Review1:

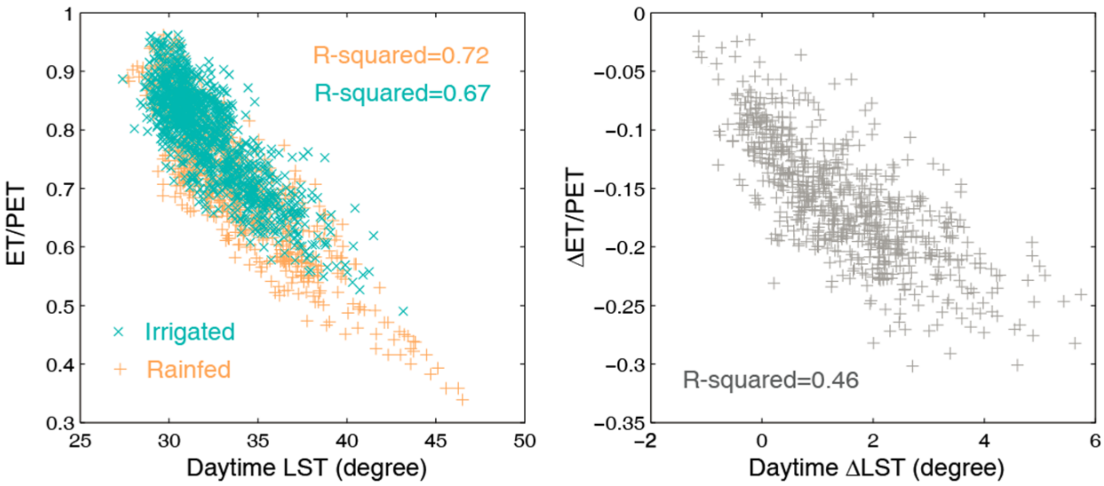
This is an interesting article describing effects of high temperature and drought on maize yield and yield components in Nebraska. The authors used remote sensing to detect high temperature stress and drought stress and also tested whether four different crop models can reproduce the effects detected by remote sensing. The article is well written, good to understand and figures are of high quality. However, I cannot recommend to publish the present version of the article in HESS. My major criticisms are:

We thank the reviewer for constructive evaluations and suggestions. We have accordingly revised our manuscript following the reviewer's suggestions, as detailed in the point-by-point response below.

1) The major source to describe high temperature and drought stress in maize are land surface temperature and ET detected by remote sensing. I think that the temperature based indicators LST and EDD are highly determined by the ratio ET/PET which was used to describe drought impacts. Which factor different from drought can explain canopy temperature differences between well watered and rainfed maize fields? Or in other words: can differences in LST and EDD at the same location happen independently of drought stress? I don't think so. If so, for example because of different LAI, then this is likely an affect of drought in previous growth stages.

It is well understood that transpiration cooling is directly controlled by the stomata conductance and vapor pressure deficit, which are again controlled by drought. This is also the reason why canopy temperature differences are often used as indicator for drought stress or even for irrigation scheduling. Consequently I think that EDD differences or LST differences between irrigated and rainfed maize in the same region are just another manifestation of differences in drought stress between irrigated and rainfed fields. From that perspective I cannot understand why the collinearity tests performed for the variables included in equation 7-9 did not show critical values.

Thank you for this comment – this is the very heart of the research question at hand: how much of temperature stress is really moisture stress (and vice versa)? While we understand your intuition that extreme heat is hurting plants exclusively through moisture (drought) stress, there is in fact significant variation in the sample between EDD and ET/PET. We show this in the collinearity tests and in the figure below.



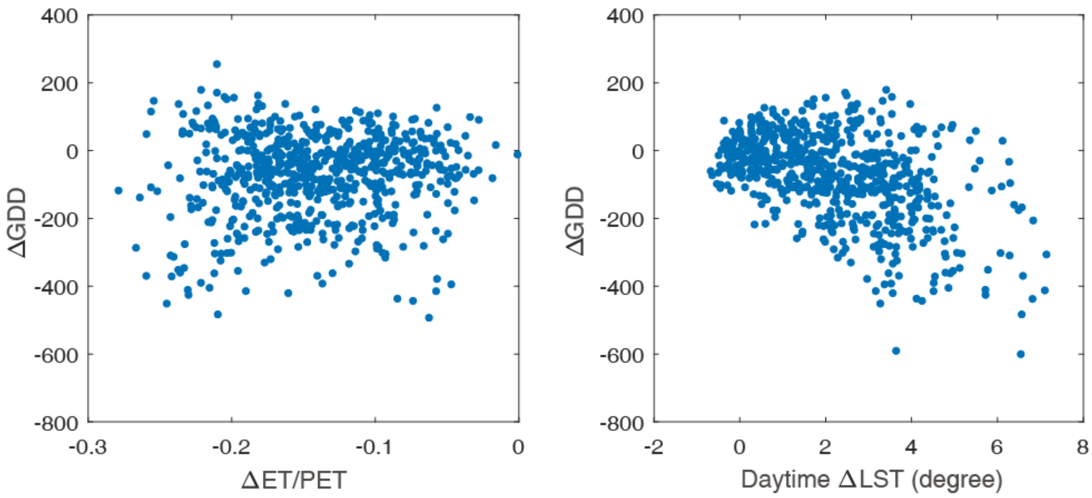
The left panel is the original growing season mean ET/PET and LST, the right panel is the difference of LST (ΔLST) and ET/PET (ΔET/PET) between rainfed and irrigated maize.

Although the difference of ET/PET and LST was still correlated, we also calculated the Variance inflation factor (VIF) to diagnose the severity of collinearity and the impact it might be having on the ability to statistically estimate the parameters of interest. The statistical rule-of-thumb is that VIFs over 10 indicate collinear variables that may be causing coefficient instability (with 5 being a more strict standard). Here the VIF in our statistical model is 2.2, suggesting the collinearity is not severe, and there remains enough independent variation to trust our estimates. The results may be surprising, but these two parameters do in fact exhibit some independent variation. This is why the variance inflation factors are quite low (and thus not problematic for the statistical estimation).

In sum, we understand the reviewer's intuition and potential surprise at the amount of independence here; this is the very reason we think this is an exciting and publishable result.

2) The authors showed that there are considerable differences in the growing season length of irrigated and rainfed maize and suggest that the differences are mainly an effect of cooler canopy temperature under well watered conditions (lines 322-337). Another potential reason could be the so called drought escape effect. It is known that many crops speed up their phenological development under drought to make sure that grains reach physiological maturity before the stress becomes so strong that the crop has to die. Again, in that case it would be a drought effect and not an effect of higher temperatures. I agree that it is not so easy to find out which effect really matters. I suggest to test the GDD computed in equation 3 for years with similar canopy temperature but different drought stress (ET/PET ratio). For example, a year that is warm and wet should result in similar canopy temperatures compared to a year that is a bit cooler but dry. Important is that the test has to be made for the same location (county) to avoid that cultivar differences between warmer and cooler regions disturb the relationship. If for years with similar canopy temperature but different ET/PET ratio the GDD is similar, then the shorting of the growing period is independently of drought and the drought escape mechanism can be excluded. If GDD is, for similar canopy temperatures, positively correlated with the ET/PET ratio, then this would point to the drought escape mechanism.

Thanks for your suggestion. We do a test based on the reviewer's suggestion. For each county, we calculated the difference of GDD between rainfed and irrigated and then plotted it against the difference of ET/PET and LST, respectively. This method ensures that the comparison is conducted for the same county to minimize the effects of cultivar differences, as the reviewer suggested. As the following figure shows, we can see there is a clear decline in ΔGDD with higher LST but no significant decline in ΔGDD with lower ET/PET.



Specific comments:

Line 175 (equation 3): Why was it decided to set the high temperature threshold to 30 dC? In the literature heat stress thresholds for maize are typically higher, about 34 dC (Sanchez et al., 2014).

Indeed there are various ways to define high temperature stress. In addition to the suggestion by the reviewer to use 34°C, as done by Sanchez et al., (2014), there are also some studies using 30 °C (Lobell et al 2011; Lobell et al., 2013; Zhu et al., 2019) or 29°C (Butler et al., 2018). So we believe the threshold we used to define high temperature stress is defensible. We also include a clarification for this point with the suggested reference added in line 180: “Following previous studies (Lobell et al., 2011; Zhu et al., 2019), 30°C is set as the high temperature threshold, although higher value might be also applicable as the temperature threshold (Sanchez et al., 2014).”

Butler E E, Mueller N D, Huybers P. Peculiarly pleasant weather for US maize[J]. Proceedings of the National Academy of Sciences, 2018, 115(47): 11935-11940.

Lobell D B, Bänziger M, Magorokosho C, et al. Nonlinear heat effects on African maize as evidenced by historical yield trials[J]. Nature climate change, 2011, 1(1): 42-45.

Lobell D B, Hammer G L, McLean G, et al. The critical role of extreme heat for maize production in the United States[J]. Nature climate change, 2013, 3(5): 497-501.

Zhu P, Zhuang Q, Archontoulis S V, et al. Dissecting the nonlinear response of maize yield to high temperature stress with model-data integration[J]. Global change biology, 2019, 25(7): 2470-2484.

Line 262 (equation 7): How was LST and ET/PET computed? As mean for the whole growing period? In the variable explanation (line 265) you call LST "local crop temperature stress" but shouldn't you then better use EDD here?

Thank you for pointing out the need for clarity here. We have edited line 202 to more clearly convey the variable construction: “Then ET, PET and ET/PET were averaged over time to get mean ET, PET and ET/PET during VP, GFP and GS with satellite derived phenology to characterize water status during maize growth.” Here our main purpose is to quantify the temperature sensitivity of irrigated or rainfed yield, so we used LST rather than EDD as the explanatory variable.

Lines 280-292: Any reason why delta EDD and delta ET/PET are NOT highly correlated?

We refer the reviewer to our answer above. Again, this may be somewhat surprising, but it is indeed the case that they exhibit independent variation that enables our analysis.

Lines 363-365: "As shown in Figure 7, we found that temperature sensitivity of yield was significantly weakened from − 6.9%/â„ƒ to −1%/â„ƒ in irrigated vs. rainfed areas ..."

=> shouldn't this be vice versa (lower sensitivity in irrigated maize)?

Thank you for pointing out this. Yes, it should be “we found that temperature sensitivity of yield was significantly weakened from −6.9%/℃ to −1%/℃ in rainfed vs. irrigated areas”

Lines 438-442: The assimilation of satellite derived LST might in fact reduce crop model uncertainty but this helps only when LST data are available. Crop models are also often used for climate change impact analysis but for simulation of potential futures LST is not available. Another disadvantage could be that LST is sensor and satellite specific, for example due to the different overpass times. Therefore another recommendation could be to improve crop models so that they can reproduce the effects that were found in the present study and use remotely sensed LST for validation.

Thank you for the insightful comments. We incorporated them in line 445: “Therefore, assimilating satellite derived LST might be a potential solution to improving crop models heat stress representation so that they can better reproduce the observed heat stress effects (Meng et al., 2009; Xu et al., 2011). These remotely sensed LST can also be used to validate model simulated LST, especially given that the recent ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) mission makes hourly plant temperature measurement available (Meerdink et al., 2019). However, it is worth noting that the availability of satellite LST presents a constraint when thinking about future climate change impact studies

In addition, some caution is required for validating model-simulated LST, since LST is sensor and satellite specific.”.

Figure 8: It seems that there is also considerable drought stress in irrigated maize because the ET/PET ratio is often much lower than 1. Any explanation why yield under irrigated conditions is often much higher for similar ET/PET ratios? Because irrigated maize is more often grown in cooler regions?

This illustrates the main point of the paper. As the previous figure shows, there is some degree of decoupling between ET/PET and LST. That means irrigation is relieving the pure heat stress (not only heat-through-moisture stress) component, so for the same ET/PET ratio, the yield is higher in irrigated areas.

References:

Sanchez, B., Rasmussen, A. and Porter, J.R. (2014). Temperatures and the growth and development of maize and rice: a review. Global Change Biology 20, 408–417.