JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D09303, doi:10.1029/2005JD006613, 2006

Time-dependent inversion estimates of global biomass-burning CO emissions using Measurement of Pollution in the Troposphere (MOPITT) measurements

Avelino F. Arellano Jr.,[1,2] Prasad S. Kasibhatla,[1] Louis Giglio,[3] Guido R. van der Werf,[4]
James T. Randerson,[5] and G. James Collatz[6]

Received 23 August 2005; revised 28 November 2005; accepted 26 January 2006; published 6 May 2006.

[1] We present an inverse-modeling analysis of CO emissions using column CO retrievals from the Measurement of Pollution in the Troposphere (MOPITT) instrument and a global chemical transport model (GEOS-CHEM). We first focus on the information content of MOPITT CO column retrievals in terms of constraining CO emissions associated with biomass burning and fossil fuel/biofuel use. Our analysis shows that seasonal variation of biomass-burning CO emissions in Africa, South America, and Southeast Asia can be characterized using monthly mean MOPITT CO columns. For the fossil fuel/biofuel source category the derived monthly mean emission estimates are noisy even when the error statistics are accurately known, precluding a characterization of seasonal variations of regional CO emissions for this source category. The derived estimate of CO emissions from biomass burning in southern Africa during the June–July 2000 period is significantly higher than the prior estimate (prior, 34 Tg; posterior, 13 Tg). We also estimate that emissions are higher relative to the prior estimate in northern Africa during December 2000 to January 2001 and lower relative to the prior estimate in Central America and Oceania/Indonesia during April–May and September–October 2000, respectively. While these adjustments provide better agreement of the model with MOPITT CO column fields and with independent measurements of surface CO from National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory at background sites in the Northern Hemisphere, some systematic differences between modeled and measured CO fields persist, including model overestimation of background surface CO in the Southern Hemisphere. Characterizing and accounting for underlying biases in the measurement model system are needed to improve the robustness of the top-down estimates.

Citation: Arellano, A. F., Jr., P. S. Kasibhatla, L. Giglio, G. R. van der Werf, J. T. Randerson, and G. J. Collatz (2006), Time-dependent inversion estimates of global biomass-burning CO emissions using Measurement of Pollution in the Troposphere (MOPITT) measurements, *J. Geophys. Res.*, *111*, D09303, doi:10.1029/2005JD006613.

1. Introduction

[2] In recent years, there has been an increasing emphasis on the use of statistical inverse-modeling analysis techniques to characterize the temporal and spatial variability of atmospheric trace gas sources and sinks. Most of the atmospheric tracer inverse-modeling applications have focused on quantifying atmospheric CO_2 sources and sinks [e.g., *Fan et al.*, 1998; *Bousquet et al.*, 1999; *Kaminski et al.*, 1999; *Law and Rayner*, 1999; *Bousquet et al.*, 2000; *Peylin et al.*, 2002; *Gurney et al.*, 2002, 2003, 2004; *Rödenbeck et al.*, 2003; *Suntharalingam et al.*, 2003], spurred by the availability of multiyear CO_2 measurements from a global network of surface sites. More recently, formal inverse model techniques have also been applied to characterize the tropospheric budgets of reactive gases such as carbon monoxide [e.g., *Bergamaschi et al.*, 2000; *Kasibhatla et al.*, 2002; *Pétron et al.*, 2002; *Müller and Stavrakou*, 2005] and methane [e.g., *Hein et al.*, 1997; *Houweling et al.*, 1999; *Butler et al.*, 2004; *Mikaloff Fletcher et al.*, 2004a, 2004b]. These studies have yielded valuable insights into the uncertainties associated with our understanding of anthropogenic impacts on the atmospheric budgets of these reactive trace gases. In addition, analysis of spatiotemporal variations in atmospheric concentrations of gases such as CO can yield insights into the factors that

---

[1] Nicholas School of the Environment and Earth Sciences, Duke University, Durham, North Carolina, USA.

[2] Now at Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, Colorado, USA.

[3] Science Systems and Applications, Inc., Lanham, Maryland, USA.

[4] Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam, Amsterdam, Netherlands.

[5] Department of Earth System Science, University of California, Irvine, Irvine, California, USA.

[6] NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

Copyright 2006 by the American Geophysical Union.
0148-0227/06/2005JD006613$09.00

control the variability of atmospheric CO_2 and CH_4 [e.g., *Langenfelds et al.*, 2002; *van der Werf et al.*, 2004; *Suntharalingam et al.*, 2004].

[3] In this study, we explore the extent to which CO measurements from the MOPITT instrument on NASA's Terra satellite can be used in an inverse-modeling framework to constrain the anthropogenic CO budget. Our study builds on several recent inverse-modeling studies focused on quantifying CO sources. Several of these studies have made use of CO measurements from a globally distributed network of surface monitoring sites [e.g., *Bergamaschi et al.*, 2000; *Kasibhatla et al.*, 2002; *Pétron et al.*, 2002] to quantify the global CO budget. Other inverse-modeling studies have focused on a more detailed regional analysis of CO sources using airborne CO measurements [e.g., *Palmer et al.*, 2003; *Heald et al.*, 2004; *Wang et al.*, 2004]. More recently, several inverse-modeling studies using newly available remote sensing CO measurements have been published. In the first application of its kind, *Arellano et al.* [2004] used CO retrievals from the MOPITT instrument [*Deeter et al.*, 2003] on NASA's EOS Terra satellite in a time-independent Bayesian synthesis inversion to derive geographically disaggregated, annual mean estimates of CO emissions on a global scale from fossil fuel/biofuel use and biomass burning. *Pétron et al.* [2004] performed a similar analysis, but estimated emissions at a monthly rather than annual timescale. The MOPITT CO measurements have also been used in other studies focused on elucidating the CO budget for specific regions [*Allen et al.*, 2004; *Heald et al.*, 2004; *Pfister et al.*, 2004; *Liu et al.*, 2005], assessing the effect of burning on atmospheric chemical composition [*Edwards et al.*, 2003; *Bremer et al.*, 2004; *Edwards et al.*, 2004], and characterizing pollution transport events [*Heald et al.*, 2003; *Lamarque et al.*, 2003; *Gros et al.*, 2004; *Kar et al.*, 2004; *Choi et al.*, 2005; *Li et al.*, 2005].

[4] In the inverse-modeling study presented here, we extend our previous time-independent analysis [*Arellano et al.*, 2004] to estimate the seasonal variation of anthropogenic CO emission, with a particular focus on emissions from biomass burning. In this respect, our study is most closely related to the inverse-modeling study by *Pétron et al.* [2004]. There are, however, some significant differences between our study and the *Pétron et al.* [2004] study. Most importantly, we explore the information content of the MOPITT measurements using a pseudo data analysis approach and provide insights into the extent to which temporal CO source variations can be deduced. In addition, we perform a detailed comparison of independent surface CO measurements from a global monitoring network to evaluate the robustness of the inverse source estimates.

7. Summary and Conclusions

[42] In this study, we have extended our previous analysis of MOPITT measurements [*Arellano et al.*, 2004] to explore the extent to which column CO measurements can provide information on anthropogenic CO emissions. The analysis presented here demonstrates that MOPITT CO column measurements, in combination with other satellite-derived fire products, can provide useful information on CO emission from biomass burning on regional and seasonal scales. Under the assumption that errors in the model measurement system are independent and Gaussian, we find that the a posteriori errors (2σ) associated with monthly mean CO source estimates for major sources are about 10–20% of the posterior source estimates. We further find that there are prior and posterior biomass-burning CO source estimates that differ significantly in terms of seasonal variability in some instances. In particular, our analysis of the MOPITT CO measurements suggests that the prior estimates of biomass-burning CO emissions in the Southern Hemisphere are biased high in the early part of the burning season, and biased low in the latter part of the burning season. Our posterior estimates are also higher than the corresponding prior estimates in spring in the Northern Hemisphere tropics and subtropics and in Europe/Russia. The extent to which these differences are due to shortcomings in the fire model used to derive the prior source estimates remains to be investigated.

[43] For the fossil fuel/biofuel CO source category, we find that the monthly mean, posterior regional source estimates are noisy, precluding the quantification of seasonal variations that are expected to be relatively modest. From an annual mean perspective, our posterior estimate is significantly higher than the corresponding prior estimate for east Asia. The posterior estimate derived here is, however, consistent with results from recent studies focused on this region. We also find significant differences between the prior and posterior source estimates in other regions, notably south Asia, Indonesia, Europe, Central America/northern South America, and southern Africa. While qualitatively consistent with energy use trends in these regions, independent verification of the accuracy of our estimates is needed.

[44] In the context of future inverse-modeling studies aimed at characterizing sources of chemically important trace gases and aerosols, there is a pressing need to develop and apply more rigorous approaches for describing model and measurement error statistics. In particular, the effect of spatial error covariances on inferred source and error estimates must be investigated. In addition, possible biases in the measurements and models must be characterized and explicitly accounted for in the inverse approach. For characterizing model biases, a useful first step would be a rigorous inverse analysis intercomparison exercise using multiple CTMs to test the sensitivity of derived source estimates to differences in the underlying CTMs. On the longer term, comprehensive and integrated analysis approaches that make use of measurements of multiple chemical species from a variety of platforms are needed in order to fully exploit the potential of space-based tropospheric chemistry measurements to quantify the sources of chemically important trace gases and aerosols.