Response to Reviewers

Reviewer 3

We thank Reviewer #3 for their comments and suggestions on our manuscript "Inverse modelling of New Zealand's carbon dioxide balance estimates a larger than expected carbon sink". In the text below, we have included all the original reviewer comments and suggestions in black, followed by our response and relevant manuscript changes in red. Page and line numbers refer to marked-up manuscript version.

Review of "Inverse modelling of New Zealand's carbon dioxide balance estimates a larger than expected carbon sink" by Beata Bukosa et al.

I read this interesting manuscript submitted for publication in ACP. The paper uses observations of CO2 from two sites in New Zealand, an inverse model that uses for transport modelling and land fluxes from two terrestrial ecosystem models plus oceanic exchange fluxes. The paper is very detailed and well written. However, as it appears from the writing, the authors are finding it difficult to reconcile the inversion estimated flux of CO2 with the country level estimations by bottom-up methods or those predicted by the land models. I have one concern that is the handling of the boundary condition which is most tricky in original model when simulating the long-lived atmospheric constituents. I am fairly convinced that this paper should be published, but a follow-up study with a variety of boundary conditions would be of interests for the research community.

We thank Reviewer #3 for their careful revision of our paper and feedback. We have provided additional information about the boundary conditions in our answers below.

Specific comments:

Line 42: typo – scalMOLes Fixed (Line 42)

Line 51-53: a bit of overstatement here, given that you are still struggling with reconcillation of bottom up and top down estimations. Of course, it is possible to get good comparison for a specific set of results which may not be universally applicable.

We appreciate the reviewer's comment and understand the concern regarding the reconciliation of bottom-up and top-down CO_2 flux estimates. While differences between these approaches are expected, especially given the complexities of CO_2 flux estimation, our intent was to highlight that national-scale inverse modelling remains the most successful and widely adopted approach for independent verification of national CO_2 budgets. The fact that only a few countries have successfully implemented these methods reinforces the challenge of applying them to CO_2, rather than diminishing their validity. That said, we recognize the importance of clarity and would be happy to adjust the wording if the reviewer finds it necessary.

Figure 2: this is one of the most important plots in my view because the clear offset with background, as seen from panel b at Lauder, will produce more pronounced sinks around Lauder, that is, the South Island of New Zealand.

That is correct, the measurements itself are already highlighting a net CO_2 sink in the South Island (now Figure 3).

Line 121-124: i think this is likely a wrong construct of the inversion, when the zonal winds are very strong over NZ! You probably need to use a global model providing 3D concentrations of CO2 for use as a background, possibly after adjusting to BHD & TF5 measurements.

We agree that the South and Northern baseline can introduce uncertainties in the background due to zonal winds. To evaluate the sensitivity of our results to this approximation, we have also tested a 3D concentration model (CarbonTracker, Section 4.2) as a background. Implementing CarbonTracker led to some differences in the national CO_2 sink (Figure 15). However, the differences were within uncertainties and they did not impact our results and conclusions in the paper. We have decided to keep the BHD & TF5 measurements as the background in our base inversions, since the 3D field are also subject to uncertainties.

Line 144: how do you define the planetary boundary layer-does it change with hour of the day? What data and method is used to determine the PBL height?

The planetary boundary layer height is a diagnosed quantity from the model. It is dependent on the boundary layer type diagnosed by the model's boundary layer scheme on every model (dynamic) timestep in each grid box. Therefore it can change throughout the day and we output it every 30 minues from the New Zealand Convective Scale Model (NZCSM). A detailed description is available in Section 3 of https://code.metoffice.gov.uk/doc/um/latest/papers/umdp_024.pdf (accessing the document requires registration with MetOffice).

Figure 8: as expected from Figure 2b, the inversion results for South Island, in particular south of Lauder, show strong negative values or CO2 sink.

That is correct (now Figure 3b).

Figure 9: the issue of strong sink south of Lauder is further clear from this plots. The green bars are bigger compare to the black ones for the regions 13 to 15.

That is correct (now Figure 10).

Figure 17: are these a priori or a poste? in any case they can clearly see the observed concentrations were lower than the model in the case of Lauder . And then as expected you would need more sink in the south ern part of the South Island (Fig. 9)

These are the posterior values (minus the observations), which is specified on Line 558: '*Residuals represent the differences between the modelled and measured CO_2 mole fractions, with the modelled values being the optimized CO_2 mole fractions by propagating the posterior flux estimates through the inversion.*'

Figure 17: caption can start with "Model – measured …"

We have modified the caption (now Figure 18).