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Atmospheric Measurement Techniques Discussions

Interactive comment on "Remote sensing CO_2, CH_4 and CO emissions in a polluted urban environment" *by* Denis M. O'Brien et al.

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We thank the reviewer for his constructive and helpful comments. The reviewer's comments are shown below in italics, while our responses are in normal font. Revised text is quoted (indented).

General Comments

General comment 1

I still do not understand well why tight CO uncertainty is need for convergence.

Our prior estimates for the CO profile deviate significantly from the truth. In each retrieval, we use the prior estimate as the initial guess. When aerosol is present, as it always is over Shanghai, we frequently found large negative steps in X_{CO}, which led to unphysical states that the radiative transfer code rejected. By using a tighter constraint, we found that the steps in X_{CO} were smaller, thereby avoiding many of the occurrences of negative X_{CO}.

The underlying reason is not clear, but we offer the following conjecture the failure of the L2 algorithm. First, the CO spectral lines overlap those of CH_4 and H_2O; indeed detecting the CO requires high spectral resolution to identify CO lines between the CH_4 and H_2O lines. Second, in response to an amplitude shift that varies slowly with frequency, such as that produced by aerosol, the retrieval algorithm mistakenly attempts to compensate by adjusting the gas concentrations. However, because the effect of CO on the spectrum is much smaller in this spectral region than that of CH_4 and H_2O, the adjustment made by the algorithm to X_{CO} often is too large, and results in negative X_{CO}. With a tight prior uncertainty, the CO profile cannot deviate far from the prior profile, resulting in fewer unphysical values.

In the results section 7.1 titled "Trace gas concentrations", we have added the following paragraphs after line 17 on page 12.

> The reason why a tight prior uncertainty for the CO profile assists convergence is not clear, but we offer the following conjecture. In response to an

amplitude shift that varies slowly with frequency, such as that produced by aerosol, the retrieval algorithm mistakenly attempts to compensate by adjusting the gas concentrations. However, because the effect of CO on the spectrum is much smaller than that of CH_4 and H_2O in geoCARB's 2323 nm band, the adjustment to CO concentrations made by the algorithm often is too large, and results in negative X_{CO}, which in turn causes the radiative transfer code to fail. With a tight prior uncertainty, the CO profile cannot deviate far from the prior profile, resulting in fewer unphysical values.

If this conjecture is correct the problem can be ameliorated by preconditioning the optimisation so that steps in X_{CO} are smaller. We note also that the masking of CO lines by CH_4 and H_2O lines will be reflected in the linear error analysis. It is reasonable to hope, then, that once numerical problems with the optimisation algorithm are overcome, the error statistics for X_{CO} will improve, perhaps considerably.

General comment 2

Is XCO error much reduced if the spectral resolution of 2.3 micron band is higher?

We believe that it would be because higher spectral resolution would allow individual CO spectral lines to be observed in the gaps between CH_4 and H_2O lines. As the resolution is degraded, the windows between CH_4 and H_2O lines narrow, until at low resolution the CO lines are barely detectable. We have initiated experiments to check these arguments. However, this work goes beyond the scope of the present paper where the spectral resolution of geoCARB is prescribed, so we have not modified the paper in response to the question.

General comment 3

How was the spectral resolution of 2.3 micron band for geoCARB selected?

We have added the following paragraph before the last paragraph of the discussion section.

Higher resolving power in the 2323 nm band probably would reduce the posterior error in X_{CO}, and thereby improve the flux inversions, provided the associated reduction in signal-to-noise ratio is not too large. However, the present design for geoCARB uses the same grating in two orders for the 2323 nm and 2065 nm bands, so the resolving powers will be the same for these bands. Furthermore, the parameters for geoCARB's 2065 nm band were selected to approximate the spectral performance of the 2065 nm band of OCO-2. Consequently, to obtain higher resolving power in geoCARB's 2323 nm band would require significant changes to the proposed instrument.

Specific Comments

Specific comment 1

Page 3 line 9, Page 6 Line 16, "model spin up" and " non-spin-up days". More explanation will help reader's understanding.

On page 3, line 9 we have replaced the sentence

> The chemistry version of the Weather Research and Forecasting model (WRF-Chem) was run for a total of ten days, allowing the extra day for model spin-up, to simulate the winds and trace gas concentrations over the target.

with the following:

> The chemistry version of the Weather Research and Forecasting model (WRF-Chem) was run for a total of ten days, allowing the extra day at the start for model spin-up, to simulate the winds and trace gas concentrations over the target. The initial spin-up period allows time for transients caused by inconsistencies between the initial and boundary conditions to decay.

We think that with this addition the later reference to "non-spin-up days" does not require further explanation.

Specific comment 2

Page 6 Line 9, "surface properties"
Brief explanation on typical surface albedo value of 4 bands over selected Shanghai region will be helpful.

In the geoCARB spectral band at 765 nm, the surface BRDF was interpolated from the MODIS BRDF at 645 nm and 859 nm. Similarly, the geoCARB band at 1606 nm used MODIS bands at 1240 nm and 1640 nm, while the geoCARB band at 2065 nm used MODIS bands at 1640 nm and 2130 nm. Lastly, the BRDF in the geoCARB band at 2323 nm was assumed to be the same as the MODIS BRDF at 2130 nm, because

MODIS BRDF is not available at longer wavelengths. This is the same procedure as used in earlier work, so we have omitted the description from the present paper.

Is surface albedo low enough to neglect multiple scattering between surface and aerosol?

We have many cases where the optical thickness of aerosol is significant. The radiative transfer code always takes interactions between the surface and aerosol layers into account. This is implicit in the discussion of the radiative transfer code cited in section 3.4.

Is it close to Lambertian surface?

The BRDF differs significantly from a simple Lambertian model. For example, the difference between the reflectance for forward and back-scattering from the surface often can be 25% of the average value. These variations are taken into account in the forward simulations of the Stokes vector at the top of the atmosphere. However, the retrieval algorithm assumes a Lambertian surface. Previous studies (for example the cited paper by O'Dell et al. (2012)) show that this limitation of the retrieval algorithm is a secondary source of error.

Specific comment 3

Page 7, Line 16
There are several versions in JPL and CSU retrieval algorithm for OCO-2 and GOSAT.

Reference or brief explanation is needed.

We used the algorithm as described by O'Dell et al. (2012), apart from the modifications outlined in subsections 5.1 and 5.2. We have replaced the opening sentence of section 5 with the following:

> The basic inversion algorithm developed by the Jet Propulsion Laboratory and Colorado State University for OCO, GOSAT and OCO-2, as described by O'Dell et al. (2012), was adapted to the spectral bands of geoCARB and applied to the simulated spectra.

Specific comment 4

Page 25, Figure 3
AOD in O2A band is not spatially uniform. Brief description of aerosol spatial distribution over the region is helpful.

Figure 3 shows the spatial distribution of aerosol over Shanghai in the four geoCARB bands at one time in the simulation. The spatial distribution changes from each time step to the next, depending on the winds, the boundary fluxes of aerosol and both the temporal and spatial distributions of sources within the region. Our simulations attempt to take these effects into account. We believe that Figure 3 gives an adequate impression of the complexity of the aerosol distributions and addresses the point raised by the reviewer.

Technical Corrections

Technical correction 1

Page 1, Line 9
Orbiting Carbon Observatory (OCO2) > Orbiting Carbon Observatory-2 (OCO-2)

Accepted and corrected throughout the paper.

Technical correction 2

Page 13, Line 15
ACOS appears firstly. Description of the ACOS team is needed.

Accepted and corrected. We have replaced the sentence beginning on line 15 of page 13 with the following.

> When analysing spectra from GOSAT and OCO-2, the Atmospheric CO_2 Observations from Space (ACOS) team introduced the concept of "empirical noise", which is treated like instrument noise but is intended to account for all sources of error in the retrievals. A similar approach could be adopted for geoCARB.

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