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Interactive comment on "Ecosystem responses to elevated CO_2 using airborne remote sensing at Mammoth Mountain, California" *by* Kerry Cawse-Nicholson et al.

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Review response to SC1

The authors thank Prof. Ballantyne for the positive review and useful feedback on this manuscript. This paper aimed to demonstrate the capability of both the natural elevated CO_2 experiment and the collection of airborne instruments to provide innovative ecology results.

We have responded to specific comments in red below:

Review: Ecosystem responses to elevated CO_2 using airborne remote sensing at

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Discussion paper

Mammoth Mountain, California

In this analysis Cawse-Nicholson use a volcanically active site where elevated CO_2 fluxes have been monitored as a natural experiment to test vegetation response using remote sensing approaches. Given the contradictory results from previous studies at this site, it seems logical to revisit using new approaches. The rationale and methods for this study seemed logical and it provides a nice testing ground for testing a range of remote sensing techniques. I was quite surprised by the results showing the apparent suppression of growth (i.e. negative relationship between NDVI and soil CO_2 flux), especially because this main conclusion was not clearly stated in the title or the abstract. It seems that the forests in this volcanic setting are responding adversely to something, but it is not clear why it would be elevated CO_2 concentrations. I think that most folks reading the title, perhaps the abstract and looking at the figures will be a bit perplexed as I was. This is a really fascinating study system that is fairly complex in terms of terrain and gases emitted.

We thank you for noting the innovativeness on using volcanically-derived elevated CO_2 as a means to assess long term ecosystem responses through remote sensing approaches. Some of the results were indeed unexpected — but, this is exactly why such a study is needed. It may be possible that the NDVI decrease is due to a progressive nutrient limitation, as has been suggested throughout the literature, but has never been tested empirically. However, much more in depth investigation is required to determine the underlying mechanisms explaining the results. As such, we frame this paper as more suggestive than conclusive, ideally leading to further work on this topic.

General Comments: The authors go to great lengths to control for distance from these hotspots of CO_2 to derive a gradient over which to investigate vegetation responses, which is no easy task, especially using remotely derived metrics over complex terrain. In particular, I wonder how cold air drainage at night affects CO_2 concentrations at these sights (Pypker et al. 2007). It is conceivable that much higher CO_2 concentrations are found downslope than upslope or adjacent to these CO_2 efflux hotspots

(Fig. 2a). In fact, biomass hotspots appear to be adjacent or downslope from the CO_2 hotspots (Fig. 2b); although it is difficult to discern without elevation contours.

We agree that a more thorough assessment of CO_2 flow through the landscape is needed. It is remarkable that we were able to detect clear signals from soil fluxes alone; we expect that the results would be improved with above- and within-canopy CO_2 measurements, and better tracking over time. Given the available measurements from USGS, the best we could do was shift the ground CO_2 dataset in all cardinal directions, to see if this resulted in an improved fit. The best model fit was found at the original ground CO_2 location. We will include elevation contours in the revised manuscript.

Where on the A-Ci curve are we operating? The vegetation at these sites is responding to the partial pressure of CO_2 in the atmosphere, among other gases at this site. Figure 1 suggests that the CO_2 flux was maybe 2 orders of magnitude greater than typical estimates at non-volcanic sites (Jensen et al. 1996), but what is the partial pressure of CO_2 in the atmosphere at these sites. I suspect that we are operating well above the asymptote on the A-Ci curve(Tissue, Griffin, and Ball 1999), such that we would see very little vegetation response to even large changes in the partial pressure of CO_2.

The partial pressures at Mammoth are about 60% of sea level. The fact that we see systematic ecosystem effects suggests that elevation is not on the flat part of the A-Ci curve. In other words, even if elevation were to reduce the CO_2 effect, we still are seeing strong CO_2 effects regardless, highlighting just how important and strong of a response we are able to detect. We will add this discussion to the revised manuscript.

What are the other gases are being emitted from this volcanic field? The negative relationship between CO_2 soil flux and NDVI is perplexing and needs explaining. Are these particularly sulfur rich volcanic fields? Has anyone developed a 'rotten egg' remote sensing index? No but seriously, if there are significant sulfur emissions this could be leading to sulfuric acid deposition and cation loss from the soils, such that the negative response to soil fluxes could actually be the result of another gas that is detrimental to plant growth other than CO_2.

There is no significant H_2S nor any SO_2 present at soil levels at this site; see, for example, data in Sorey et al 1998, Werner et al, 2014, and a number of papers on volcanic degassing at Mammoth Mountain by our USGS co-author Lewicki (2006, 2007, 2008, 2012, 2014). Furthermore, the direct areas of CO_2 emissions, which impacts the local soil conditions, do not contain any vegetation (kill-zones) and were removed when we used a threshold for fractional cover. We will add and clarify this detail in the revised manuscript.

Specific Comments: The abstract is a bit vague reporting statistical relationships but not the apparent negative response to increased soil CO_2 flux and without any response numbers (change in NDVI per change in Soil CO_2 flux).

We will add more statistics to the revised manuscript.

P2 L14 to 26 Perhaps the most fundamental flaw of FACE studies is very few have concomitant warming, which greatly limits ourinsight for the real world.

The FACE studies have been invaluable to our understanding of the CO_2 effect, which contributes to among the largest uncertainties in projections of Earth's climate. While it is true that they primarily assess CO_2, we argue that the actual biggest limitation of FACE is the short durations —there has been no way to assess long-term changes in ecosystems. This is where the long term emissions of volcanic CO_2 can play a game changing role in how to assess the long term CO_2 effect on ecosystems.

P3 What other gases are being emitted from these volcanic fields.

As discussed above, CO_2 dominates by up to 99% of gas volume.

P3 L37 'can be applied'

This will be corrected.

P4 L20 is this g C or g CO_2 per day...you might want to make this absolutely clear in the units

These are $g.m^{-2}.d^{-1}$ of CO_2, and will be clarified.

P4 L27 why were these data not just aggregated to a coarser resolution. Further smoothing of already smooth data may lead to loss of meaningful variance.

The original raw field CO_2 flux measurement data are no longer available. We worked from the 1m data that were provided to us by the USGS, which are aggregates of data collected by several different surveys in the 2011–2012 time frame, with the Horseshoe Lake area visited multiple times to characterize any very subtle temporal variation (Fig. 1 in Werner et al, 2014).

P5 L20 some discussion of cold air drainage important in this mountainous terrain (see Pypker below).

Thank you, we will include this discussion and reference.

P7 L 12 as demonstrated by the authors- where?

As demonstrated by Ma et al (2018). This will be made clearer in the next version.

P11 L 18 Why not use a random forest model to identify variables of greatest importance.

We considered random forest models and obtained similar result. We presented the results of the linear regression since the model itself is more easily interpretable by the reader.

P12 L3 'well modeled' be more descriptive precisely or accurately?

Canopy height and biomass were accurately modelled with high R^2. Will edit in the revision.

Fig. 1 could benefit from a log y-scale or even better some estimate of pCO_2

This will be modified in the revised manuscript.

Fig. 3 the caption seems to be incomplete in describing all the panels.

This will be modified in the revised manuscript.

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