

## ***Interactive comment on “Non-additive effect of day and night warming on soil respiration in a temperate steppe” by J. Xia et al.***

**J. Xia et al.**

swan@ibcas.ac.cn

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Answers to Referee #1

General comments

This paper describes an interesting study addressing differential effects of day vs. night warming on soil respiration. The paper shows that nighttime warming potentially has very different (opposite) effects on soil respiration and gross ecosystem exchange than daytime warming and those effects of night- and daytime warming are not additive. The authors ascribe these differential effects to substrate supply and use net photosynthesis and net ecosystem exchange measurements as supporting evidence. Overall, the study is well executed and the results are interesting. The introduction makes a clear

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case for the need of studying effects of day- vs. nighttime warming on ecosystem processes and as such this paper represents an interesting contribution to the existing literature on effects of climate change on soil respiration. Overall, the methods are clear and the experiment appears to be well designed and thought out. Authors thank Referee #1 for the positive comments on our manuscript.

There were a few issues however that I feel need to be addressed:

One issue that is not discussed is the fact that net ecosystem exchange (NEE) and ecosystem respiration (RE) were only measured during the daytime while other parameters were measured around the clock so inferences made about gross ecosystem exchange (GEE) and correlations between various parameters and GEE are based only on daytime measurements. The overall conclusion appears to be that GEE increases with nighttime warming and decreases with daytime warming. This may be true but how about effects of day- and nighttime warming on nighttime GEE? Soil respiration obviously represents the belowground part but what about aboveground nighttime respiration? This aspect is not discussed so I would be a little bit careful about making sweeping statements regarding GEE. Thanks for the reviewer's valuable comments and suggestions. Across the growing seasons, in this ecosystem, sun rises around 5:00am and sets at about 19:00pm. Thus, we measured ER from 6:00 to 18:00 (6:00, 9:00, 12:00, 15:00) and NEE at both day- and night-time (6:00, 9:00, 12:00, 15:00, 18:00, 21:00, 0:00, and 3:00). In fact, values of NEE in night equal to those of ER. Thus, we calculated GEE (and therefore GEP) from NEE and ER only during daytime (from 6:00 to 18:00). We have addressed this issue in the revised version (Line 151-156). The reviewer is right that soil respiration only represents the belowground part and that aboveground part is also very important. In order to assess the responses of aboveground respiration to day- and nighttime warming, we measured diurnal patterns of leaf gas exchange for two dominant species in this ecosystem. Across the two species, night warming increased nighttime leaf C release via respiration by 36.3%, but day warming decreased it by 14.0%. We added the information and into the discussion

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in revised version (Line 360-362).

Another issue that was somewhat confusing to me was that the authors claim that effects of day and nighttime warming are non-additive. Yet, when looking at the ANOVA results presented in Table 1, effects on absolute rates appear to be additive since no interactions between day- nighttime warming are found. It appeared that the authors base their analysis on the regressions of observed vs. predicted GEE as presented in Fig. 5. This may be correct but this is not in agreement with the ANOVA results. Thank for the reviewer's comment. In table 1, we used seasonal mean values for the analyses of three-way ANOVAs. We used temporal data (data of different sampling days) for the regression analyses in Fig. 5. Thus, the results of regression analyses may be not in agreement with the ANOVA results. We have changed "additive" or "non-additive" into "are equal to" and "be predicted by" across the manuscript and made it clearer in the revised version (Line 185-187).

In addition, it was not entirely clear what data were used for the ANOVAs compared to the data used in Fig 5. In the ANOVA did the authors use all data from all rings at every single measurement time or were data aggregated in some way? I assume each plot was used as an experimental unit and the two measurements conducted in each plot were averaged. Thank for the reviewer's comment. We first calculated the daily mean value in every observational day in the 3 growing seasons, and then the treatment effects were calculated by Meantreatment - Meancontrol. We used data in all observational days to plotted the predicted (sum of day- and nighttime warming effects) effects against the observed (diurnal warming effects) effects in Fig. 5. In the ANOVA analysis (Table 1), we used all seasonal mean data from all rings. In the revised version, we have made it clearer (Line 176-179).

In the discussion the authors mention using a repeated-measures ANOVA while the ANOVA carried out to produce the results presented in Table 1 does not appear to be a repeated-measures ANOVA according to the methods section. Why was one chosen over the other? In Table 1, we want to test the effects of three factors, including daytime

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warming (D), nighttime warming (N), and year. Year was considered as an important factor in this study because there was a great variation in precipitation amount among the 3 growing seasons. Our results suggested though the parameters vary greatly among growing seasons, no interaction was found between treatment and year. Thus, three-way ANOVAs were used in Table 1. In the discussion (Line 349), however, we used all data across the 3 growing seasons (from 2006 to 2008) to test the effect of diurnal warming on GEE in this study. The role of year was not considered here and thus we used a repeated-measured ANOVA and found that diurnal warming showed no effect on GEE across the 3 growing seasons.

Specific comments

Page 4389, line 4-7: Do the authors have estimates for % cover and/or biomass for these species? This would be helpful to know in order to determine how representative the leaf-level gas exchange data measured for *S. Krylovii* were on an ecosystem level. The authors state that *S. Krylovii* it is the dominant species but this is rather vague. In late August from 2006 to 2008, we have clipped aboveground biomass of forty 1 × 1 m<sup>2</sup> plots near our experimental plots. Living plant aboveground tissues were separated from dead tissues, over-dried, and weighted. The data showed that, across 2006 to 2008, *S. Krylovii* represented 13.2% and 45.6% of the aboveground biomass for total community and grass species, respectively. This information has been added in the revised version (Line 165-169).

Page 4389, line 20-21: What ecosystem C fluxes were compared? We compared gross ecosystem exchange (GEE), ecosystem respiration (ER), and net ecosystem exchange (NEE) in late August, 2005. This information has been added in the revised version (Line 113).

Page 4390, line 15: I assume the soil moisture was volumetric. This would be good to add. The reviewer is right. We have added "volumetric" in the revised version (Line 134).

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Page 4390, line 19-20: Why was GEE only measured during the daytime while all other parameters were measured during the night as well? I can understand there were logistical issues that prevented the authors from measuring GEE at night but for the overall story it is important to emphasize that GEE was not measured during the night. Potentially, increased GEE during the day in response to nighttime warming could be offset by increased RE during the night. In fact, we measured NEE both in day- and nighttime and ER in daytime. In fact, values of NEE in the night, without light, equal those of ER. Thus GEE, which was calculated by  $NEE - ER$ , only has data during the daytime. We use GEE (and hence GEP) here as the parameter of ecosystem C uptake, which only occur in the daytime. We have addressed it clearer in the revised version (Line 151-157).

Page 4391, line 12-13: The authors mention that GEE is measured as the difference between NEE and ER. This would be the case if either NEE or ER were considered to be negative. The general convention would be though that  $NEE = GEE - RE$ . As a result GEE would equal  $NEE + RE$ . In this study, we considered C uptake (GEE) to be negative while C release (ER and SR) to be positive. Thus, GEE in this study was equal  $NEE + ER$ . We have addressed this issue clearly in the revised version (Line 156-157).

Page 4392, line 23: More details are needed on the ANOVA analysis in terms of number of replicates, temporal/spatial aggregation of data, etc. It looks like annual data were used. If so, why didn't the authors include monthly data? It would have been interesting to determine during what time of the year effects of treatments were most prevalent. Thanks for the reviewer's thoughtful and valuable comments. We added more details of the ANOVA analysis in the revised version (Line 173-179). In addition, as the reviewer suggested, we added an analysis for day and night warming effects on soil respiration in different months. We found that day warming showed no effects in any month (all  $P > 0.1$ ) during the growing seasons. Night warming significantly increased soil respiration in June ( $P = 0.003$ ) and July ( $P = 0.030$ ), and showed marginally

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significant impacts in May ( $P = 0.052$ ) and September ( $P = 0.058$ ). In August and October, night warming showed no effect (all  $P > 0.1$ ) on soil respiration. Additionally, no interaction between day and night warming was found in any month (all  $P > 0.05$ ) in this study (Table 2).

Page 4393, line 1-3: I am not convinced that volumetric moisture measurements are accurate enough to make a distinction between 0.31% and 0.39% changes in soil moisture. In addition, the ANOVA results suggested no difference in response between day- and nighttime warming so I would not emphasize these small, if at all measurable, changes. In addition, given the already low soil moisture, are reductions by 0.3% ecologically relevant. In the discussion, the authors discuss the possibility that direct effects of increases in temperature are off-set by temperature-induced reductions in soil moisture. Yet, changes in moisture seem rather small. The changes in soil moisture (0.31% and 0.39%) were absolute (treatment minus control) rather than relative ( $(\text{treatment minus control}) * 100 / \text{control}$ ) differences between the treated plots and the control plots. Several previous studies in the same area suggested that C fluxes, including ecosystem gas exchange (Niu et al. 2008) and soil respiration (Liu et al. 2008), were primarily limited by soil water availability in this ecosystem. An incubation experiment in the laboratory (Fig. 5 in Liu et al. 2008) showed that microbial respiration reduced rapidly when soil moisture was decreased, especially at low moisture levels. In addition, regression analysis in this study (Fig. 3b) showed that spatial variations of soil respiration were positively correlated with soil moisture. Given the relatively low soil moisture content across the growing seasons, the small absolute changes in soil moisture may play roles in regulating responses of ecosystem C exchange in this system. Nevertheless, even though the indirect effects of warming via temperature-induced reduction in soil moisture were considered in this study, the substrate changes are also important in response to day and night warming.

Page 4393, line 8: The % changes in GEP mentioned in the text do not appear to match those presented in Fig. 1. Especially, according to Fig. 1 the changes in GEP in

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response to nighttime warming seem to be much larger than 4.24%. Perhaps the y-axis on the right side of the graph is off. Thanks for the reviewer's valuable comments. In this study, we used complete random block design with two main factors, including day and night warming. Thus, the treatment-induced changes in parameters in "Results Section" were the main effects of day and night warming. Day and night warming effects were calculated by  $(\text{MeanD} + \text{MeanW} - \text{MeanC} - \text{MeanN})/2$  and  $(\text{MeanN} + \text{MeanW} - \text{MeanC} - \text{MeanD})/2$ , respectively. We have revised Fig. 1 with absolute changes in the revised version (Line 176-179).

Page 4393, line 15: The authors talk about seasonal mean soil respiration. It was unclear how the authors defined the seasons. It almost appears that the authors talk about annual mean soil respiration rather than seasonal. In Fig. 2 it would be helpful to include some indication of significant differences between the treatments for each month using different letters identifying significant differences. Even though some of the statistical analyses indicate overall significant differences, it would be informative to know if these differences occur throughout the year or if they are restricted to certain periods. One possibility explaining the absence of any significant effects of day warming on soil respiration may be that relative effects of temperature are higher at low temperatures, i.e. a 4 degree increase in temperature has a larger effect when the ambient temperature is 2 degrees vs. 30 degrees. Thanks for the reviewer's thoughtful and valuable comments. We have added a table (Table 2), including warming effects in different months, in the revised version (Line 539-541). We found that day warming showed no effects in any month (all  $P > 0.1$ ) during the growing seasons. Thus, the absence of any significant effects of day warming on soil respiration may not be explained by the larger warming effects at low temperature. The information has been added into the "Result" in the revised version (Line 228-233).

Page 4393, line 22: What do the authors mean with pooling all data together? Do the authors mean to say that they used all data including control and treatment data? Were the relations between soil respiration, temperature, moisture and GEE the same for

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control and warming treatments? We pooled the data in control plots (without warming plots) in all the measuring dates of the 3 growing seasons to test the dependence of soil respiration upon its controlling factors in natural conditions. We have made it clear in the revised version (Line 235-238).

Page 4394, line 3-22: Although the authors show several significant correlations between soil respiration, temperature, moisture, and GEE, many of these parameters explain a relatively low amount of the variability. In the discussion, the authors emphasize that the substrate supply may be an important factor in explaining differential day- and nighttime warming effects. This may be true but still GEE (which is used as a proxy for substrate supply) only explains 21% of the spatial variation observed in soil respiration. As a result I would be a little bit careful with emphasizing this too much. Thanks for the reviewer's valuable suggestions. In the revised version, we have avoided emphasizing the importance of substrate supply too much. For example, we have deleted the claim that substrate was more important than soil temperature and moisture in controlling the non-additive effects of day and night warming on soil respiration (Line 342-344).

Page 4397, line 20-22: The authors discuss presence/absence of additive effects of day and night warming on GEE stating that effects are non-additive. However, according to the ANOVA presented in Table 1 there were no interactions so the analysis presented in Fig. 5 appears to contrast the ANOVA results. This needs to be clarified and explained. Why do these analyses come up with different results? Looking at Fig. 5 I was wondering if the individual regressions were significant given the large amount of scatter and the regression between observed and predicted appears to be highly non-linear. We have rephrased the description in the revised version. We changed "additive" or "non-additive" to "equal to" and "be predicted by" to avoid confusion. Also see our previous response.

Page 4398, line 2: The authors present results from a repeated-measures ANOVA. How is this analysis different from the ANOVA presented in Table 1? Since the same measurement locations are being used for GEE and soil respiration, repeated-

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measures ANOVA would be appropriate for these parameters. Thank for the reviewer's comment. As mentioned previously, we want to test the effects of three factors, including daytime warming (D), nighttime warming (N), and year. We considered year as an important factor in this study for its great variation in precipitation amount among years. Thus, three-way ANOVAs were used in Table 1. In the discussion (Line 349), however, we only wanted to assess the impact of diurnal warming on GEE across the 3 growing seasons. Thus we used a repeated-measured ANOVA here and found that diurnal warming showed no effect on GEE across the 3 growing seasons. In fact, two-way ANOVA including year and diurnal warming also showed no effect of diurnal warming on GEE ( $P = 0.281$ ).

#### Minor comments

Title: I would probably change the title to 'Differential effect of day and night . . . .' We have changes the tile to "Differential effects of day and night warming on soil respiration in a temperate steppe".

Page 4386 line 6: Replace 'neutral' with 'no'. line 9: Insert 'of increased temperature' after 'positive effects'. line 16: Insert 'most likely' after 'was'. Page 4387 line 2: Insert 'surface' after 'land'? line 4-5: Delete 'it is theoretically reasonable to expect' and replace 'can' by 'may'. line 6: Replace 'consequent' by 'subsequent'. line 18: Add 'to date' after "However" and replace 'were' by 'have been'. line 20: Insert 'been' after 'have'. line 26: Replace 'in combination' with 'combined' and insert of' after 'effects'. Page 4388 line 13-15: Remove the symbols for the different treatments and insert these in the methods section. line 16: Replace 'record' with 'data records'. Replace that' with 'the'. line 18: Replace 'contradictory' by 'opposite' or 'differential'. line 20: Delete 'whether'. line 22: Replace 'drives' with 'what are the main drivers for'. Page 4389 Line 8: Replace 'distributing' with 'of the precipitation falling'. How much of the precipitation falls as snow? Line 14-16: Insert the symbols for the various treatments. Line 16: Insert 'each treatment was' before '6 times'. Page 4390 Line 7: Start sentence with 'A'. Line 9: Start sentence with 'Any' and delete '(if there are)'. Line 13: Delete

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'Diurnal cycle'. Line 27: Delete 'some'. Page 4391 Line 25: Start sentence with 'Effects of the experimental treatments on soil respiration were presented. . .'. Line 27: Replace 'with' by 'compared to'. Page 4392 Line 3: Replace 'whether' by 'to determine if'. Line 4: Replace 'infers' by 'suggest'. Line 7: Delete the second 'and'. Line 11: Delete 'the depth of' and add 'depth' after 'cm'. Line 19: Replace 'increased greater' by 'showed a large increase'. Line 21: Replace 'to affect' by 'on'. Page 4393 Line 1: Replace 'slight' by 'slightly'. Line 4: Replace 'to inñCuence' by 'on'. Line 17: Delete 'its'. Page 4395 Line 16: Replace 'aggravate' by 'exacerbate'. Page 4396 Line 11: Delete 'In'. Line 19: Insert 'the' before 'Southeastern'. Page 4397 Line 14: Replace 'could' by 'should' and replace 'additively' by 'additive'. Line 22: Not sure if 'antagonistic' is the right word here. Page 4398 Line 4: Insert 'be' after 'could'. Page 4399 Line 20: Replace 'helps' by 'help'. Authors thank the reviewer for the detailed suggestions. All the grammatical errors have been corrected.

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