Response to Reviewers

Reviewer 1

We thank Reviewer #1 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.

General comments:

This paper presents an update to a previous study (Steinkamp et al., 2017) that estimated New Zealand's CO_2 uptake from atmospheric CO_2 measurements. This new study provides a significant update, as it extends the original 3-year study to 10 years, it improves the resolution of the atmospheric transport by a factor of about 10 (which was important to test due to New Zealand's complex topography), and used 2 prior terrestrial models that have been calibrated with country-specific data (in contrast to the Steinkamp study that used one model that was not calibrated for New Zealand). It is worthwhile that these improvements have been made to confirm the general conclusion of the Steinkamp study that the observations show strong CO_2 uptake by forests in New Zealand.

The paper is very well written and worthy of publication. My main comment is that it would be worthwhile putting the key details of the inversion methodology into the main part of the paper (e.g. move Section S1 to the main paper, or if condensed then include that the inversion is solved analytically, for fluxes in 25 regions at weekly resolution, there is a smoothing on week-to-week variations). The paper currently doesn't really describe well enough what are the unknowns that are solved for - are these scale factors for the regional fluxes for 25 regions x number of weeks? And also that the spatial flux pattern within regions is maintained. As part of this, I would recommend moving Fig S1 from the Supplement to the main part of the paper, which will also help with some of the discussion later. Even though all of the details are in Steinkamp, I believe the main details of the inversion should be repeated here in the main paper, as the inversion is so central to the study.

We thank Reviewer #1 for their careful revision of our paper and feedback. As suggested by both Reviewer #1 and #2 we have moved the inversion description from the Supplementary Information (S1) to the main paper (now Section 2.1) and provided additional information about the inversion system, outlined below.

Specific comments:

Line 139 - I would emphasise that the custom NZCSM was at ~1.5 km (i.e. "... input data for the period 2014-mid 2016 at 1.5 km (herinafter ...". Also, at line 146, I would put "... so the mid-term switch from NZLAM at ~1.5 km to NZCSM-generated input data at ~12 km spatial resolution was considered ...". Neither of these changes are critical, but I think they would aid clarity.

We have added the information that the custom NZCSM model was also at a ~1.5 km spatial resolution (Line 171) and specified the spatial resolution between NZCSM and NZLAM when discussing the switch between models (Line 178).

Line 153 - Perhaps change to "time-disaggregated modelled footprints ..." or add other information to explain the disaggregated footprints a bit more.

We have modified the text to say time-disaggregated instead of disaggregated for clarity (Line 185).

Line 188 - there's not much Northwest at Lauder with NZLAM, mainly north.

We have corrected the text to North only (Line 221).

Fig 5 - I would put the NZLAM to the left of NZCSM, in the order they are used in time, so either (Meas, NZLAM, NZCSM) or (NZLAM, NZCSM, Meas) - the 2nd option is probably better. In the caption, I would put '(top)' after 'Baring Head', and '(bottom)' after 'Lauder'.

We thank the reviewer for the suggestion. We have corrected the plot and figure caption as suggested, the updated order is: NZLAM, NZCSM, Meas (Page 11).

Line 197 - I presume this sentence means that the prior fluxes were used "with the observations in the inversion" to estimate the posterior fluxes. It could be misunderstood how it is.

That is correct. The prior fluxes were used with observations (and a transport model) to estimate the posterior fluxes. We have updated the sentence for clarity (Line 231).

Line 312 - What does it mean that you "used" the individual flux components? These components were both estimated in the inversion?

While Gross Primary Production (GPP) and Ecosystem Respiration (ER) were not estimated in the inversion, our inversion system provides an estimate of the Net Ecosystem Exchange (NEE). However, we used the individual GPP and ER components to define the uncertainties for the prior NEE fluxes. We used the individual terms, instead of only NEE, to avoid low uncertainties at times, especially in spring and autumn, when fluxes were very small and could switch between negative and positive. It also provided a better representation of the CO_2 seasonal cycle in the uncertainty term (i.e., leading to lower uncertainties in winter when both GPP and ER were small).

Line 143 - It would help with this text if Fig S1 was in the main paper. In the previous sentence, the region name is mentioned before the number, I like this better than mentioning the number first (you do need to mention both).

We have moved Figure S1 into the main paper (now Figure 1, Page 5), as suggested.

Figs 10 and 11 (and perhaps elsewhere) - The captions say 'air-land flux', but a negative value in the figures indicates a positive air-land flux (uptake) and a positive value in the figures indicates negative air-land flux (source, or land-to-air flux). This could be misleading, and worth specifying in the caption what positive and negative values indicate, and possibly using a different term from air-land flux to avoid the implication of a direction of flow for a positive value. Steinkamp's Fig 5 y-axis label is land-to-air flux.

We have modified the 'air-land' (and air-sea) flux term to 'land-to-air' (and sea-to-air) flux in the figure caption and throughout the text (both main text and Supplement) and stated that negative values suggest an uptake while positive values suggest a net source of CO_2 (Line 110).

Line 510 - "the overestimated sink is less pronounced" - this could be expressed more clearly.

We have added additional text to clarify (Line 547). Specifically: *"for later years the overestimated sink due to the diurnal cycle bias is less pronounced, and the results even suggest and underestimated sink (Fig. S16)."*

Fig 17 - Put a thin black zero line over the top of the plots so it is clear how the data compares to zero. Also, adding a scale and tickmarks to the right side of the right plots would help too.

We have added the zero line to each subplot (red colour, since black was not visible enough), and tickmarks on the right side (Page 28).

Line 556 What two features does "Both features" refer to? The previous sentence only mentions one feature (supressed autumn/winter respiration).

We have corrected the text (Line 597), we were only referring to the supressed autumn/winter respiration, hence this was a mistake in the text.

Line 572 - "in the prior" - is this supposed to be "compared to the prior"? Or "in the prior" if it was included in the prior model? This part of the sentence is not clear.

It is "in the prior ", referring to the exclusion of the animal respiration process in the prior model (Biome-BGCMuSo). We have updated the text to clarify (Line 613).

Line 751 - 'less sensitive' that what? Than to the other regions?

That is correct, we were referring to the other regions. We have updated the text to clarify this statement (Line 793).

Section S1 - What are the unknowns that are solved for in the inversion? I.e. what is x? Are they scale factors for the priors in the 25 regions? As mentioned above, some details of the inversion system should be described in the main paper, and I would put all of Section S1 into the main paper, with a bit of extra detail.

We have moved the entire S1 Section into the main paper (Section 2.1), and we have provided additional information about the inversion system. Specifically, '*Our inversion system was estimating absolute net CO_2 fluxes, rather than scaling factors, for 25 geographic regions (Fig. 1) on a weekly scale, with negative land-to-air fluxes suggesting a net CO_2 sink and positive values pointing to a net source. Since we estimated regional fluxes, the spatial flux pattern within regions was maintained.*' (Line 109).

Typographical errors/technical corrections:

Line 57 - It could be useful to add '(boundary conditions)' after 'background values', as some other studies use this terminology. Fixed/Added (Line 57)

Line 42 "scalMOLes" Fixed (Line 42)

Line 173 - replace ':' with 'see', Replaced (Line 206)

Line 229 - Fore New Zealand Fixed (Line 265)

Line 324 - move comma "Australian, region" Fixed (Line 358)

Line 340 - add "such" - "such as the" Added (Line 374)

Line 403 - 'report' -> 'reported. Give a reference for the Inventory here. Fixed and reference added (Line 440)

Line 479 - 'process' -> 'processes' Fixed (Line 516)

Line 543 - 'owing' -> 'showing' Fixed (Line 583)

Line 643 - add 'on the' after 'depending' Added (Line 684)

Line 771 - Check the end of the sentence 'and other .' Checked and fixed to 'and other regions' (Line 814)