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Interactive comment on "Designing a network of critical zone observatories to explore the living skin of the terrestrial Earth" *by* Susan L. Brantley et al.

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We appreciate the comments on our paper reviewing the arc of CZ research and proposing a strategy for the future design of an observatory network. We found the reviewers' comments thoughtful and helpful as discussed below. We also appreciated the comments from outside the U.S.A., specifically reviewers from Sweden (K. Bishop) and Australia (E. Bui), who attest to the importance of the CZ concept. Both E-Surf reviewers suggested we improve the structure of the manuscript. As pointed out by Tunnicliffe, we now see the utility of bringing Section 3 forward in the article. This will bring the discussion of the intellectual heritage ahead of the discussion of funding strategies to provide a more logical sequence that emphasizes the evolution of scientific thinking. We will also emphasize the four common elements of CZOs earlier in the paper, perhaps in the new section incorporating Section 3. We will also work on paragraphs 3 and 4 as suggested by Reviewer #2, so that they describe, in order, the research initiatives and evolution followed by the limits of those research programs and the potential to go beyond those achievements. As requested by Reviewer #2, we will also emphasize Tables 2, 3, and 4 in the manuscript.

Tunnicliffe points out that this re-organization could then allow the article to better live up to the title of the manuscript. We agree that perhaps the article as written and the title are a bit out of sync. After re-organizing and re-emphasizing, we will return to the title of the manuscript to see if a better title is warranted. Tunnicliffe also requests elimination of the use of the word "experiment" to describe the CZ science venture. We will edit out that word and use one of the more precise terms suggested.

Another set of words were also the focus of a few more of Tunnicliffe's comments – paradigm and transformative. "Paradigm" is defined by Merriam Webster as "a philosophical and theoretical framework of a scientific school or discipline within which theories, laws, and generalizations and the experiments performed in support of them are formulated" (accessed at https://www.merriam-webster.com/ on 9-7-17). Scientific paradigms include definitions of what should be studied, the questions of interest, and the broad approach of study. We argue that CZ science is at least a paradigm shift in that it emphasizes that the CZ is one entity and must be investigated in its entirety. Reviewer E. Bui agrees. Therefore, we propose to include a more complete discussion of why CZ science is a paradigm shift: but we will qualify our assertions appropriately. We will also plan to use the term paradigm only for the overall CZ science initiative and not for the emergent hypotheses in Section 6, and we will emphasize use of the word "transformative" for the CZ enterprise rather than the individual hypotheses in Table 4.

The reviewers had comments on figures that we will address. For example, Tunnicliffe suggested changing Figure 1 to emphasize biological aspects. We will consider possible revisions for Figure 1. Given that both reviewers questioned Figure 3, we will modify the caption by pointing out in our revision that the figure includes sites associated as CZOs and that all the sites shown derive from networks within the U.S.A., Germany, France, and China, noting that some sites in China are co-funded and studied by scientists from the United Kingdom. The RBV and Critex networks (France) include sites outside of Europe. We will also add this information to the caption: RBV stands for the Réseau des Bassins Versants (Network of Drainage Basins), CRITEX is not an acronym, and TERENO stands for the Terrestrial Environmental Observatories.

Tunnicliffe and Bui made comments about CZ modelling efforts. Bui wrote that the future should emphasize CZ science that "facilitates extrapolation from CZO-based science and put[s] the results in broader regional and continental context. This means working with researchers . . . who build predictive spatial models of soil and geochemistry over large regions. Spatially distributed reactive transport models would be the ultimate objective here." She also argued for a future CZO science that ... "aims to predict the change trajectory that Earth systems might take under global warming (as proposed in the paper). This will require working with land surface modelers to refine the scale of their models." Likewise, Tunnicliffe wrote, "Table 3 seems to catalog a broad array of models, most of which were not specifically designed for CZ research. It would be more interesting to list emerging numerical models, or amalgamations of existing models, next to the specific CZ questions being pursued."

We agree with these comments about models completely. As Table 3 indicates, the initial CZ modeling efforts may be characterized into four groups. The first includes modifications and adoption of existing models to incorporate new couplings between hydrology and biogeochemistry, ecology and biogeochemistry, etc. The second includes identifying and filling critical gaps or knowledge of new processes such as hyporheic exchange, weathering, etc. The third includes development of a new generation of models that takes advantage of emerging streams of high resolution data such as airborne and UAV (unmanned aerial vehicle) based LiDAR and hyperspectral data. The fourth includes coupling between fast and slow processes across many time scales. Slow processes provide the template for the fast response variable, while the accumulative effect of the latter results in the evolution of the former. Both mathematical frameworks and data to support such modeling are still in their infancy.

Dialogue is ongoing as to whether the critical zone community will be best served through a single modeling framework or a library of existing models that allows more targeted exploration. The challenge lies in the central critical zone focus: "...generalizing and scaling place-based studies to principles-based understanding ..." Place-based studies can demand very specific investigations that are highly tuned to the biogeomorphic setting of a specific location, but that provide little deeper understanding. In contrast, a model that is broadly applicable may simplify the representation of a given site so much that the model results in reduced accuracy of prediction. Therefore, both the advancement of critical zone science and critical zone modeling will likely progress in an intertwined manner. These issues will be articulated in the revised manuscript.

Tunnicliffe also writes, "Table 4 is missing any mention of hypotheses related to the social science aspects of the CZ...It would be good to see how this strand of the research fits in!" Likewise, reviewer E. Bui emphasizes that the future NSF network should "address current 'wicked' societal problems and help formulate better land development environmental management policies." We could not agree more. However, the CZO enterprise in the U.S.A. so far has not emphasized social science and no such hypothesis has yet emerged from the community. We will emphasize in the revised manuscript that such hypotheses are needed and should be part of the future of the network. For example, in the revision we plan to specifically mention the idea proposed by reviewers P. Shroeder and E. Bui that an urban CZO would be of great interest.

Reviewer #2 points out that "paragraph 7 mentions briefly the publication of numerous datasets (p. 7, l.1) sometimes spanning several decades of measurements...the creation of this repository as well as the website . . .should be highlighted in the text." We agree with the reviewer. The intent of the CZO network is to serve the research community beyond those directly involved in the ongoing collection of CZ data for each of the individual sites. As such, a key motivation of the network is the development of publically available datasets pertaining to the structure and dynamics of the CZ under investigation at each of the sites. The wide variety of CZO datasets can be accessed through http://criticalzone.org/national/data/. As shown there, each of the CZOs are collecting numerous data types. These datatypes commonly include sensor/sampler network measurements showing time series response of different locations in the CZ to meteoric events, spatially-resolved geophysical and geochemical measurements of CZ structure, and LiDAR measurements of vegetation and bare earth topography, among others. As discussed in the paper, there is a coordinated effort underway to ensure that measurements are comparable across sites (i.e., the "common measurements" effort), and that the posted datasets can be used by others to make cross-site comparisons and conduct cross-site studies with existing data.

Tunnicliffe noted that "Table 2 does not back up your point about long-term measurements. It would be more helpful to see the length of these records, rather than a smattering of similar measurements that may or may not relate to broader hypotheses being tested across CZOs." This reviewer also noted that, "Pg 9, ln 307 makes reference to the 'extremely long' duration of the datasets - this could use some quantification."

We will clarify these points in the revision. In short, the time-series datasets (sensor and sampler arrays, eddy covariance, hydrometeorology, vadose zone and saturated zone aqueous chemistry, etc.) have durations that are roughly equivalent to the age of the CZO sites, determined by the initiation of NSF funding, with the caveat that CZOs have often added new study locations that were not among the original set. Three sites (SSCZO, BCCZO and SSHCZO) have been in operation since 2007, and so their longer-term observational datasets extend roughly over that duration. Three other sites (CJCZO, LQCZO and CRCZO) that initiated operations two years later have measurements dating to 2009, and three newer sites (IMLCZO, CHCZO, RCCZO and ERCZO) have datasets dating to 2013. Therefore, at present, continuous time series datasets range in duration from ca. 4 to 10 years. In addition, however, several of the sites are located in sites that provide longer datasets through previous measurement programs. The question of duration of dataset is thus somewhat complex, but we will try to make this information more transparent in the revision.

Please also note the supplement to this comment:
https://www.earth-surf-dynam-discuss.net/esurf-2017-36/esurf-2017-36-AC1-supplement.pdf

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Discussion paper