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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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Anonymous Referee 1

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Overview and significance In this analysis Cawse-Nicholson et al. describe ecological attributes measured through several remote sensing platforms in relation to ground-measured and modeled elevated CO2 originating from volcanic degassing. The primary objective and novelty of this study is to estimate the impact of elevated CO2 on plant growth and whole ecosystems by utilization naturally occurring gradients of ele-

vated CO2 from volcanic degassing. Previous experiments and studies in estimating the impact of elevated CO2 on plants and ecosystems approach scaling limitations; whether through limited species diversity, space or time of exposure to elevated CO2, and/or cost of artificially elevating CO2. Therefore conclusions of experimental CO2 enhancements are limited to relatively few species and over short periods of time without leveraging natural gradients of elevated CO2. Methodologies to use natural CO2 gradients in determining plant and ecosystem responses to elevated CO2 described herein, in conjunction with elevated CO2 experiments, will fill important gaps in understand how individual plants to whole ecosystems will respond to continually increasing levels of CO2. The hope for the methodology described herein is for it to be applied where gradients of CO2 exists in order to understand the impact of elevated CO2 across multiple biomes.

We thank the reviewer for noting the novelty of our study in overcoming scaling limitations of previous studies, and the important gap that we aim to fill in understanding how plants and ecosystems will respond to continually rising CO2.

General comments: The authors outline their objectives as 1. Evaluate the viability of using a passively degassing volcano system to study the properties of ecosystems; 2. assess the detectability of ecological responses to elevated soil CO2 emissions via airborne data alone; 3. Present key lessons enabling future studies to extend our framework to other biomes.

Objective 1 is approached using soil CO2 flux measurements at a spatial resolution of 1 meter. This was made possible through the records of soil CO2 flux measurements at Mammoth Mountain. The authors acknowledge that measurements from soil CO2 fluxes will be much different and more stable than atmospheric fluxes of CO2 (page 5 line 10 and page 15 line 35). This approach makes estimating actual atmospheric CO2 measurements intractable under known methodologies but is strong enough to infer that atmospheric CO2 was greater than background where soil CO2 flux was greater.

Mammoth Mountain included a tree-kill zone for which the authors selected the trees around this zone. The presence of a tree-kill zone naturally leads to hypotheses that elevated CO2 will have a negative effects on vegetation at some point up the CO2 gradient. Previous studies pointing this out are cited in the manuscript and detected by NDVI (Rouse et al. 2010 and Cholathat et al. 2011) and through tree ring anal- and biomass measurements derived from Lidar as proposed in Objective 2. Soil CO2 flux was shown to be a significant predictor for these indices and remotely sensed attributes. While the vegetation indices are all slightly different they are largely related to one another vs. the other measurements of biomass, plant foliar traits, and canopy evapotranspiration. Some explanation as to why looking at several different vegetation indices and comparing each individually to enhanced CO2 may be beneficial for understanding how plant physiology is impacted and what methodologies may be selected in investigating other biomes (Objective 3).

While all vegetation indices are indeed related, they differ enough to be considered independent variables. E.g. some account for soil moisture, others weigh plant greenness more heavily. This was an exploratory effort in investigating the effects of CO2 on any measure of plant function, composition, and structure, and so we attempted to cover all avenues of investigation. A note to this effect will be included in the next revision of the manuscript.

We note for clarification that the “kill-zone” is the exact location of volcanic gas seeps along fractures, where CO2 is predominantly emitted from the soilâĂŤa property of the soil being altered by the emission; but, we focus on the “fertilization zone”, which is away from those emission points, with unaffected soils, where tree canopies are exposed to the CO2, which has diffused in the atmosphere away from the emission points.

The hypothesis and observations that elevated CO2 has negative effects on vegetation is contrary to many greenhouse and FACE experiments of artificially enhancing CO2, but is likely related to the intensity of elevated CO2 at the volcanic site. The authors

also speculate that elevated soil CO2 may lead to oxygen deprivation of roots and soil acidification (page 15 line 34 and cited in Farrar et al., 1995; Qi et al., 1994; McGee and Gerlach, 1998). This has major confounding effects on being able to use volcanic degassing to detect the impact of elevated atmospheric CO2 on photosynthesis and carbon sequestration if suitable soil chemistry for plant growth becomes a limiting factor. Rouse et al. (2010) did observe that in multispectral analysis of vegetation revealed that plant vigor degraded under high CO2 but slightly increased under low CO2. Along the same lines that Cawse-Nicholson et al. have speculated, slight increase in plant vigor may exist in zones where soil O2 is still above a certain threshold and/or soils are adequately buffered. I suggest that in order for the methodology put forth by Cawse-Nicholson et al. to effectively capture the impact of elevated atmospheric CO2 on ecosystem traits that measurements be made of soil O2, soil pH, and atmospheric CO2 be made in future studies. As is, the study of Cawse-Nicholson et al. provides a valuable step forward in being able to scale-up the impact of elevated CO2 on plants to whole ecosystems and across differing biomes.

We thank the reviewer for complementing our study as a valuable step forward, as well as the suggestion for measurements in future studies. As one of our objectives was to provide guidance for future studies, these suggestions fit well with our objectives.

As in our previous response above, we will clarify that any vegetation impacts are due not to soil changes from direct CO2 emissions, as we excluded the emission zones from our study. We will also clarify that the effects should not necessarily be given a subjective description of ‘negative’; rather, it is important to note that the CO2 fertilization effect is unlikely to continue indefinitely, particularly at the same rates that FACE studies have shown only in the short-term. All other experiments have been unable to show long-term effects. Our study suggests that over the scale of decades, some of these hypothesized greening or biomass increases may not be sustainable. Other results, such as an increase in canopy nitrogen with increasing CO2, do seem to remain consistent with our study, however.

Specific comments: - Table 2. As the primary subject of this paper is elevated CO_2, a complete ranking of the explanatory variables against CO_2 would be informative even for dependent variables in which eCO_2 was not the most influential variable.

This is a good suggestion, and the complete ranking will be included.

Technical corrections: Page 11 line 15 slope and aspect seem mixed up as slopes of 350 are not feasible.

Thank you. This has been corrected.

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