Identification of CO plumes from MOPITT data: Application to the August 2000 Idaho-Montana forest fires

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[1] This study focuses on the identification of carbon monoxide (CO) released during the forest fires that took place primarily in Montana and Idaho during the summer of 2000. We focus our analysis on the most intense period of the fires during the second half of August. During that period, the MOPITT instrument onboard the EOS-Terra platform collected extensive measurements of CO. A simulation of the dispersal of the CO from the fires, constrained by the AVHRR observations of fire location and extent, clearly identifies the affected regions. The model results are compared with the CO observations from the COBRA experiment flight on August 19. Using these various data, we are able to identify the transport of the CO plume originating from the fires. In particular, it is shown that the CO travels eastward from the fires, reaching as far as the East coast and the Gulf of Mexico in a few days. Although the distribution of CO over the U.S. is clearly a combination of a variety of sources it is found that wildfires are a strong component of the summer tropospheric CO. *INDEX TERMS:* 0322 Atmospheric Composition and Structure: Constituent sources and sinks; 0345 Atmospheric Composition and Structure: Pollution—urban and regional (0305); 0368 Atmospheric Composition and Structure: Troposphere—constituent transport and chemistry. **Citation:** Lamarque, J.-F., et al., Identification of CO plumes from MOPITT data: Application to the August 2000 Idaho-Montana forest fires, *Geophys. Res. Lett.*, *30*(13), 1688, doi:10.1029/2003GL017503, 2003.

1. Introduction

[2] A product of incomplete combustion, carbon monoxide (CO) is an important indicator of fossil fuel and biomass burning. Large amounts of CO are released during forest fires, both in the active and smoldering phases of the fire [*Susott et al.*, 1991; *Hao and Liu*, 1994; *Cofer et al.*, 1998; *McKeen et al.*, 2002]. Because CO is a relatively long-lived species, with a lifetime of weeks to months in the mid-latitudes [*Brasseur et al.*, 1999], it can potentially travel long distances. In the process of identifying the separate contributions of natural and anthropogenic sources, this characteristic makes it difficult to identify the signature from a localized source, unless the associated CO signal is significantly above the background CO distribution.

[3] During the summer of 2000, large wildfires burned more than a million acres over the U.S. Northwest and Rocky Mountain region, with a particularly high intensity in Idaho and Montana. In particular, during the last 10 days of August 2000, large fires were active in the region between 44°N and 46°N, and 113°W and 117°W (Figure 1). To identify the location and extent of the fires we use Advanced Very High Resolution Radiometer (AVHRR) [*Malingreau et al.*, 1989; *Stocks et al.*, 1991] observations analyzed and compiled by the United States Forest Service for the Western portion of the United States (see http://www.fs.fed.us/r4/rsgis_fire/intro.html for details).

[4] During the same period, extensive CO measurements were taken by the Measurement of Pollution in the Troposphere (MOPITT) instrument, which was launched in December 1999 onboard the NASA EOS-Terra platform (see http://www.eos.ucar.edu/mopitt/for details). MOPITT has been collecting data since March 2000. The data consist of CO profiles and total column with a footprint of 22 × 22 km^2 enabling a global coverage in approximately 3 to 4 days [*Drummond*, 1992]. The MOPITT data have undergone extensive validation that indicates little to no bias in the retrieved CO profiles compared to in-situ measurements, especially in the northern mid-latitudes. The MOPITT validation procedure and analysis is documented in http://www.eos.ucar.edu/mopitt/. Specifically, over the United States, the retrieved CO profiles have a bias and accuracy of about 5% and 10–20%, respectively (L. Emmons, personal communication, 2003).

2. MOPITT Data Analysis

[5] Due to gaps in the MOPITT data from cloud clearing [*Warner et al.*, 2001] and swath patterns, it is necessary to combine several days of data to create a continuous picture. For that purpose, we bin the retrieved MOPITT data on a constant latitude-longitude grid. For this study, we use a bin size of 0.5 degree and a binning period of two weeks. In order for the binning to be statistically representative, only bins with at least 5 data points are considered. We focus our analysis on the retrieved values at 700 hPa (approximately 3 km of altitude) since this level provides an almost complete coverage of the continental U.S. While the MOPITT retrieved values are referenced at specific pressure levels, they are sensitive to a range of altitudes [*Pan et al.*, 1995; *Edwards et al.*, 1999]. Over the considered region,

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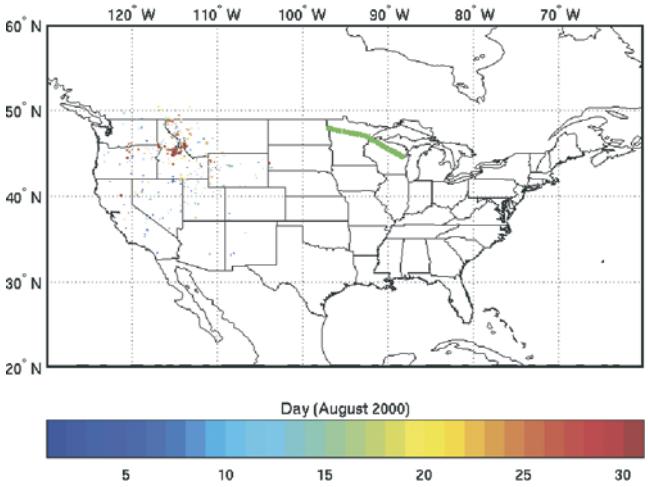

Figure 1. Composite of daily distributions of fires from AVHRR. Each observed fire is colored according to the day of observation. The thick green line is the COBRA flight track (see section 3 for details).

the 700 hPa averaging kernel [*Rodgers*, 2000] has a pronounced peak between 500 and 700 hPa, and with some contribution from 850 hPa [*Deeter et al.*, 2003].

[6] The 2-week binned MOPITT data are displayed in Figure 2 for the second half of August, i.e. when the fires are the most active. At that time, the location of the high CO values over the Idaho/Montana border coincides very well with the location of the fires (Figure 1). Significant CO values are also found 500 km downwind, eastward and northward, of the fires. From the average wind distribution (Figure 2), the 700-hPa flow at 45°–50°N over the West coast is mostly from the west, with a CO background of approximately 100–120 ppbv upwind of Idaho. Therefore, the 700-hPa MOPITT CO distribution hints at a considerable impact of the fires on the summertime CO distribution in the wake of the fires, with maximum mixing ratios larger than 200 ppbv. Over most of the Midwest and the East Coast, the MOPITT CO values range between 100 and 150 ppbv. These values extend all the way to Eastern Canada and the Atlantic Ocean. Also note the sharp gradient between the tropical air and the polluted continental air over the Gulf of Mexico and across Florida. Over all these regions, the CO distribution in MOPITT is however a combination of background, anthropogenic, and biomass burning (including other fires than the ones considered in this study) originating CO and it is therefore not clear how much the Western fires are contributing from the analysis of this figure only.

3. Model Experiments and Results

[7] In order to identify the transport patterns of the CO plumes from the forest fires, we use the NCAR/Max-Planck Institute chemistry/transport model MOZART-2 [*Horowitz et al.*, 2003] to follow the evolution of the CO released by the fires. The goal is also to identify the contribution from the Western (mostly Montana, Idaho, and Wyoming) fires only, i.e. their perturbation over the background CO distribution. Therefore, no other CO emission is considered in this model exercise. The simulation begins on August 1 (with the CO initialized to 0 everywhere) and the results are analyzed for the second half of August. The meteorological data were obtained from the NCEP Aviation forecasts. The model is run at a horizontal resolution of T170, approximately 50 km over the United States. The model has 42 vertical levels, including 8 under 900 hPa. Such a resolution should enable a relatively realistic representation of the transport of CO plumes.

[8] In order to limit the computational cost, the model simulates the evolution of CO only. The model uses an August 2000 OH distribution (which is responsible for the CO chemical loss) from a T42 simulation in which the full tropospheric chemistry is considered.

[9] The emissions of CO from wildfires are based on the timing, location, and extent of the Western U.S. fires as identified by AVHRR. First, we calculated the daily cumulative area for each identified fire. A comparison of the daily burnt area as calculated from the AVHRR fires extent and from the United States Forest Service ground reports (http://www.cidi.org/wildfire/index.html) indicates that our estimate might be low by 25 to 50% (not shown), but with a consistent time evolution. In this study, we make the assumption that the CO emissions from the forest fires are directly proportional to the burnt area. Because most of the fires in this study were forest fires, we use a single fixed ratio of 4250 kg of CO per ha of burnt forest [*Wotawa and Trainer*, 2000]. This ratio is an average value describing the active and smoldering phase of the fire [*Cofer et al.*, 1998] and is based on fuel densities for the boreal forests of northern Canada and Alaska. Following the analysis of *Leenhouts* [1998] (available online http://www.consecol.org/vol2/iss1/art1), we believe that such fuel loads are applicable to the fires considered in this study. We also assumed that the emissions are constant over the course of one day and set so that the daily area burnt is equal to the value found from AVHRR. Within these assumptions it is evaluated that over the course of the month of August, the fires released an amount of CO (approximately 9 Tg) equivalent to half the U.S. anthropogenic CO emissions for August.

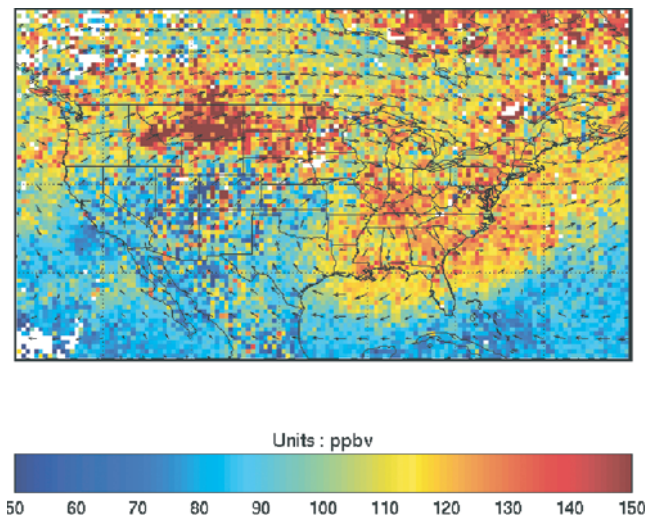

Figure 2. Composite map of MOPITT CO (in ppbv) measurements at 700 hPa (see text for details) for August 16–31, 2000, binned on a regular 0.5° × 0.5° grid. Average NCEP wind at 700 hPa is superimposed as wind vectors.

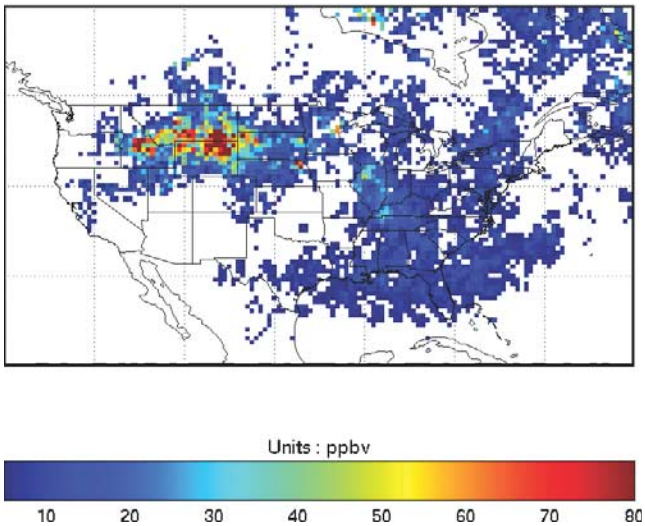

Figure 3. Same as Figure 2 but for the modeled CO tracer (see text for details).

[10] Since a significant fraction of CO is emitted during the smoldering phase of the fires, we release the emissions at the surface only. Results from this simulation are discussed below. However, as a sensitivity study, we perform a second simulation in which the emissions are equally distributed (in mixing ratio) between the surface and 5 km to simulate the effect of fire-initiated convection. Overall, the results from this second simulation are very similar to the base simulation (not shown). This indicates that in this study the model rapidly transports the surface emissions to higher altitudes, even without the explicit consideration of fire-initiated convection. Significant differences are noted below.

[11] Figure 3 shows the modeled concentration of the CO released by the fires, sampled at the time and location of MOPITT pixels and weighted in the vertical using the MOPITT averaging kernel valid for each MOPITT observation. This allows for a direct comparison of the model results and the MOPITT observations (Figure 2). As described in section 2, this method of displaying model results is different from displaying the model field at 700 hPa since it includes contributions from a pressure range centered around 700 hPa.

[12] The model results indicate a significant perturbation to the CO distribution at 700 hPa, as identified in the analysis of MOPITT data (see section 2). The location of the large CO values over Idaho, Montana, and Wyoming is the same in the model results and the MOPITT data. Similarly, the model accurately reproduces the transport of CO to the northeast coast of Canada. Finally, over Florida and the Eastern United States, the extent of the transport is well marked and coincides with the transition to tropical air seen in the MOPITT data. The ratio of the modeled CO from the considered fires (convoluted with the averaging kernel) to the collocated MOPITT data ranges between 10 and 20% of the CO over Florida and most of the East coast at 700 hPa. These ratios are indicative of a significant perturbation to the CO distribution but the actual values could vary from these estimates.

[13] It is clear that the modeled CO distribution does not always agree with MOPITT data. Although the model shows CO transport over the Eastern Canada, the values are somewhat lower than what MOPITT data indicate as increase over the background. Also, the high CO plumes in the vicinity of the northern Wyoming border are clearly not present in the MOPITT data. These high values are actually associated with a large fire in Idaho on August 26. The reason for the discrepancy is either a mismatch in the timing of the CO emission for this particularly large fire or more likely a misrepresentation of the boundary layer venting. Indeed, these high values are absent from the simulation in which the CO emissions are distributed along the vertical.

[14] To gain confidence in the accuracy of the CO distribution from the model, we compare the CO model distribution to the August 19 CO observations from the CO_2 Budget and Rectification Airborne (COBRA) experiment [*Gerbig et al.*, 2002]. On that day, the flight path (Figure 1) intercepted several plumes (Figure 4). The model results are interpolated to the time and location of the observations. Because the model only simulates the CO released by the fires, a constant background of 80 ppbv (defined by the values of CO in the COBRA data where the model shows no CO from fires) is added to the model CO only to help the comparison. In other words, the important features in the model results in Figure 4 are the intensity and location of the peaks.

[15] The model simulates successfully the timing and location of the main plumes, albeit at a coarser resolution than the 1-second observational data. In particular, for these plumes, the model CO provides a reasonable estimate of the CO increase due to the fires. It is however interesting to note that the model does not reproduce the high altitude (8000 m and above) plumes found in the data. This could be due to the lack of fire-initiated convection [*Clark et al.*, 1996] in the model that can rapidly bring large plumes to high altitudes. However, the simulation with vertically distributed emissions does not find those plumes either (not shown). It is also possible that those high concentrations are not related to the fires. But, at the highest altitudes

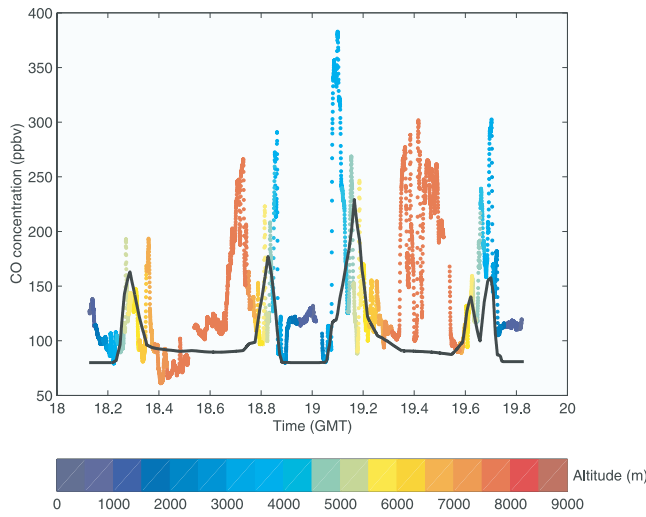

Figure 4. COBRA CO measurements (colored by the altitude of the measurements) and modeled CO interpolated to the time and location of the observations. This flight took place on August 19, 2000. A constant background value of 80 ppbv was added to the model values for ease of comparison.

of the flight, the COBRA data indicate that the ratio of the enhancements in CO and CO_2 ($\delta CO/\delta CO_2$) is approximately 0.11, consistent with biomass burning emissions.

[16] This comparison of the model results with *in-situ* measurements indicates that the CO distribution from the model describes reasonably well the emissions and transport of CO from the Western fires.

4. Discussion and Conclusion

[17] We have used MOPITT observations in August 2000 to identify the regions affected by the large forest fires in Idaho, Montana and Wyoming, and to a smaller extent in California, Washington, and Colorado. Using the fire location and area from AVHRR observations and a single CO to burned area emission ratio [*Cofer et al.*, 1998; *Wotawa and Trainer*, 2000], we have modeled the transport of the CO released by the fires and identified the transport of CO plumes over a large fraction of the United States east of the Rocky Mountains. Sensitivity to the vertical distribution of the emissions indicates little impact in this study.

[18] Significant amounts of modeled CO are found in the lower to mid-troposphere all the way to Florida and Texas. The comparison with the *in-situ* COBRA observations is used to demonstrate the model capabilities in reproducing the wildfires CO emission and transport.

[19] In the wake of the fires, the 700-hPa MOPITT retrieved CO concentrations reach up to 250 ppbv, indicating at least a doubling of the local concentrations from the fires. The model shows similar patterns and indicates that significant amounts of CO (estimated to be 10–20%) are found in the lower troposphere downwind from the fires. This study shows that the transport of the CO from forest fires can be successfully studied by the combination of satellite data (AVHRR fire location and MOPITT CO) and high-resolution chemistry/transport model. In particular, the study of the transport of CO plumes exclusively displays the perturbation above background from these fires and enables the clear localization and identification of the amplitude of the perturbation at the regional and continental scale. A study with the full chemical impact of fires is underway.

[20] The distribution of CO over the U.S. is clearly a combination of a variety of sources but Western U.S. wildfires can be a strong component in the seasonal and interannual variability of tropospheric CO, especially in the summer.

[21] **Acknowledgments.** We would like to acknowledge the insightful comments from P. Hess, C. Wiedinmyer, and an anonymous reviewer on a previous version of this manuscript. This research was supported in part by the NASA MOPITT project. The National Center for Atmospheric Research is sponsored by the National Science Foundation under the direction of the University Corporation for Atmospheric Research.

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