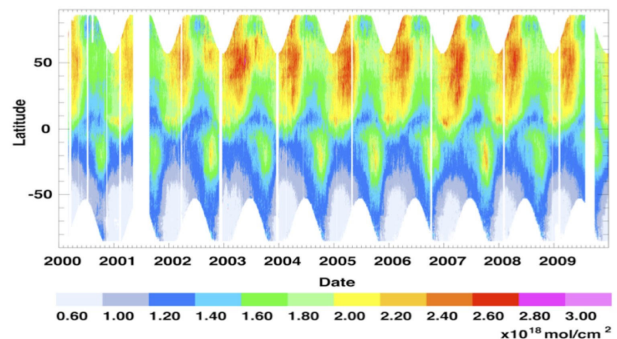


Figure 1. Zonal plot showing the daytime total CO column at different latitudes over the past decade as observed by MOPITT.

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For example, of the ten years of data available from the Terra satellite, the winter and spring of 2002/2003 showed anomalously high NH pollutant loadings compared to other

years. Eastern European and western Russian peat and forest fires in the late summer and fall of 2002 resulted in high emissions. This produced an early build-up of NH winter CO, and concentrations reached a minimum in July 2002, two months earlier than usual. The CO levels measured in the spring of 2003 were again higher than other years as a result of agricultural and wildfire emissions from south-eastern Russia. These produced large plumes out over the Pacific Ocean and significantly affected the CO loading as far away as the eastern USA [Edwards et al., 2004].

In the Southern Hemisphere (SH), biomass burning in South America, southern Africa, Australia and Indonesia are the dominant CO sources and punctuate the seasonal cycle each year from August–November. The shifting latitudinal dry-season burning dominates the observed pollutant distributions. Although these general patterns are followed each year, it is also evident that there is significant inter-annual variability that can usually be associated with changes in biomass burning [Edwards et al., 2006]. This underscores the need for continuous observations to produce long-term datasets for atmospheric composition and AQ studies and to investigate the feedback and response to climate variability. For example, drought periods over Indonesia are often brought on by the shift in the Walker circulation over the tropical Pacific associated with El Nino conditions, such as in the latter part of 2006. At these times the rainforests of Sumatra, Kalimantan, and Malaysia, which only burn in years with below average rainfall, are particularly susceptible to fire. The resulting smouldering burn of large peat deposits released large amounts of carbon into the atmosphere [Edwards et al., 2006]. The resulting pollution plumes had a significant impact on the regional pollutant concentrations compared to La Nina years such as 2005.

3. RETRIEVAL OF CO IN THE LOWERMOST TROPOSPHERE

Improving local- and regional-scale atmospheric composition and AQ analysis through the use of current remotely sensed trace gas and aerosol information has been challenging because of the different spatiotemporal scales and measurement sensitivities involved. In particular, there has been very limited retrieval information in the LMT. This is important for the characterization of pollutant sources and pollution variability within the planetary boundary layer (PBL). A measure of LMT concentration in conjunction with the free troposphere (FT) profile also permits study of pollution venting out of, and entrainment into, the PBL.

Work is underway to assess the value of the new MOPITT multispectral CO retrievals in characterizing LMT pollution spatial and temporal variability at the regional scale. Achieving this goal will provide important societal dividends for public health advisories, for policy applications related to managing AQ, and assessing the impact of daily human activity on the distributions of important trace gases and aerosols and their short-timescale variability—known as ‘chemical weather’—as well as on climate.

An example of the significant improvements in MOPITT sensitivity to surface CO is shown in Figure 2 for a comparison of TIR-only vs. TIR+NIR retrievals for the September–November seasonal average over central/east Asia. Since the TIR measurement is sensitive to CO primarily in the FT, the retrieval at the surface is dominated by the constant a priori used in this example. Compared to the TIR-only retrieval, the

multispectral TIR+NIR retrievals show clear patterns of elevated surface CO corresponding to high-density population areas.

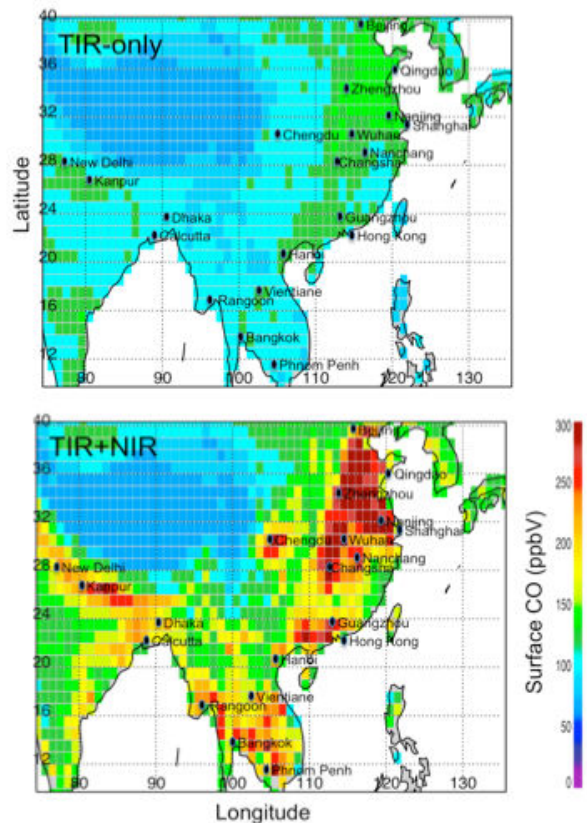


Figure 2. Surface CO averages for September–November, 2005–2008 in central/east Asia. The top panel shows the TIR-only retrieval results and the bottom panel shows the multispectral TIR+NIR retrieval [from Worden et al., 2010].

4. SUMMARY

MOPITT now provides an unprecedented decadal record of CO from space. The data have been extensively employed by the international research community in chemistry/transport studies [see http://www.acd.ucar.edu/mopitt/mopitt_ref.shtml for a list of publications] and work continues to evaluate how the MOPITT mission has improved our understanding of the processes determining the seasonal and inter-annual variability of CO. The data are both illustrative of specific events; pollution releases, fires, and the subsequent transport pathways, and valuable for quantitative studies such as improvements to source emission estimates through inverse modelling. As the most thoroughly and continuously validated satellite measurement of CO, MOPITT products continue to be used as the primary reference for evaluating CO products from newer satellite instruments.

Northern Hemisphere AQ is increasingly impacted by wildfire emissions that often respond to climatic conditions that vary year-to-year and affect rainfall and vegetation drying. MOPITT CO observations are also being used to constrain estimates of the emissions of carbon dioxide (CO₂) from combustion sources and the availability of satellite CO₂ observations from GOSAT provides an opportunity for joint assimilation at the same time as planning for combining with future OCO-2 measurements.

The recently demonstrated multispectral retrievals with sensitivity to the CO concentration in the LMT serves as an important demonstration of the type of CO measurement capability planned for the future NASA Decadal Survey GEO-CAPE geostationary satellite mission. MOPITT experience is informing observing system simulation experiments (OSSEs) (Edwards et al., 2009) aimed at improving model predictions and analyses of surface CO and regional to global AQ analysis in general.

REFERENCES

- Deeter, M. N., et al. (2003), Operational carbon monoxide retrieval algorithm and selected results for the MOPITT instrument, *J. Geophys. Res.*, 108, 4399, doi:10.1029/2002JD003186.
- Deeter, M. N., D. P. Edwards, J. C. Gille, and J. R. Drummond (2009), CO retrievals based on MOPITT near-infrared observations, *J. Geophys. Res.*, 114, D04303, doi:10.1029/2008JD010872.
- Drummond, J. R., J. Zou, F. Nichitiu, J. Kar, R. Deschambaut, and J. Hackett (2010), A review of 9-year performance and operation of the MOPITT instrument, *Advances in Space Research*, 45, 760-774.
- Edwards, D. P., C. Halvorson, and J. C. Gille (1999), Radiative transfer modeling for the EOS Terra Satellite Measurement of Pollution in the Troposphere (MOPITT) instrument, *J. Geophys. Res.*, 104, 16,755–16,775.
- Edwards, D. P., et al., (2004), Observations of Carbon Monoxide and Aerosol From the Terra Satellite: Northern Hemisphere Variability, *J. Geophys. Res.*, 109, D24202, doi:10.1029/2004JD0047272004.
- Edwards, D. P., G. A. Pétron, P. C. Novelli, L. K. Emmons, J. C. Gille, and J. R. Drummond (2006), Southern Hemisphere carbon monoxide interannual variability observed by Terra/Measurement of Pollution in the Troposphere (MOPITT), *J. Geophys. Res.*, 111, D16303, doi:10.1029/2006JD007079.
- Edwards, D. P., A. F. Arellano Jr., and M. N. Deeter (2009), A satellite observation system simulation experiment for carbon monoxide in the lowermost troposphere, *J. Geophys. Res.*, 114, D14304, doi:10.1029/2008JD011375.
- Emmons, L. K., D. P. Edwards, M. N. Deeter, J. C. Gille, T. Campos, P. Nédélec, P. Novelli, and G. Sachse (2009), Measurements of Pollution In The Troposphere (MOPITT) validation through 2006, *Atmos. Chem. Phys.*, 9, 1795–1803.
- Rodgers, C. D., and B. J. Connor (2003), Intercomparison of remote sounding instruments, *J. Geophys. Res.*, 108(D3), 4116, doi:10.1029/2002JD002299.
- Worden, H. M., M.N. Deeter, D. P. Edwards, J. C. Gille, J. R. Drummond, and P. Nedelec (2010), Observations of near-surface carbon monoxide from space using MOPITT multispectral retrievals, *J. Geophys. Res.*,doi:10.1029/2010JD014242.