ASSIMILATION OF SCIAMACHY TOTAL COLUMN CO

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1 Abstract

Carbon monoxide total column observations from SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) on board ENVISAT are assimilated into the Global Modeling and Assimilation Office (GMAO) constituent assimilation system for the period April 1-October 31, 2004. SCIAMACHY is a near infrared spectrometer with nearly constant sensitivity to CO in the Troposphere. As such, retrievals should contain significant information on variability of CO in the boundary layer, where concentrations are significantly higher.

Carbon monoxide is retrieved from the 2324-2335 nm wavelength band (channel 8), in which the CO line is relatively weak, and is superimposed by stronger water vapor and temperature lines. This results in a large fraction of retrievals that are rejected as poor fits to the pre-selected vertical profiles. In addition, a significant portion of the retrievals are cloud contaminated and the retrievals use a correction factor from the ratio of retrieved to *a priori* methane column. The effect of this correction factor on the retrieval error statistics is not yet well understood.

In spite of these limitations, initial assimilation results have demonstrated that significant improvements to estimated CO fields can be made using SCIAMACHY observations. In this work we assimilate cloud free observations and compare changes to the CO field with *in situ* observations. Errors in the field are found to decrease globally above 800 hPa, and in some locations nearer the surface. We focus on three regions: Western Europe, Eastern North America and the Arabian peninsula.

2 Introduction

Carbon monoxide is an important atmospheric trace gas for the global carbon cycle and air quality. A number of recent satellite missions carry spectrometers that measure radiances at wavelengths sensitive to CO, including the Atmospheric Infrared Sounder (AIRS) [*McMillan et al.*, 2005], Measurements of Pollution in the Troposphere (MOPITT) [*Deeter, et al.*, 2003] and the Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) [Buchwitz *et al.*, 2007]. Infrared AIRS and MOPITT radiances are most sensitive to CO between pressures of 400 and 700 hPa. In contrast, the near infrared waveband from which SCIAMACHY CO is retrieved is sensitive to variations within the boundary layer.

Chemical constituent data assimilation involves combining observations with chemical transport models in order to improve estimation of the distribution or sources (in the case of chemical inversion). Assimilation provides a useful tool to evaluate the accuracy of retrieved satellite data. Total column measurements cannot be directly compared with *in situ* point observations without a knowledge of the complete atmospheric profile. However, if the analysis fields are drawn closer to highly accurate independent data as a result of assimilating satellite observations, it gives a strong indication that the latter provide useful information.

In this paper we evaluate the impact of SCIAMACHY total column CO observations on the CO assimilation system developed at the Global Modeling and Assimilation Office (GMAO) within NASA's Goddard Space Flight Center. The assimilation is evaluated using *in situ* observations from the Measurement of Ozone, water vapor, carbon monoxide and nitrogen oxides by Airbus in-service airCraft (MOZAIC) observing system [Nedelec,*et al.*, 2003]. We also consider what the assimilation and comparisons with *in situ* data can tell us about the source of errors in the model. The assimilation system is run for the period July 18 - October 31, 2004, with the last 2 months used for comparison with MOZAIC data.

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3 SCIAMACHY observations

Total column carbon monoxide observations are retrieved from SCIAMACHY using the WFM-DOAS algorithm, which is a least squares technique that uses the scaling and shifting of pre-selected vertical profiles to fit the ratio of the measured nadir radiance to the solar irradiance spectrum [*Buchwitz et al, 2007*]. The sensitivity of measured radiation to variations in CO at different levels in the atmosphere is characterized by the vertical column averaging kernels, shown in Figure 1). Each curve represents the sensitivity of the retrievals to changes in CO at each level, for different solar zenith angles (SZA). For SZA $< 75^o$, the averaging kernels are very close to unity, which means that SCIAMACHY is equally sensitive to CO near the ground as it is higher in the Troposphere. The observation data includes a cloud contamination flag, and in this work we only consider cloud free observations.

4 Assimilation system

The CO assimilation, developed at NASA/Goddard, uses the Physical-space Statistical Analysis System (PSAS) sequential algorithm , [Cohn, *eta al*, 1998]. The forecast error covariance is specified using a separable model with anisotropic horizontal error correlation (See [Stajner *et al*, 2001] for details). The forecast error standard deviation is assumed to be proportional to the the local CO mixing ratio. Tuning runs have been used to determine optimal parameter values of 20% for the standard deviation proportionality constant and 100 km for the correlation length scale.

The GCM uses the semi-Lagrangian transport finite volume scheme [Lin , 2004] with 55 vertical levels. The meteorological analyses are generated using the GEOS-4 assimilation system [Bloom, *et al*, 2005]. CO production and loss estimates use monthly climatological anthropogenic and biomass burning except for North America, where biomass burning specific to 2004 are used [Turquety *et al.*, 2007]. Monthly mean climatological OH concentration fields are used to specify CO destruction.

5 Results

The vertical distribution of the analysis increment from a single observation is shown in Figure 2. The large correction near the surface is due to the higher CO concentrations, which increases the estimated forecast errors in the boundary layer. This leads to the question as to whether the boundary layer corrections actually improve estimates of CO near the surface. Comparisons with MOZAIC data is particularly useful because it allows the calculation of error profiles in many different regions. Regional comparisons focus on three 10^o latitude $\times$ 10^o longitude boxes centered near Frankfurt, Germany; New York, USA; and Dubai, UAE. Separating the comparisons with independent data in this manner allows us to consider the impact of the geographic variability of the accuracy of the source estimates on the assimilation. The jet takeoffs and landings in each region provide CO profiles numbering from around 12 (Dubai and Abu Dhabi) to about 150 (Frankfurt) from near sea level to about 200 mb for the period September 1 to October 31, 2004.

Global comparisons indicate that the free running model (without assimilation) produces CO values that are too low in the mid to upper troposphere, possibly due to OH values that are too large. Errors in the model are less consistent nearer the surface, and are dependent on the accuracy of emissions inventories in each region. Figures 3-5 show the relative mean (left panels) and RMS (right panels) errors with respect to MOZAIC observations for regions near Frankfurt, New York City and Dubai, respectively. In all three regions, the assimilation is seen to reduce the mean and RMS errors in the free troposphere. However, near the surface the errors are reduced by the assimilation only over Dubai, where they are much larger.

Figures 6-8 show the two month average CO fields (ppmv) for the layer at around 700 hPa, over Western Europe, Eastern United States and the Arabian peninsula, respectively. The left panel in each is from the free running model and the right panel is from the analyzed CO fields. In this layer the assimilation is observed to substantially increase CO in all three regions, consistent with the fact that the model is generally too low at this level.

In the model surface layer the two month average CO values increase over the Arabian peninsula (Figure 9), but are essentially unchanged over Europe and eastern United States (not shown). This reflects the smaller errors in the free running model for the latter two locations. It may also be the result of far fewer cloud free observations over these regions. In fact, the biggest correction in the Arabian peninsula occurs at its center where the largest number of observations occur.

6 Conclusions

Assimilating SCIAMACHY carbon monoxide observations into an on-line chemical transport model is found to draw the CO fields closer to MOZAIC *in situ* observations. Improvements are most apparent above 800 mb in all three regions studied, but improvements near the surface are only significant in the Arabian peninsula. We have not found any regions where the assimilation SCIAMACHY CO substantially increases errors relative to MOZAIC observations.

The improvements found in the middle east raise the question as to whether SCIAMACHY observations can be used to determine which regions in the model have large emissions errors. The difference between the observation and forecast represents the difference between the total amount of CO seen by the satellite in the column and the projection of the model solution onto the observation space. These $(O-F)$s represent the sum of forecast and observation error, without explicit information on which error source predominates, or what level in the atmosphere should be corrected the most. The partition of these errors is specified through the error covariance estimates and in the averaging kernel. For SCIAMACHY this results in corrections to the CO field at all levels in the Troposphere. The large corrections and improved comparisons with MOZAIC shown in Figure 5 indicate that model errors in the middle east are larger than other regions. The improvements in the upper troposphere that are found in all regions could then be interpreted as a combination of low emissions estimates transported globally and values OH that are too high. Resolution of these issues will require sensitivity studies with different CO emissions and OH estimates.

7 References

Bloom, S.C., A.M. da Silva, D.P. Dee, M. Bosilovich, J.-D. Chern, S. Pawson, S. Schubert, M. Sienkiewicz, W.-W. Tan, M.-L. Wu (2005), Documentation and Validation of the Goddard Earth Observing System (GEOS) Data Assimilation System (DAS) - Version 4. Technical Report Series on Global Modeling and Data Assimilation 104606, NASA, Vol. 26.

Buchwitz, M., I Khlystova, H. Bovensmann, and J.P. Burrows (2007), Three years of global carbon monoxide from SCIAMACHY: comparison with MOPITT and first results related to the detection of enhanced CO over cities, *Atmos. Chem. Phys.*, *7*, 2399-2411.

Cohn, S.E., A. da Silva, J. Guo, M. Sienkiewicz, D. Lamich (1998), Assessing the effects of data selection with the DAO physical-space statistical analysis system, *Mon. Wea. Rev.*, *126*, 2913-2926.

Deeter, M.N., L.K. Emmons, G.L. Francis, D.P. Edwards, J.C. Gille, J.X. Warner, B. Khattatov, D.Ziskin, J.F. Lamarque, S.P. Ho, V. Yudin, J.L. Attie, D. Packman, J. Chen, D. Mao, and J.R. Drummond (2003), Operational carbon monoxide retrieval algorithm and selected results for the MOPITT instrument, *J. Geophys. Res.*, *108* (D14), Art No. 4399.

Lin, S.J. (2004), A "vertically Lagrangian" finite-volume dynamical core for global models, *Month. Wea. Rev.*, *132*, 2293-2307.

McMillan, W.W., C. Barnet, L. Strow, M.T. Chahine, M.L. McCourt, J.X. Warner, P.C. Novelli, S. Korontzi, E.S. Maddy and S. Datta (2005), Daily global maps of carbon monoxide from NASA's Atmospheric Infrared Sounder, *Geophys. Res. Lett.*, Vol. 32, L11801, doi:10.1029/2004GL021821.

Nedelec, P., J.P. Cammas, V. Thouret, G. Athier, J.M. Cousin, C. Legrand, C. Abonnel, F. Lecoeur, G. Cayez, and C. Marizy (2003), An improved infrared carbon monoxide analyzer for routine measurements aboard commercial Airbus aircraft: technical validation and first scientific results of the MOZAIC III programme, *Atmos. Chem. Phys.*, *3*, 1551-1564.

Stajner, I., L.P. Riishöjgaard and R.B. Rood (2001), The GEOS ozone data assimilation system: Specification of error statistics, *Q.J.R. Meteorol. Soc.*, *127*, 1069-1094.

Turquety, S., *et al.* (2007), Inventory of boreal fire emissions for North America in 2004: Importance of peat burning and pyroconvective injection, *J. Geophys. Res.*, *112* D12S03, doi:10.1029/2006JD007281.

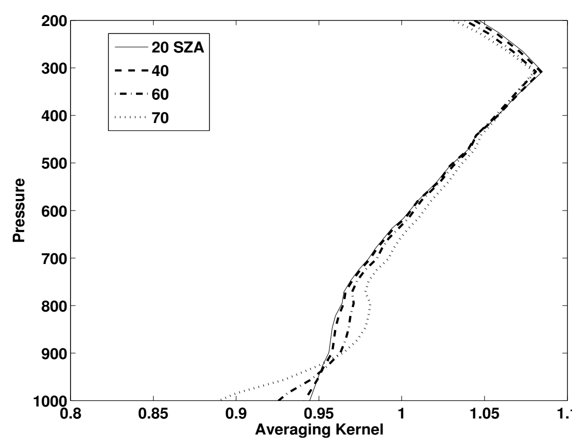


Figure 1: SCIAMACHY averaging kernel for Solar Zenith Angles (SZA) of 20, 40, 60 and 70 degrees.

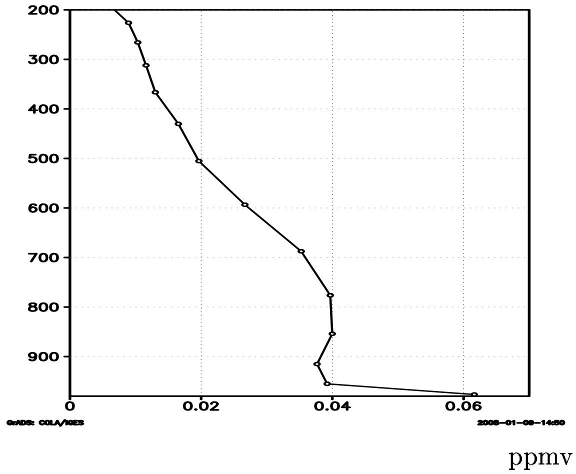
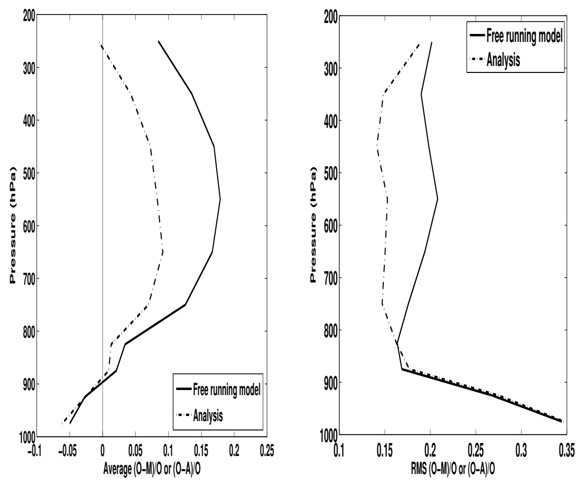
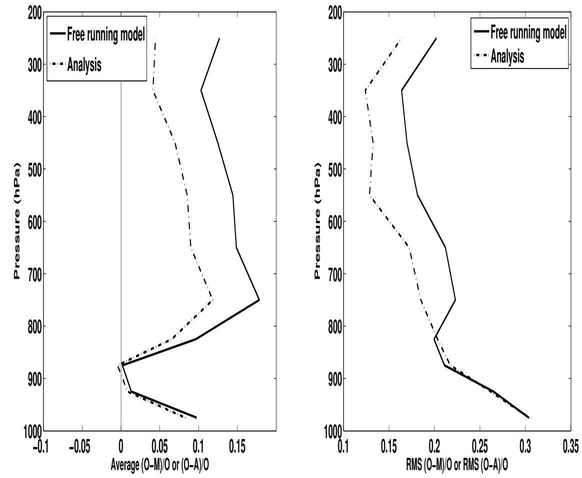


Figure 2: Vertical distribution of SCIAMACHY analysis Increment for a single observation in ppmv



(a) (b)

Figure 3: Relative mean (a) and RMS (b) errors for CO compared with MOZAIC data, for all flights into Frankfurt airport during Sept.-Oct. 2004. The solid line is for the free running model and the dashed line is for the analysis field.



(a) (b)

Figure 4: Relative mean (a) and RMS (b) errors for CO compared with MOZAIC data, for all flights into New York area airports airport during Sept.-Oct. 2004. The solid line is for the free running model and the dashed line is for the analysis field.

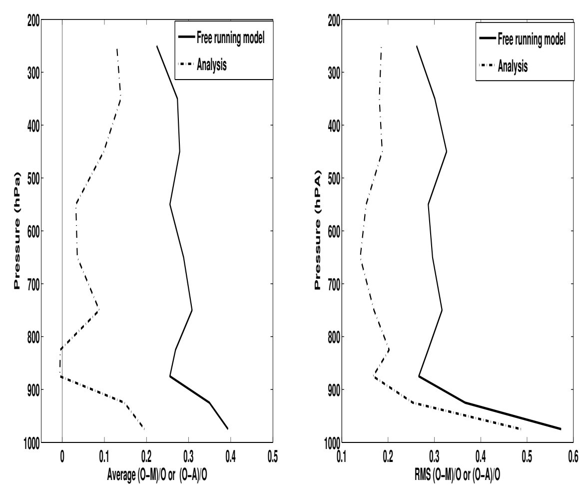


Figure 5: Relative mean (a) and RMS (b) errors for CO compared with MOZAIC data, for all flights into Dubai and Abu Dhabi airports airport during Sept. and Oct. 2004. The solid line is for the free running model and the dashed line is for the analysis field.

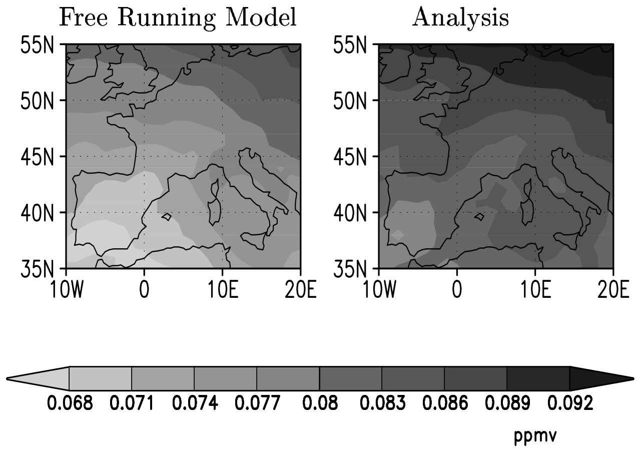


Figure 6: Mean CO field at model layer near 700 mb over western Europe for the months of Sept. and Oct, from free model run (left panel) and Assimilation (right panel).

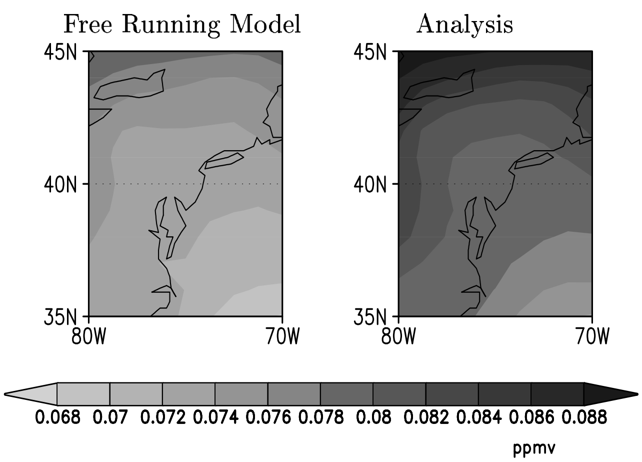


Figure 7: Mean CO field at model layer near 700 mb over eastern United States for the months of Sept. and Oct, from free model run (left panel) and Assimilation (right panel).

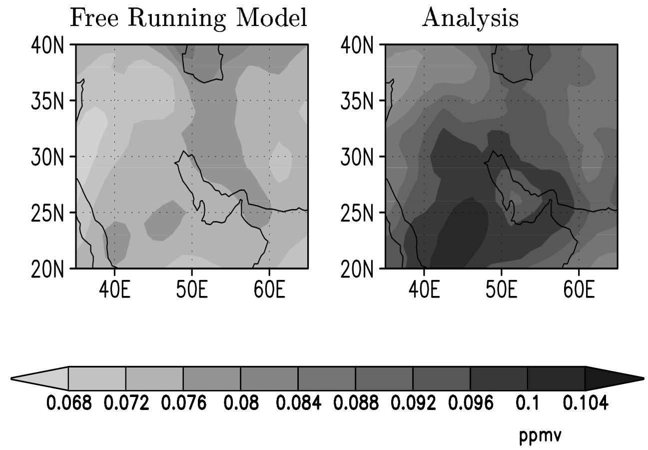


Figure 8: Mean CO field at model layer near 700 mb over the Middle East for the months of Sept. and Oct, from free model run (left panel) and Assimilation (right panel).

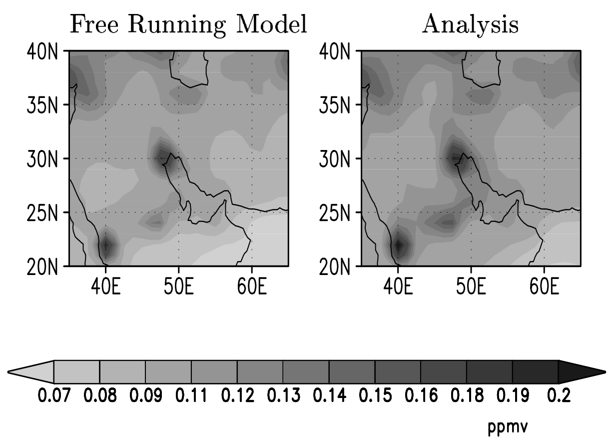


Figure 9: Mean CO field in the model surface layer over the Middle East for the months of Sept. and Oct, from free model run (left panel) and Assimilation (right panel).