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Interactive Comment

Interactive comment on "Technical note: an interannual inversion method for continuous CO_2 data" *by* R. M. Law

R. M. Law

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Sander Houweling's review has been useful in identifying some gaps in the presentation of this work and in challenging some of the statements that I had made. It has encouraged me to re-examine the results and to perform some additional tests in order to better justify some of my reasoning. While this new analysis has had little impact on the conclusions reached, the reviewer raised valid questions that it was worthwhile to address. I detail below my detailed responses to each of the issues raised.

GENERAL COMMENTS

Method

The review raises two methodological issues a) the treatment of fluxes beyond the 12 months of the response length and b) how the posterior uncertainties compare between the sequential and batch inversion.

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Interactive Discussion

Discussion Paper

a) The sequential inversion described here uses response functions that are one year in length and the inversion is performed in two year blocks. An exponential decay towards a well-mixed background concentration is used to extend the 12 month response to 2 years. This information will be added to the text. After two years, the global distribution is assumed to be uniform and this 'offset' value is estimated by the inversion. It is true that the inversion neglects any contribution to the observed concentration from sources more than two years previously. It is unlikely that this will make any significant difference to the estimated sources since any signal will be very weak after two years, both spatially and temporally. The reviewer raises the question of the consequent incompatibility between concentrations reconstructed from the response functions and those generated from the forward simulation. Regardless of the treatment of the response function extension, this incompatibility will occur because the advection scheme used in the transport model is non-linear. This was discussed in the Appendix of Law et al. (2002)[L02]. An iterative solution was implemented there but a similar process tested here gave almost no improvement in the source estimates (RMS bias for 1982-1997 flux decreased from 0.125 to 0.120 GtC/yr). This implies that the non-linearity of advection is not the major cause of biased source estimates in this case.

b) The monthly uncertainties are very similar for the sequential and batch inversions except for the uncertainties on the December estimate. In December the uncertainties are over-estimated in the first iteration (as would be expected because the December estimates do not see the data constraint from the following January). The second iteration improves the December uncertainties, for many regions giving lower uncertainties than in the batch case. Presumably this results from ignoring the covariance. I will add information about this uncertainty comparison in Section 2.1.

Discussion

a) Comparison of current findings with previous work

The inversion set-up currently being used has been influenced by some of the limitations found in previous work. For example, L02 solved for only 22 regions across the globe and found that the results were unsatisfactory. A case study was then performed for Australia using grid-cell resolution. Here we take an intermediate path and divide the globe into 116 regions, giving smaller regions than previously except for Australia. This change in spatial resolution, along with a change in the number of sites being used in the inversion, makes any comparison with the previous work difficult. With that proviso, the results here appear to be broadly consistent with those of the previous work. The cyclo-stationary method provided a suitable test case, given that the tests used model-generated concentrations with annually-repeating transport.

b) Inverting real continuous data

It is my intention to use a similar inversion set-up to the one described here to try to invert real continuous data. It is true that there are currently only around 20 continuous sites world-wide and these are mostly in Western Europe and Japan, but the set-up can accomodate both continuous and flask measurements simultaneously. It remains to be determined whether it is better to construct monthly means from the flask samples or whether to use the measurements at the real sampling time. Some changes to set-up will be required: for example a different transport model will be used that can be run nudged to analysed winds, a different set of ˜100 regions will be used and some regions will be solved for both constant monthly fluxes and daytime only fluxes to better fit any diurnal cycle in the CO2 measurements. I will expand the Conclusions section to incorporate some of this information.

c) Priority of continuous measurements

This study indicates that estimates of interannual variability can be improved when continuous data are used in the inversion. Given that many of the site locations used here are currently sampling approximately weekly, the implication is that better source estimates could be achieved if measurements were taken continually instead. This

ACPD

3, S2414–S2420, 2003

Interactive Comment

study does not, however, give any clear indication whether these are the best locations for continuous measurements, since this depends strongly on what sources or component of the sources we want to estimate more accurately. It is worth noting that developments in the capability of continuous instruments (e.g. Francey and Steele, 2003) have removed many of the difficulties of older instruments, which required high volumes of reference gases and frequent operator intervention to maintain good links to CO2 standards.

SPECIFIC COMMENTS

Page 5979 Method

We use the MATCH transport model in the configuration used by Law and Rayner (1999) with 5.6 x 2.8 degree resolution and 24 levels. This information will be added in the second paragraph of Section 2.

Synthetic data provides a good test for the method development work presented here because the inadequacies of the inversion can be distinguished from other potential causes of error such as imperfect transport. It is clear that using synthetic data is a simpler case than using real data, which may not be well represented by grid-box average model concentrations etc. Thus it is likely that the results provide an optimistic view of the inversion performance, in both the 4 hour and monthly data cases. This will be noted in Section 2.2.

Page 5981 Data

a) Diurnal information

Since the fluxes used to create the synthetic data for this test have no diurnal variation, any diurnal variation in concentration is due to atmospheric transport alone. However in the real world, there will be useful information about the fluxes in the diurnal cycle of concentration. I have investigated how to solve for this information in a paper submitted to Global Biogeochemical Cycles (Law et al., Inversion of diurnally-varying synthetic

ACPD
3, S2414–S2420, 2003

CO_2: network optimisation for an Australian test case). I will note the neglect of diurnal variations in flux in section 2.2.

b) Confusion over sqrt(n) and data uncertainties

I agree that this section was confusing. I will re-write it and combine the information about the 4HR and MON inversions so that the reasoning behind the factor of two is clearer.

Page 5982

1981/1997 source estimates

It is true that the estimates for the final months in 1997 will also be less reliable and perhaps the ideal is to use mid 1981 to mid 1997 results, but it is generally more convenient to work with complete calendar years. Text will be added to the end of section 2.1 to note this.

Page 5983

Bias

a) Could it be temporal rather than spatial aggregation?

The basis functions are a constant flux through the month that the pulse is 'on' and then no flux (already noted in text) while the synthetic data were created from monthly fluxes with linear interpolation between months (will be added to the text). It is possible then, that this difference in temporal structure could contribute to the biases seen in the long-term mean estimates. To test this, a new set of pseudodata were created by keeping the input sources fixed through the month rather than interpolating between months. These new pseudodata were then inverted, giving a test case in which temporal aggregation should be eliminated. Overall there were very small improvements in the source estimates. For example, the root mean square bias in the 1982-1997 mean was reduced from 0.125 GtC/y to 0.124 GtC/y. Therefore it seems clear that tempo-

ACPD

3, S2414–S2420, 2003

Interactive Comment

ral aggregation is not a major contributor to the biases found here, although it could be more important in a real-world case when there will be larger temporal differences between the basis functions and the true sources.

b) Contrast with Law et al. (2003)?

The statement quoted from Law et al. (2003) was for an Australian test case where sources were estimated for each grid-cell over Australia. This effectively removed spatial aggregation as a cause of biased estimates. The statement quoted is applicable in that context but not in this case when spatial aggregation is apparently causing significant biases.

c) Contradiction with Kaminski, biases appear largest away from data?

I think that some regions show large bias due to an interaction of a poor data constraint with spatial aggregation. An example was given in L02 where it was shown how the inability to fit the data at Cape Rama, India by its local land region due to spatial aggregation led to large, incorrect sources in SE Asia as this region tried to improve the Cape Rama fit. There was only a weak response from SE Asia at Cape Rama (and little response at other sites) and so large source estimates were needed to try and match the data. It is likely that similar interactions are occurring here. I will add some of this information in Section 3.1.

MINOR COMMENTS

page 5979 Figure numbers

There was no reference to Figure 6 (except in the Table 1 caption) as I had submitted the tables and region figure as supplementary material. Since they have been included in the paper, I agree that it makes more sense to re-number figure 6 as figure 1 and to refer to it directly. I will do this.

page 5999 Figure 5

ACPD

3, S2414–S2420, 2003

Interactive Comment

I have rearranged these figures so that panels c and d are to the right of panels a and b. This should allow them to be larger, at least on the landscape, online page.

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Interactive comment on Atmos. Chem. Phys. Discuss., 3, 5977, 2003.