Assimilation of the 2000–2001 CO MOPITT retrievals with optimized surface emissions


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1. Introduction

[2] Inverse modeling and data assimilation are increasingly used to study the budget, transport and sources of pollution in the troposphere. The MOPITT instrument onboard the NASA Terra satellite provides the first multi-year CO retrievals that can be actively employed for studying the sources and transcontinental transport of pollution.

[3] The goal of this letter is to present the data assimilation of MOPITT CO retrievals in a CTM that uses the inverted CO emissions constrained with the same monthly MOPITT data [Pétron et al., 2004]. In some respects, the study of Pétron et al., submitted manuscript (2004) and this paper present a two-step strategy for the analysis of the MOPITT CO retrievals. The first step is to use the CTM and MOPITT data to obtain optimized monthly CO emissions and reduce the related model-data discrepancies before the assimilation. The second step is the data assimilation of CO retrievals in the CTM with the ‘MOPITT-based’ (Pétron et al., submitted manuscript, 2004) CO surface fluxes. The paper is organized as follows. Section 2 presents a brief description of the MOPITT retrievals. Section 3 describes the CTM, CO surface emissions, and tracer assimilation schemes. Section 4 presents results and their discussion. Our conclusions are in section 5.

2. Data

[4] The MOPITT instrument [Drummond, 1992] began providing radiance data on March 3, 2000. The instrument cooler failure, on May 6, 2001, divides the stream of MOPITT CO retrievals into two phases. During Phase I (March 2000–May 2001) all 8 IR channels can be used in the data processing. However, due to reasons discussed by Deeter et al. [2003] only channels 1, 3, and 7 have been utilized. The CO retrievals are reported on seven levels between the surface and 150 hPa. The validation of retrievals has been described by Emmons et al. [2004]. The measured radiances are mainly sensitive to CO amounts between 700 and 350 hPa. The MOPITT algorithm employs the concept of ‘characterized retrievals’ [Deeter et al., 2003], that is, for every MOPITT pixel, in addition to the retrieved CO profile, the retrieval covariance matrix is provided to ensure adequate comparisons between retrievals and correlative CO observations (simulations). By combining this covariance matrix with a single a priori CO profile (qa) and its error statistics, one can calculate the averaging kernel matrix (A) and map the correlative CO profile onto the MOPITT vertical retrieval grid. For example, the transformation of the assimilated CO profile (qt) interpolated onto the retrieval grid can be expressed as:

\[ q_t = q_p + A(q_a - q_p). \]

With non-zero off-diagonal elements of A, this transformation smooths the fine vertical structures in the vertical CO profiles (qa). It also reduces differences between the
MOPITT CO and transformed vertical profiles in the regions where the instrument is less sensitive to CO (near the surface, above 250 hPa, and poleward of 65°C).

3. Forecast Model, Surface Emissions and Data Assimilation Schemes

To forecast CO we use the MOZART (Model for OZone And Related Tracers) CTM [Horowitz et al., 2003], driven by NCEP meteorological fields [Kalnay et al., 1996]. The CTM horizontal resolution is 2.8° x 2.8° with 28 levels between the surface and 1 hPa. The MOZART photo-chemical scheme describes the major mechanisms of CO production and loss. The other mechanisms that control the simulated CO include the resolved transport, sub-grid vertical turbulent and convective mass fluxes, and CO surface emissions. The spatial and temporal variability of surface emissions creates a serious challenge for the CO forecast and data analysis. The data assimilation schemes of MOPITT CO used in this study are based on the 3D sub-optimal sequential tracer assimilation scheme described by Khattatov et al. [2000], Lamarque et al. [2004] introduced the forecast bias correction in the sequential assimilation of CO retrievals. For example, if Observed minus Forecast (OmF) CO systematically differ by 10 ppbv then the bias estimator algorithm evaluates this difference first, and on the second step the 10 ppbv correction is applied to the CO forecast without changes in the model CO sources/sinks that may be responsible for the estimated bias.

In this letter we concentrate on the impact of CO emissions on the data assimilation of MOPITT retrievals. We use two sets of emissions, the ‘standard’ fluxes based on the EDGAR-2 (Emission Database for Global Atmospheric Research) technological emissions [Olivier, 2002] with biomass burning of Hao and Liu [1994] and ‘MOPITT-based’ surface fluxes. The term ‘MOPITT-based’ denotes the optimized monthly CO emissions using the MOZART CTM and MOPITT CO retrievals (Pétron et al., submitted manuscript, 2004). In the next section we will discuss the following simulated and assimilated CO distributions produced by: (a) MOZART CO forecasts with ‘standard’ and ‘optimized’ emissions, (b) assimilation of MOPITT retrievals in the CTM with ‘standard’ and ‘optimized’ emissions, and (c) assimilation using the on-line bias correction of Lamarque et al. [2004] with the ‘standard’ CO emissions.

4. Results and Discussions

Figure 1 presents the time evolution of the hemisphere-averaged CO fields at the seven MOPITT levels. The first column represents the MOPITT CO retrievals. The right column presents the data analysis with the optimized surface emissions. The middle column illustrates the transformation of the analyzed CO to the MOPITT grid (see section 2).

Figure 1. The daily and hemisphere-averaged CO mixing ratios over the NH (top) and the SH (bottom). The left column presents the MOPITT retrievals. The right column presents the data analysis with the optimized surface emissions. The middle column illustrates the transformation of the analyzed CO to the MOPITT grid.

Figure 2. March 2001 global monthly averaged observed (MOPITT) minus forecast (OmF) CO for various CTM simulations with (solid lines) and without (dashed lines) data analysis schemes. The forecast-only simulations with the ‘averaged’ and ‘MOPITT-based’ CO emissions are illustrated by the red and green curves, respectively. The three data analysis results correspond to the MOPITT CO assimilations with the ‘MOPITT-based’ surface fluxes (red), and ‘averaged’ emissions with (yellow) and without (blue) bias correction of the forecast errors.
transformed on the MOPITT levels as discussed in section 2. In the Northern Hemisphere (NH, top row), the retrieved and assimilated transformed CO distributions show remarkable agreement. The linear regression analysis of these two distributions gives a regression coefficient of 0.992. For both hemispheres, we calculate the frequency distribution of the OmF CO fields at 700, 500, and 350 hPa using daily-averaged values on a horizontal grid. From the so defined probability distribution function (PDF) of the OmF fields (not shown), the NH positive bias is approximately 2.5 ppbv that corresponds to the size of the histogram bin. In the SH (bottom row) the agreement between the data and analysis is not as good. The Southern Hemisphere (SH) linear regression coefficient is 0.772. The SH PDF of OmF (not shown) reveals bimodal distributions with an average bias of ~12 ppbv. The first maximum of the OmF PDF of ~1–3 ppbv characterizes the good agreement between data and analysis in the SH tropics and subtropics. The second maximum in the PDF, formed by the mid- and high-latitude OmF values, reflects the persistent bias between the forecasted CO and MOPITT retrievals.

Both types of errors (retrieval and model), may contribute to this bias. In the SH middle and high latitudes, poor knowledge of CO emissions, circulation, and water vapor patterns can initiate systematic errors in the tracer forecast. On the other hand, the MOPITT retrieval algorithm uses a priori information (single global profile and covariance matrix) that is mainly constrained by the available NH CO observations compiled before the Terra launch [Deeter et al., 2003]. From the forecasted CO fields we can expect significant differences between the typical SH and NH CO a priori specifications. The SH CO retrievals and CO forecast can be evaluated using the CMDL CO surface measurements [Novelli et al., 2003]. For three SH latitudinal bands (tropics, mid-, and high latitudes), inspection of the PDFs based on the CMDL and MOPITT CO reveals the positive biases of MOPITT retrievals. The biases increase toward the South Pole from 5–10 to 20–30 ppbv.

The overall global performance of the different data assimilation schemes and forecasts by themselves in terms of the OmF distributions is summarized in Figure 2 for March 2001. The ‘MOPITT-based’ CO analysis and forecast provides significant reduction (50%) in the OmF fields compared to the CO forecast with the ‘averaged’ emissions. The two data analysis schemes with CO ‘averaged’ emissions also show improvement compared to the corresponding CO forecast-only results. Globally, the bias correction data analysis scheme shows an OmF profile similar to the ‘MOPITT-based’ assimilation. Regionally, however, there are differences between these two OmF distributions.

Figures 3 and 4 illustrate respectively the zonal mean and the 700 hPa distributions of the March 2001 OmF fields for the CO forecast with the optimized emissions (a) and the three CO data analysis schemes (b)–(d) described above. The results presented in the bottom rows highlight
the importance of the correction of the model errors. In the tropics over the land, the CO fields assimilated with optimized CO emissions (c-plates) provide a good fit to the retrievals in the mid-troposphere. MOPITT validation efforts [Emmons et al., 2004] indicate a positive bias of the CO retrievals. In that sense, the data assimilation algorithms, especially the bias correction scheme, need to be further evaluated against independent observations.

[11] The data assimilation schemes of MOPITT CO with corresponding averaging kernels may help to improve the fine structure of CO profiles that can be compared with the independent high-resolution flight measurements mapped on the CTM grid. For February 27, 2001, Figure 5 shows the ability of the data assimilation scheme with the optimized fluxes (red solid curves) to reproduce the vertical patterns of the composite flight profiles from TRACE-P (TRansport And Chemical Evolution over the Pacific) mission for two longitudinal regions (yellow curves). For comparison, the CTM results (green curves) and MOPITT averaged profiles (blue curves) are also shown. The dot-dashed red curves illustrate the transformed 'smoothed' analysis on the MOPITT grid according to the equation in section 2. The averaging kernels (A) are shown in the left part of Figure 5. The a priori profile (\(q_0\)) is illustrated by the blue dash-dotted curves. In the mid-troposphere (2–4 km) CO plumes above the boundary layer are successfully depicted by the daily-averaged data analysis output. Above 5 km and below 1.5 km, some disagreements between the flight observations and data analysis can be seen. Looking at the overlapping MOPITT kernels it would be difficult to expect dramatic improvement in our data analysis outside of the mid-troposphere.

5. Concluding Remarks

[12] The discussed results present a summary of the assimilation of the Phase I MOPITT CO retrievals. The assimilation of CO retrievals in the CTM is shown to help restore fine vertical structures of CO that are not seen by MOPITT due its low sensitivity outside of the mid-troposphere. Data assimilation also suggests the possible retrieval biases, particularly in the SH mid- and high latitudes. A series of assimilation results confirm that misspecification of the surface emissions leads to systematic model errors. In this study the emissions were optimized separately from the assimilation and later used in the analysis. Ideally, with high quality global observations, the inverse modeling of CO sources and profile assimilation should be performed simultaneously, exploiting sensitivities of the observed tracer distribution to the emissions and initial conditions. At present, we cannot perform the simultaneous state mapping and source correction on a day-to-day basis due to the low instrument sensitivity to the CO amounts near the surface. On monthly scales, however we can correct CO fluxes using the mid-troposphere MOPITT retrievals. While on-line empirical bias correction methods can help to decrease discrepancies between data and analysis, emission inversion before analysis provides a more promising avenue for reducing systematic model errors in data assimilation.

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