Response to Reviewer #2 for bg-2016-449

"Author Responses are indented and in bold-text"

Thanks for the opportunity to review this paper. Overall it was very informative and is suitable for publication with some minor revisions. I believe that the authors do a good job informing the audience about the development and design of the colossal SPRUCE endeavor. This is no easy task and I think that the authors are 95% of the way there.

> **Thank you. No response required.**

I am somewhat less satisfied with the comparison with other approaches, as I do not think they have enough space to go as deeply as I would like. I will make a couple for suggestions for that section of the paper along with some comments related to the presentation of experimental results. My strongest concern about this paper is that the manner in which the data is presented does not let the reader really evaluate the effectiveness in context rooted to temporal ecological processes. They have effectively shown how on average SPRUCE works. I would like to see the data presented in a slightly different manner that would also allow a deeper dive into understanding (from and ecosystem context) where the approach successful and limited. This would help readers with hypothesis development and aid the discussion limitations and successes.

> **The full data sets on performance for half-hour, above and below ground temperature responses, and aboveground CO_2 levels are archived and available in Hanson et al. (2015). For the 12 experimental plots covered by this initial project data set there are already over 23,000,000 observations (by plot: wind x2, air temperature x5, soil temperature x33, relative humidity x5, rain x1, PAR x1), and over 21,000,000 assessments of variation within half-hour periods. In the paper, we summarized concisely the nature of the response data for these variables over short to long term time intervals.**
>
> **Hanson, P.J., Riggs, J.S., Nettles, W.R., Krassovski, M.B., Hook, L.A.: *SPRUCE Whole Ecosystems Warming (WEW) Environmental Data Beginning August 2015*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, U.S.A. http://dx.doi.org/10.3334/CDIAC/spruce.032, 2016.**
>
> **In the following text, we provide responses to Reviewer #2's questions and recommendations for the improvement of our paper.**

The experimental objectives are to replicate ambient conditions while altering only the change factors we have chosen at all spatial and temporal scales of the experiment. Thus, it is important to show experimental function in this manner. This would start by showing the distribution of above and belowground temperature data for each of the treatments.

> **The objectives are to add temperature (or CO_2) differentials onto existing ambient patterns while conserving (as much as possible) the natural half-hour, diurnal, and seasonal patterns of the ambient environment. We have already attempted to illustrate this conservation for half-hour data in Figure 7, diurnal data in Table 2, and seasonal/annual amplitudes in Table 3. As we understand the reviewers new request**

for additional "distribution" data, we have constructed the following histograms for the half hour data set over the period of observations archived in Hanson et al. (2015).

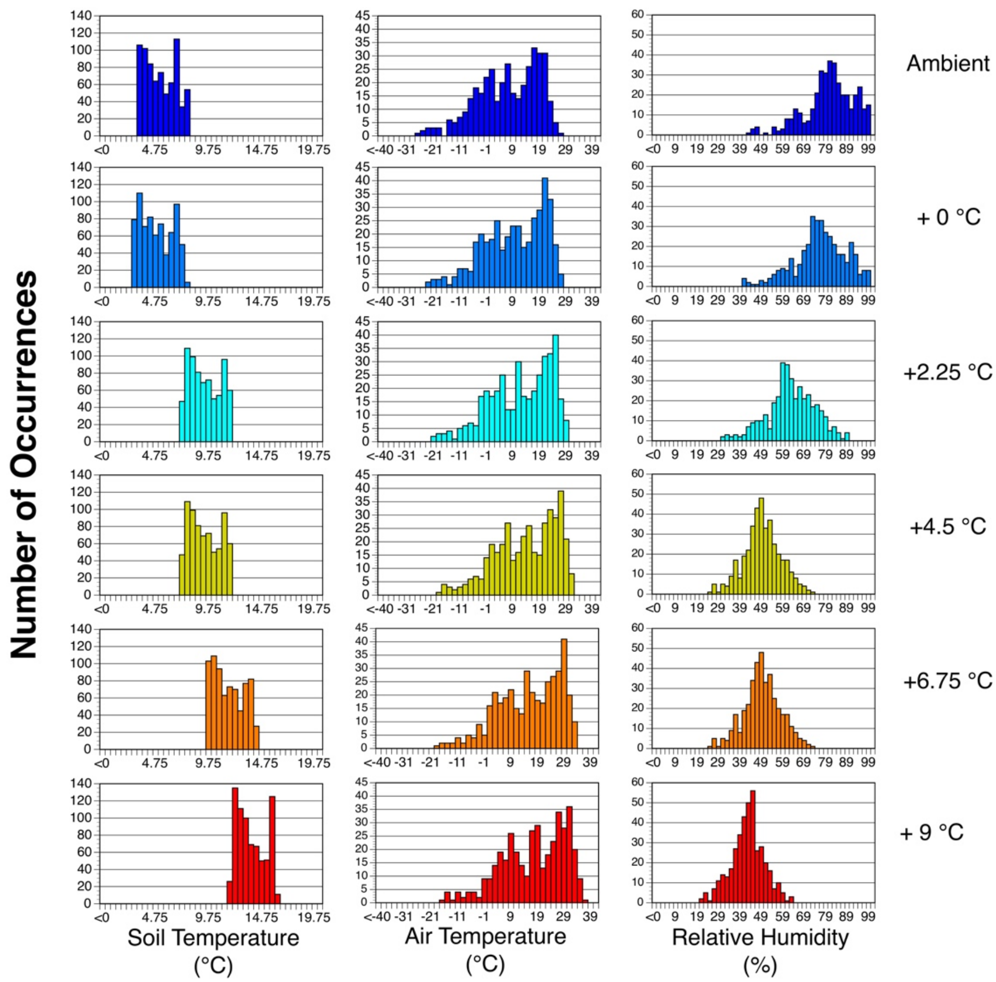


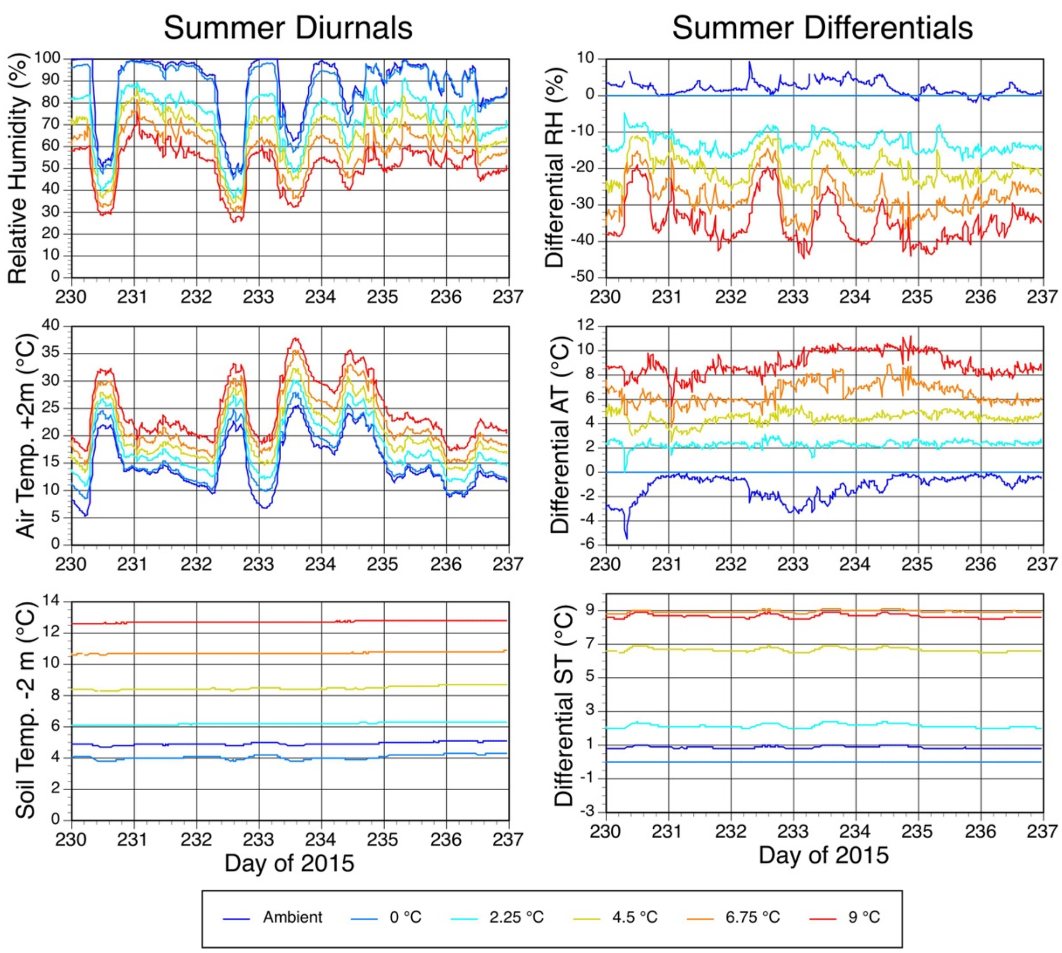
Figure Caption: Frequency distributions for daily mean soil temperature at -2 m (left column), air temperature at +2m (middle column), and daily mean relative humidity at + 2m (right column) throughout the evaluation period in 2015 and 2016. Data in the frequency distribution for soil temperature include the period from September 2014 through September 2016 which includes the deep peat heating period. Data in the frequency distributions for air temperature and relative humidity include data from August 2015 through September 2016.

These data show that the overall distribution of temperatures is largely retained under the warming scenarios, but warm plot relative humidity is constrained for the warmer treatments.

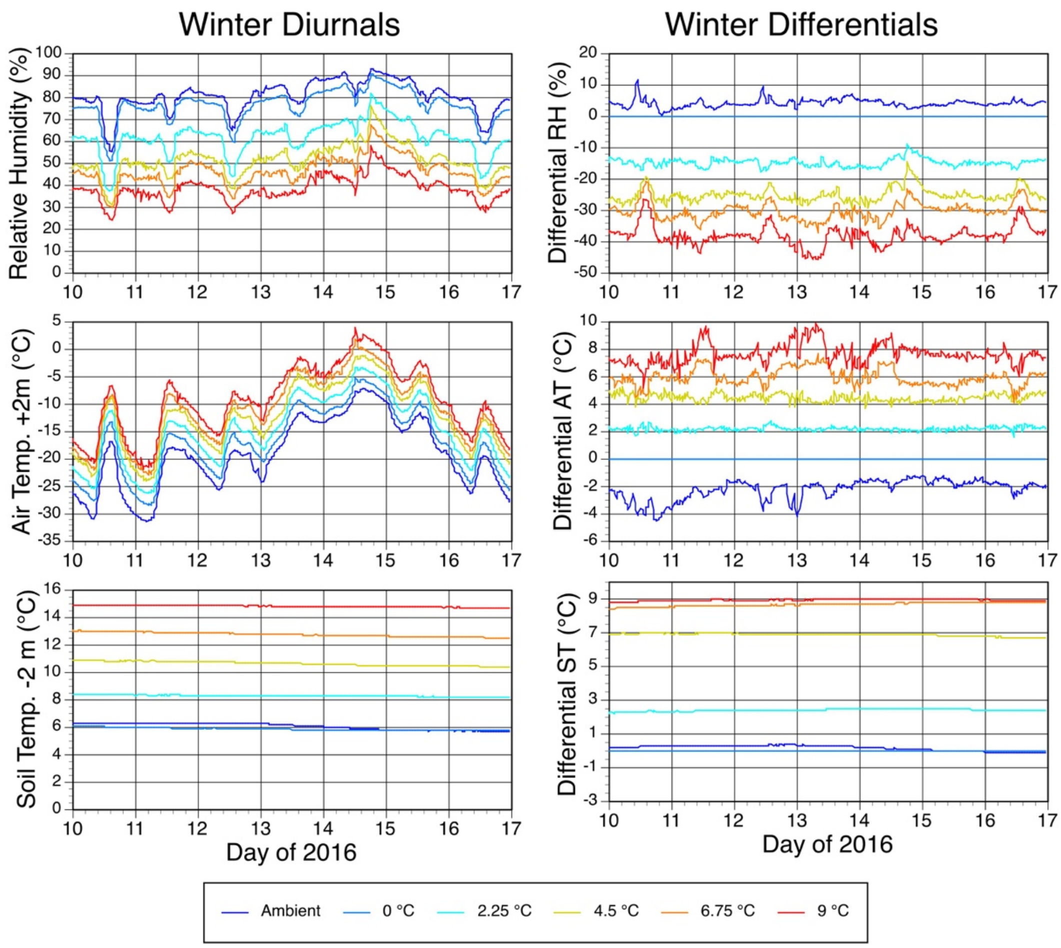
It is important to present at least some the data in a manner that does not just show that the treatments are different on average, for narrow bands of time. Rather I would like to see some exploration of the daily and annual patterns observed versus what we would expect to see.

Annual patterns of the observed absolute mean daily data for air temperature and soil temperature are already plotted in the upper graphs of Figures 3 and 4, respectively. These figures include all dates for each individual enclosure. We had not previously presented figures from the half-hour data set (Hanson et al. 2015) because they overwhelm the capacity of our graphics program. As requested, the following graphs for summer and winter periods were prepared for possible use in a revised Section 3.3 on temporal variation, or addition to the Supplemental Materials appendix.

The following graph shows a week of the half-hourly observations by SPRUCE treatment for a summer period in late August 2015 when annual temperatures were at their maximum annual values. Data for relative humidity and air temperature at +2 m and soil temperatures at the control depth of -2 m are shown.

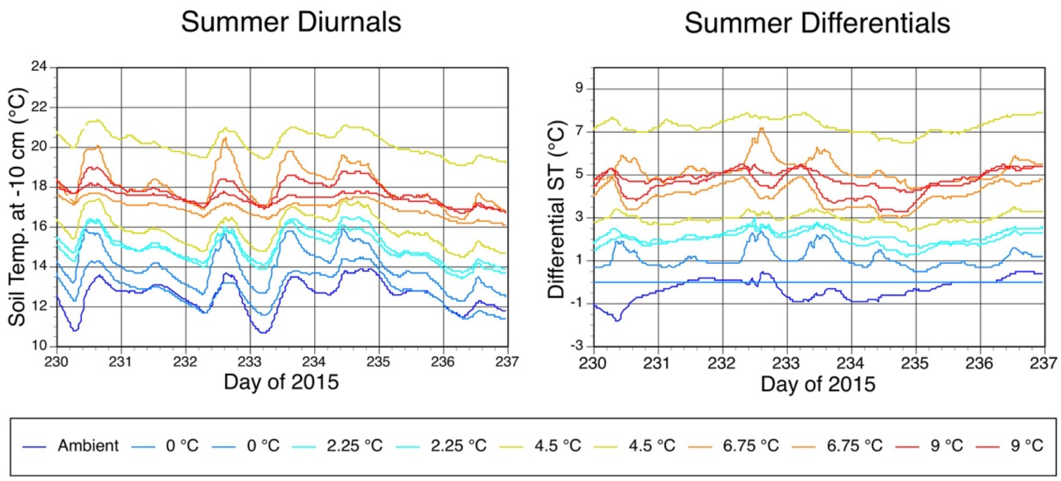


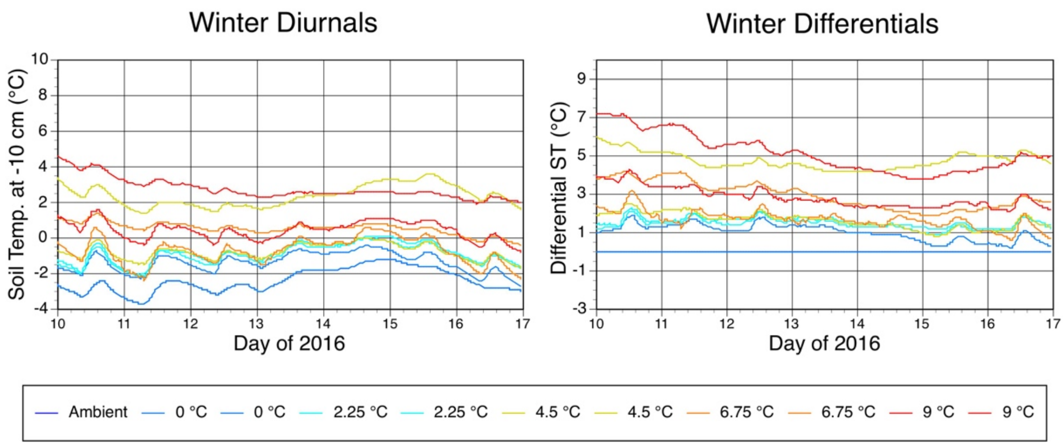
The next graph shows a week of the half-hourly observations by SPRUCE treatment for a winter period in January 2016 when annual temperatures were at their minimum annual values.



For both summer and winter conditions you can see that the SPRUCE system is capable of sustaining differential temperatures throughout diurnal cycles in a very consistent manner as was the case for Figures 3 and 4 of the paper. Relative humidity which is reduced with warming (see also manuscript Table 4) also follows the diurnal patterns with treatment.

Away from the active control positions (+2 m for air temperature; -2 m for soil temperature) it is important to point out that the stratification is similar, but not always maintained. The following figures for soil temperature at -10 cm, clearly show that the treatments are largely maintained up through the soil profile (see also manuscript Figure 5), but that some differences can develop driven by the unique energy balance relationships for a given SPRUCE enclosure. Such differences are driven by variable tree-cover conditions that effects local energy balance responsible for the development of soil profile temperature differentials above the -2 m control depth.





The previous examples of diurnal temperature patterns and differentials will be added to the manuscript or the supplemental material at the discretion of the editor.

As this data is currently presented, there is strong difference in the daily averages of each treatment and they seem to be consistent throughout the year. But these data lump seasonal and diurnal variability and may mask patterns of efficacy that are important for the reader to understand.

Seasonal variability is already presented in Figures 3 and 4 and Table 3, and diurnal variation is characterized in Table 2. Examples of diurnal variation across treatments are shown in the newly drafted figures above. Real-time and archived SPRUCE data are also available for consideration at http://sprucedata.ornl.gov/vdv.

The authors should use the delta from ambient as a measure of the experiment look at the average and variability across various ecological scales. Hour of day (not just an individual day) would be the most important but also by time of year.

On this point we disagree. The fully-constructed-control enclosures include shading effects and internal turbulence (as described in the paper) that need to be considered when contrasted with warmed plots (+2.25, +4.5, +6.75, and +9 C). For belowground studies, one might rationalize that the ambient plots (Plot 7 and 21) can be interpreted as another treatment level. In completed response papers we have been characterizing them as -2 °C plots (e.g., Wilson et al. 2016). Hour-of-day data are described with representative plots in the previous answers.

The limited number of sensors makes spatial variability harder to explore in this manner but it would be important as well.

Spatial variation was an important consideration during the development of the belowground and air warming protocols (Barbier et al. 2012) during construction and testing of the full size prototype in Oak Ridge, TN. In that system, a 3D-monitoring approach included a central tower and spaced sensors located at various heights and distances from the center of the plot. They were established and monitored to capture spatial details. During prototype development, we also monitored soil temperatures to -2 m along a radius from edge to center of the plot in that prototype. Results from the Barbier et al. (2012) paper demonstrated little spatial variation belowground, and some variable aboveground spatial homogeneity driven by external wind velocities. The greatest variation in the warm air envelope above ground occurred under calm conditions, and a full discussion of spatial considerations is included in Barbier et al. (2012).

I would also like to see the overall distribution of temperatures for each of the treatments. It is important that the distribution of temperatures match ambient as much as possible along with differing in mean.

This figure was drafted has been shown previously above. It will be included in the revised manuscript. The distributions reveal a very good representation of the ambient distributions for soil and air temperatures, but a somewhat constrained distribution for relative humidity as the warming treatments increase. Such variation is inherent to the experimental system. No attempt to correct this small change was attempted because there is not <u>consistent</u> guidance from climate models as to the exact nature of such distributions to expect for future climates.

Some of the papers they reviewed in this ms use analyses like those suggested, I would also the see if there are seasonal patterns as well. It is easier to use the deltas for these analysis then the overall temperature.

See our responses above.

It is likely that variability in treatment is higher in parts of the day or times of the year and that would be important to know.

As demonstrated in the figures above, this is typically not the case near the control points, but is inevitable as you move up the soil profile away from the -2 m controlled zone.

I would also like to see multivariable traces and deltas for 10 days or at an hourly scale. This could be in the supplement and help the reader see the efficacy of the experiment in an ecological context.

Half-hour data are provided in the figures above and will be included in the paper with the approval of the editor.

It is probably beyond the scope of this paper but I would like to see an analysis linking directly the specific temperature/ light and rh conditions of sampling area with measurements just in thoses areas.

To the extent that we could afford sensors throughout the enclosures, they have been added to allow individual tasks to associate their task-specific observations to the most appropriate environmental sensors. Temperature and relative humidity data are available at 0.5, 1, 2 and 4 m to allow canopy responses for surface vegetation, shrubs and *Picea* and *Larix* foliage to be most appropriately represented by their actual growth conditions. Due to good mixing, there isn't a lot of difference (see the lower graph - Figure 5). Soil temperature data are available at 0, -5, -10, -20, -30, -40, -50, -100 and -200 cm to allow peat and microbe response analyses to be appropriately characterized by depth. In addition, soil temperature is assessed along these depths at three different zones within the plot to allow us to associate measurements to the closest appropriate zone. All of these data are available to project members during active operation, and through the public archive (Hanson et al. 2016) for future analyses.

I am not sure what spatial data is available but it would reassure readers to know that the sampled area variability is minimized.

<u>Answer repeated from above:</u> Spatial variation was an important consideration during the development of the belowground and air warming protocols (Barbier et al. 2012) during construction and testing of the full size prototype in Oak Ridge, TN. In that system, a 3D-monitoring approach included a central tower and spaced sensors located at various heights and distances from the center of the plot. They were established and monitored to capture spatial details. During prototype development, we also monitored soil temperatures to -2 m along a radius from edge to center of the plot in that prototype. Results from the Barbier et al. (2012) paper demonstrated little spatial variation belowground, and some variable aboveground spatial homogeneity driven by external wind velocities. The greatest variation in the warm air envelope above ground occurred under calm conditions, and a full discussion of spatial considerations is included in Barbier et al. (2012).

As it is a whole ecosystem model with some range in values, it would be nice to know whether the sampling area occupies that entire range or is experimenting a narrower range of treatments. For example, it would be great if RH decline with temperature in areas sampled was less than chamber level.

As described above relative humidity is assessed at 0.5, 1, 2 and 4 m above the ground to provide such data. Due to good mixing within the enclosure (Barbier et al. 2012) a horizontal array of such sensors was deemed unnecessary. Of course, more data are always useful, and users of SPRUCE may add other localized sensors.

I am especially concerned about pattern of nighttime temperature with distance from chamber wall and RH variation with distance from blower manifold.

See the Barbier et al. (2012) paper and previous answers. Through additional spot checks, but not automated and continuous measurements, we have demonstrated that the warm air leaving the 8 source diffusers on each of the enclosure walls becomes well mixed very quickly. Nonetheless measures of shrub or tree canopies directly impacted by the source warm air are avoided and minimized.

There is very little discussion of soil temperature behavior during freezing and thawing cycles or by depth. This need to be include somewhere.

Section 3.5 of the paper and Figure 11, together with the modeling of ice development in Section 4.2.4 and Supplemental Figures S6, S7 and S8 cover this issue in some detail.

I expect that soil and air temperatures invert at some point during the year and it might be better analyze these data separately.

This is true, and it is captured in the archived data base. Future model-data intercomparison exercises underway may choose to look specifically at this phenomenon, but they are not added here to manage the length of the paper. It is important to point out, however, that such phenomenon occur in zones of the enclosures that develop their patterns due to natural energy balance phenomenon that are not impacted by the active control of deep soil temperatures. As applied, our system only produces a modified deep soil temperature to simulate future deep temperatures to be achieved with climate warming. Soil temperature patterns exhibited on diurnal and annual time steps are the result of natural energy balance changes through time.

Again a delta based analysis of soil temperature differences would be better to show treatment effects compared to ambients rather that overall temperatures.

Figures 3 and 4 include the differentials together with the absolute temperature values.

It would be nice to know that the delta variability at each depth was comparable with ambient.

Examples of such data were provided in Figure 5, and we have added the -10 cm soil temperature figures presented earlier for this purpose. With millions of data points, we have tried to choose wisely to present the data of use to the most readers.

Daily pattern in RH would also be nice to know as well.

Example data have been graphed and are provided above.

Line 211- Is this really 12-18m deep below wetland. Please check.

Yes. The helical piles needed to be driven very deep to meet the engineering requirements for stability over a decade of operation.

The figure sharpness seemed lacking throughout, I assume that will be corrected. I like figures with sd bars rather than separate symbols

We will provide higher resolution images with the final revised manuscript.

Table 2 explanation was confusing to me.

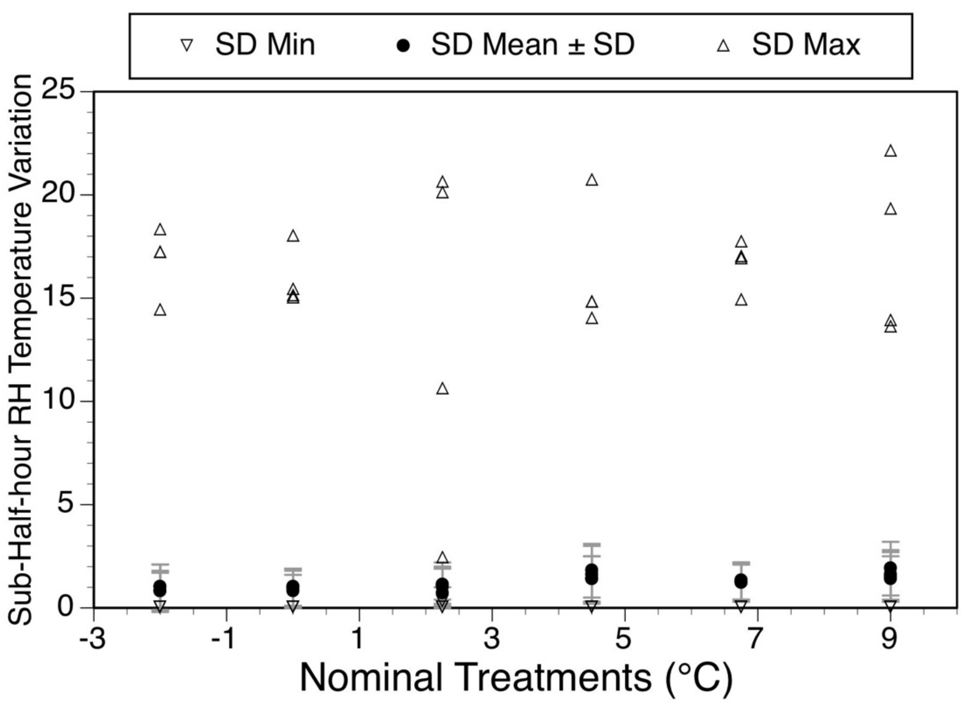
The wording of the table caption has been modified to clarify the content of the Table.

Soil moisture data to back up discussion of RH and ET?

A discussion of peat moisture content and water table data is provided in the Response to Reviewer #1, and a figure demonstrating peat moisture variation in the peatland hollows was added to the Supplemental Materials section.

Figure 7 is good. I would like to see more like this. I would like to see the same analyses for differing sensor variables. One could be in paper and other in supplement.

We have constructed a similar figure for RH data for use in Section 3.3. It is reproduced below. For soil temperatures, there is essentially no variation at the sub-half hour time step and we have not provided those data in a figure, but the data are recorded and available within in Hanson et al. (2015). In the case of RH data below, the sub-half hour variation does not increase with warming treatment. The following figure will be added as a new figure or stacked within Figure 7.



Right now the comparison discussion between this and other warming experiment seems underdeveloped. I suggest picking a couple of key comparisons to develop discussion.

The overall goal of this paper is to document the capacities of the SPRUCE enclosure system. As we stated in Section 4.1 other studies have provided an in depth discussion of the advantages and disadvantageous of other approaches (Aronson and McNulty 2009, Amthor et al. 2010, Kimball 2011, LeCain et al. 2015), and we didn't choose to provide a comprehensive point-by-point comparison that would lengthen an already long paper. Rather, we wanted to provide data in Table 6 to describe the breadth of available approaches to make the point that other options are available for other ecosystems and questions.

Temporal pattern, dewpoint, soil moisture and RH be interesting to include more of. What should RH and dewpoint looked in a good manipulation?

Example data have been graphed and are provided above, and we have discussed the implications for the design on dewpoint formation. All data are archived for in-depth future analyses (Hanson et al. 2016).

The summary table also need to be checked. The data from at least one of these papers is incorrect.

Unfortunately, we have not found the error that the reviewer located. We would be happy to make a change or changes if specific adjustments can be suggested.