

Interactive comment on “Ecosystem responses to elevated CO₂ 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-

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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.

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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 green-ness 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 soil—A 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

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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.

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Specific comments: - Table 2. As the primary subject of this paper is elevated CO₂, a complete ranking of the explanatory variables against CO₂ would be informative even for dependent variables in which eCO₂ 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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